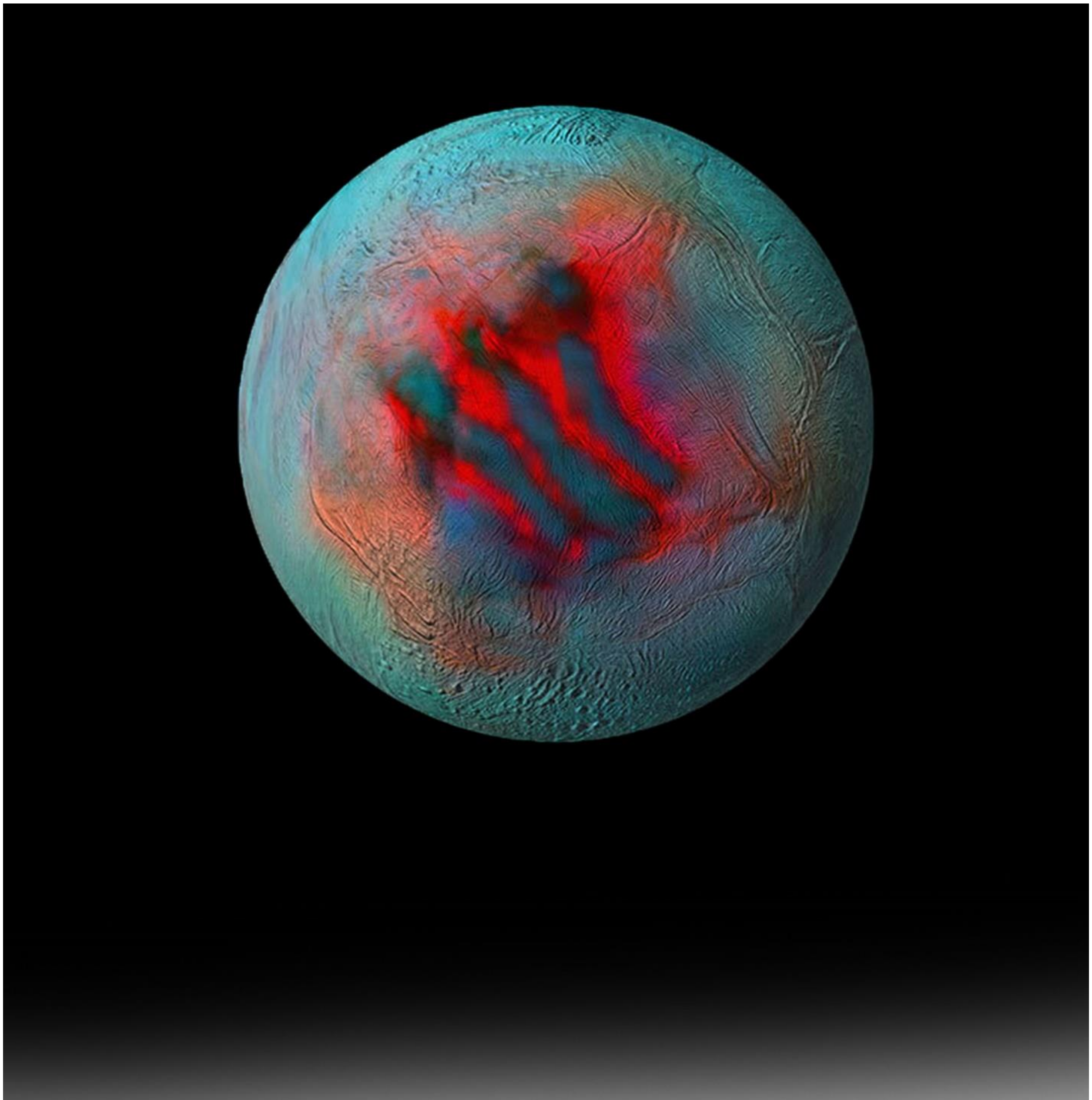


NASA L'SPACE Mission Concept Academy
Rover to Enceladus

Team 28 H2GO

Table of Contents

4. Payload Design and Science Instrumentation

4.1. Selection, Design, and Verification

4.1.1. System Overview

4.1.2. Subsystem Overview

4.1.3. Manufacturing Plan

4.1.4. Verification and Validation Plan

4.1.5. FMEA and Risk Mitigation

4.1.6. Performance Characteristics

4.2. Science Value

4.2.1. Science Payload Objectives

4.2.2. Creativity/Originality and Significance

4.2.3. Payload Success Criteria

4.2.4. Experimental Logic, Approach, and Method of Investigation

4.2.5. Testing and Calibration Measurements

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

4.2.7. Expected Data & Analysis

5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

5.1.2. List of Personnel Hazards

5.1.3. Hazard Mitigation

5.2. Lander/Payload Safety

5.2.1. Environmental Hazards

5.2.2. Hazar Mitigation

6. Activity Plan

6.1. Budget

6.1.1. Administrative Budget

6.1.2. Science Budget

6.1.3. Engineering Budget

6.2. Schedule

6.3. Outreach Summary

6.4. Program Management Approach

7. Conclusion

1.1. Team Introduction

Andrew

Andrew Headley is a second-year online student attending Southern New Hampshire University. His major is Information Technology, with a concentration in Robotics and Artificial Intelligence. Andrew has a passion for learning, and likes to spend time building computers and learning Python for robotics and AI applications. Andrew has been a part of a FIRST robotics team, working as a safety officer, ensuring that proper safety protocols were followed. Andrew's positions for this project are Safety Officer and Research Scientist.

Calli

Calli Veautour is a second-year student at Montana State University in Bozeman, Montana. She is majoring in Environmental Science- Soil and Water Science, with a minor in Astrobiology. In high school, she was the Chief Operations Officer for her school district's FIRST Robotics Team, the lead light designer for the theatre program, and the captain of the color guard. These high school leadership experiences inspired her to apply for her current job as a Resident Advisor. Calli also works as an Undergraduate Research Assistant in a soils lab, which is giving her valuable laboratory skills. Calli spends her winters skiing and snowboarding at Bridger Bowl, and her summers hiking and stargazing. Calli gained further leadership and delegation experience serving as the Project Manager, Environmental Scientist, and Record Keeper over the course of this project.

Jake

Jake Horstmann is a third-year student at Montana State University in Bozeman, Montana. He is majoring in Physics, with a focus in Astronomy. He assists with Undergraduate Research, focusing on high proper motion stars and uses Python for analysis. Jake works in the learning center at MSU and tutors in a variety of math courses. In his free time, he likes to study how things work, read books, and go hiking. During the project, Jake worked on the science team as the Physicist.

Jessica

Jessica Clarke is a fourth-year student studying Information Science at the University of Colorado Boulder in Boulder, Colorado. She is obtaining two minors in space and computer science, and has an interest in the tech, aerospace, and the gaming industry. During her first two years at CU, Jessica studied Film and worked at the Rainbow Trail Lutheran Camp during the summers of 2018 and 2019 as the videographer/photographer; at night, she would teach the campers more about astronomy. She then switched to Information Science, pursuing a desire to learn more about programming and data analytics. As president of Women of Aeronautics and Astronautics, Jessica is passionate about creating a community that welcomes women, non-binary students, and allies to the field of aerospace, ensuring that they are included. Jessica is also a member of the Women in Computing club at CU, where she enjoys developing her software skills, learning about the tech and gaming industry, and finding community with other programmers. In her free time, Jessica enjoys playing a variety of instruments such as the guitar, viola, and piano. Jessica served as the Science sub team lead and Data Scientist during this project.

Karson

Karson Tice is a second-year Aerospace Engineering student currently attending Paradise Valley Community College in Phoenix, Arizona. He is planning on transferring to Arizona State University or Embry-Riddle Aeronautical University. Karson has worked in multiple leadership roles throughout his career and is now dedicated to his studies in STEM. Karson enjoys fishing, writing, and spending time with family and friends in his free time. During the project, Karson served as Aerospace Engineer and Outreach Director.

Kathleen

Kathleen Sullivan is a third-year student at Colorado School of Mines in Golden, Colorado. She is studying Mechanical Engineering, with a minor in Biomechanical and Areas of Special Interest in Aerospace and Space and Planetary Science and Engineering. Kathleen has gained time management and organizational skills working in the Mines Admissions office as a student assistant and has gained leadership experience as a Peer Mentor for first-year students. She is proficient in SolidWorks, MatLab, Arduino, LabView, and Abaqus. In her free time, she enjoys hiking, drawing, and spending time with family and friends. Kathleen served as a Mechanical Engineer, Co-Systems Engineer, and PDR Editor on this project.

Madison

Madison Clark is a second-year student at Estrella Mountain Community College and Rio Salado Community College in Arizona. She is majoring in Computer Science, with a focus in Software Engineering. Madison is proficient in Java programming, digital design, Blender 3D modeling, putting together PC's, troubleshooting, and she is very tech-savvy with software. Madison has completed a previous NASA Community College Aerospace Scholars Program (NCAS) as a Lead programmer and software engineer and took her team into first place, also being awarded a medal for team MVP. Madison works as a Senior Ambassador/Manager with DMB Community life, where she has gained experience with leadership, digital/physical teamwork, and communication skills. She enjoys spending time making computer programs, creating 3D models, and learning new programming languages such as Python, C++, and Java. Madison's positions during this project are Software Engineer and Co-Systems Engineer.

Mysaruh

Mysaruh Massoud is a second-year student at El Paso Community College in El Paso, Texas. He is majoring in Electrical Engineering with a focus in power and energy systems. Mysaruh is proficient in maintenance procedures, troubleshooting, repairing, replacing, and maintaining military and non-military heavy equipment vehicles. He has 5 years experience in electrical, mechanical, hydraulic, and pneumatic systems. Mysaruh is experienced with OSHA HazCom; OSHA Lock Out Tag Out and all OSHA Fire Protection regulations, Master Safety Data Sheets, and Personal Protective Equipment. For fun, he enjoys camping alone or with friends in Ruidoso, New Mexico, and disconnecting from the digital life. Mysaruh's positions during the project are the Lead Administrator and Financial Advisor.

Nick

Nick Wright is a second-year student at Glendale Community College in Glendale, Arizona. He is majoring in Mechanical Engineering, with a concentration in Energy and Environment through Arizona State University. Nick has worked in local restaurants, honing skills in team communication and leadership; he currently works with Maricopa Community Colleges as a mathematics tutor for various levels of math. For fun, Nick enjoys hiking in the mountains as well as practicing a variety of coding languages, such as Python, Java, and C++. Nick's position during this project, as Deputy Project Manager and Mechanical Engineer, assigned him the responsibilities of optimizing communication between team leads and put his relevant Mechanical Engineering skills to use.

1.2. Mission Overview

A high-level overview of the mission is introduced and discussed including the major mission goals, constraints, requirements, mission success criteria, and major phases of the mission and launch are discussed in this section.

1.2.1 Mission Statement

The main goal of Team H_2GO is to examine the Saturnian moon of Enceladus to determine the elemental composition of its core, whether or not it is porous, and to conclude if the core contributes to the activity of the plumes. To complete this mission, data will be gathered in many ways. Spectroscopic data of sediments carried up from the core by the geysers will be analyzed to give clues on the composition of the core. Infrared radiation levels and seismic data will be recorded to provide insight about the internal and external structure of Enceladus. Combining the data sheds light on the differences between theoretical model data and empirical data.

A secondary goal is to avoid potential hazards to the unsullied environment of Enceladus. We will collect imaging data of the moon's surface topography, as well as potentially gather images of its subsurface ocean and seismograph readings of the core. This mission aligns with current decadal goals to understand icy worlds and the potential for how life might develop on other celestial bodies.

1.2.2 Mission Requirements

The constraints for this mission were to develop a lander that would not exceed 77 kg (170 lbs.) and fall within the volume of 51 cm by 51 cm by 76 cm (20 in by 20in by 30 in). The budget allotted for this mission is $400 million and the landing would take place within the tiger stripes area during the summer months of Enceladus. To complete this, an Alkaline (AFC) fuel cell was chosen since this design approach was the best for lander performance within the -330 degrees Fahrenheit temperature; however, the Cargo within the rover will hold all Scientific tools in a warmer temperature to function at full capacity. Currently, the rover's structural weight totals to 53.28839506 lbs. The current total electrical weight is 135.66053 lbs. The total predicted rover weight is 188.9489251 lbs. Material selection was taken into account, and graphite fiber was chosen for the structural panels due to its favorable strength-to-weight ratio. The assembly components are the 5083 aluminum alloy (Aalco – Ferrous and Non-Ferrous Metals Stocklist. https://www.azom.com/article.aspx?ArticleID=2804. Retrieved November 21, 2020). The rover will use a back motor to help navigate in the snow; this will have snow spikes on it in order to push the rover and the front will have two snow sled-type legs which will be powered by the motor. For landing, a parachute and propulsion system will be utilized. The following scientific instruments will be used within the rover: APXS (Alpha Particle X-ray Scanner) which will be taking samples outside in the rover's environment and analyzed within the rover's cargo body. Next, the MEMs seismometer will be used to scan the seismic activity of the environment. To provide visuals, a single camera from Perseverance's MastCam-Z will be used. This will take high-resolution images using various filters placed over the lens, including a light source that will emit light at multiple wavelengths (UV, IR, Visible). The cargo will also include the TIRS (Thermal infrared sensor) to collect IR data for our rover. Lastly, we will see the PanCam, to gather images at a 20/20 resolution to date different wavelengths from near UV to near IR, along with our Communication system used to communicate the findings with our team and to store and collect the data found. All scientific instruments will be held within the cargo and main body of the rover, fully covered in gold metal painting to maintain heat being produced to keep temperatures down.

1.2.3. Mission Success Criteria

Alpha Proton X-ray Spectrometer (APXS)

For successful data analysis of the rock, or snow surface samples, the APXS will use an alpha proton X-ray spectrometer to measure the chemical element compositions of the collected samples. The success of the APXS is determined by its ability to find elements with particles on the energy spectrum of 25% - 100% of initial alpha particles. The heavier the elements in the sample, the more likely our X-ray emissions will be able to detect them.

Micro-Electromechanical System Seismometer (MEMS)

To be considered successful, the Micro-Electromechanical System, or MEMs, seismometer would ultimately discern the makeup of the Enceladus' core. To do this, it will measure seismic activity occurring on Enceladus' surface. In order to achieve a full conceptualization of the core, multiple seismometers are needed, which could be deployed directly from the orbiter as it flies over the surface. The MEMs is ultra shock-absorbant, so it is able to withstand the shock of a hard landing on the surface.

Cameras

Success for the camera system is defined as producing images of Enceladus' surface that are at least 1024 by 1024 pixels in size through different light wavelength filters. These images must be in focus and relatively free of imaging artifacts or distortions so they may be stitched together to form a 360° panoramic image. Taking these images at various stages during the mission will provide information about the topography of Enceladus's surface, from materials on the surface to navigability for future missions.

Environmental Sensors

For the environmental sensors to be considered successful, they need to take measurements of small things with relative tiny uncertainty (around 10%). Enceladus is not very big, so each value measured will be much smaller than the same measurement on Earth. Although the sensors need to be sensitive to measure these small values, they also need to be durable. A key concern of these delicate instruments is that they are easily susceptible to damage; they require careful positioning within the lander to not get jostled upon impact. With success, these sensors can provide immense insight into the internal workings of Enceladus and its surface activity.

Overall Mission Success

For this mission to be considered a success, accurate and precise data must be received to the aforementioned standards. The science goals for the mission are to discern the core composition and porosity of Enceladus, by using seismic, environmental, and spectrometer data, as well as to collect temperature, atmospheric pressure, and wind data to determine the environment on the surface.

1.2.4 Concept of Operations

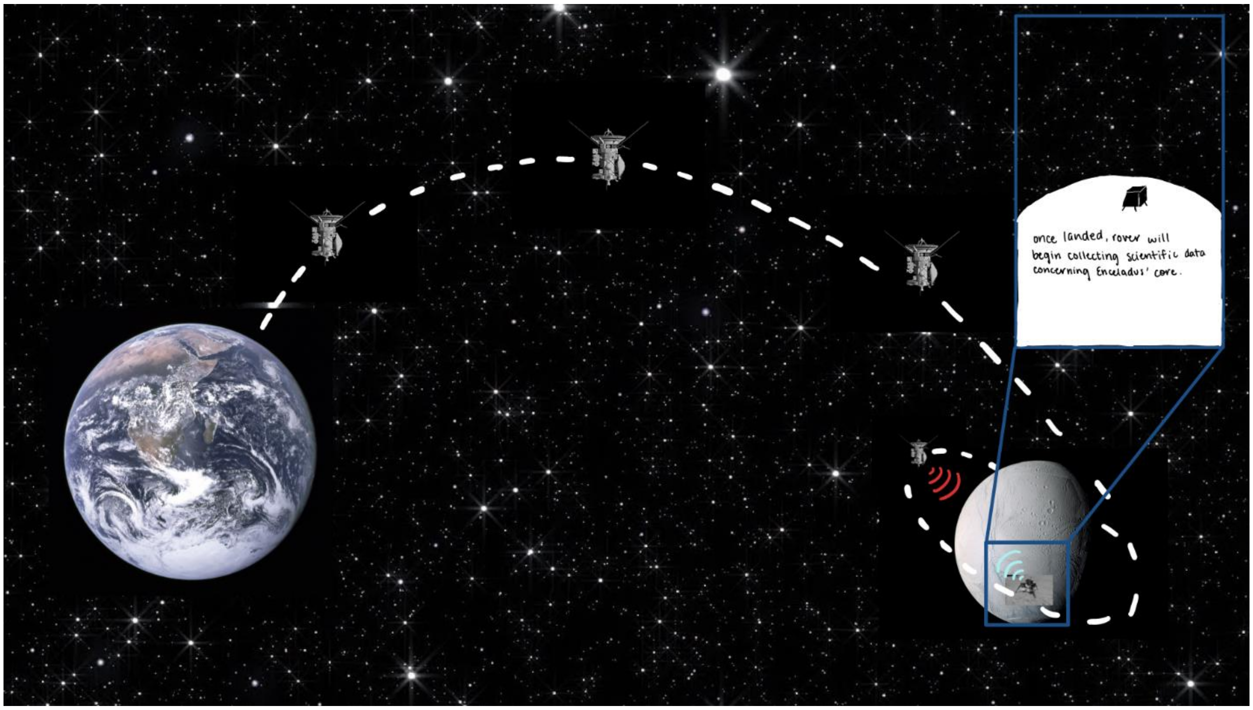


Figure 1. Concept of operation diagram illustrating major stages of the mission

The main phases of the mission from launch to completion are illustrated in Figure 1. The initial stage, launch, takes the payload from Earth to the orbit of Enceladus. Enceladus’ orbit has an eccentricity of 0.25, meaning that the orbiter will not be the same distance from the moon at all points as it travels around it. The next stage of the mission is to reach the surface of Enceladus. Orbital to surface descent calculations are discussed in section 1.3. Once on the surface, the rover will begin collecting samples. To communicate data back to Earth, the surface lander will transmit information to the orbiter.

1.2.5 Major Milestones Schedule

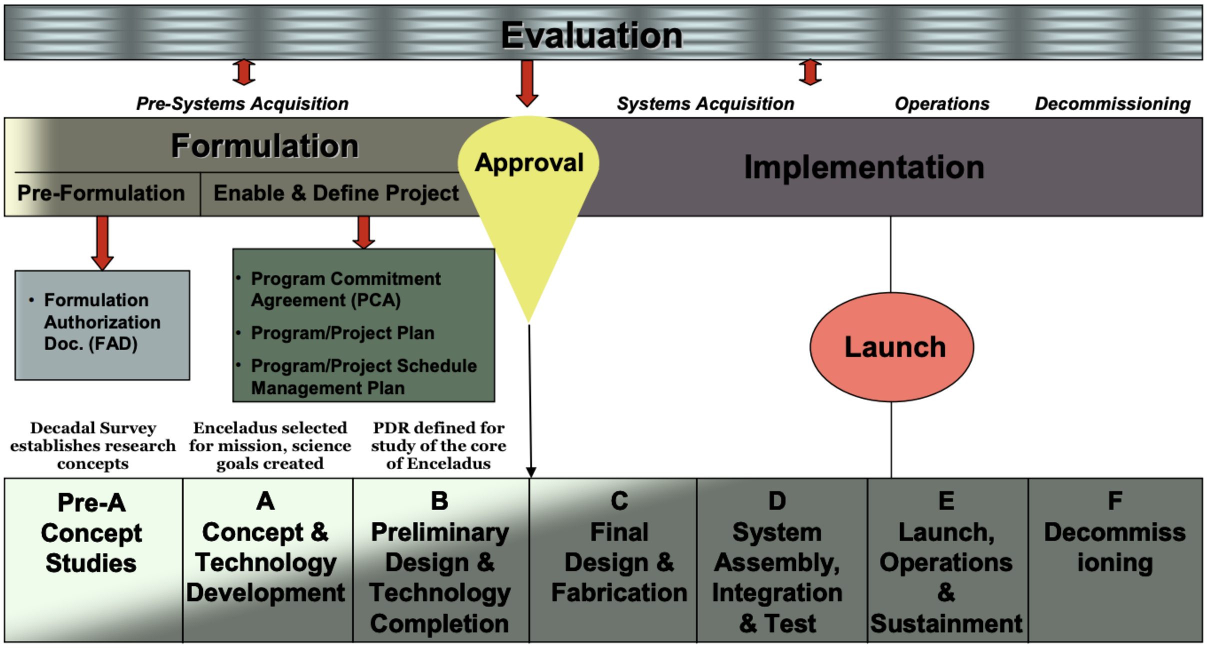


Figure 2. Phases of the mission from concept to closeout

1.3. Descent Maneuver and Lander Summary

Approaching Enceladus, the payload will aim for the polar region near the relatively thinner icy crust, called the Tiger Stripes. Most of the moon's active geysers are present in this area; this is where the most valuable measurements will be taken. Precautions will be taken to avoid potentially active geysers which pose a hazard to a smooth landing. Upon entry from orbit, the parachutes and propulsion systems will be deployed to allow the payload to withstand landing impacts. The terrain of the southern region is smooth and reflective, which hints that the ground could be covered in fresh snow and/or containing solid ice. To maneuver the rover safely across the icy or snowy terrain, the payload will have propulsion technology, designed to hop from point A to point B. Gravity on Enceladus is proportional to Earth's at 0.113 m/s^2, so minimal thrust will be necessary to get the 132.418 lb payload moving. A parachute and propulsion system will be used to assist with accurate descent and landing. The parachute, made of Kevlar-Nylon material, will be deployed at an optimal point upon entering the supposed atmosphere. This parachute will weigh approximately 1.00 pounds and have a diameter of 20.0 feet. During descent, a single STAR 3A rocket booster will be utilized to get the payload from orbit into the atmosphere. A STAR 3A rocket on the top of the lander will create a thrust to send it towards the moon's surface. Once the lander enters the atmosphere, the parachute will be released and it will expand to slow down the lander. As the lander nears 20mph, two additional STAR 3A rocket boosters, positioned on the bottom of the payload, will slow the lander to a safe speed so that none of the instruments or lander components are damaged upon contact with the surface. A smooth landing will ensure the instruments aboard the rover are left undamaged. The design of the lower body and footing of the rover will be wide, containing the maximum possible surface area to enable maneuvering through an unknown, icy terrain. Data will be collected near non-active geysers as well as within non-active geyser plumes. If the mission constraints allowed for more space and weight, a secondary payload would be included to explore the subsurface ocean.

The secondary payload option presents a bug-like extension, which would be connected by a strong cable material capable of allowing a wall-crawling device to descend a maximum of a kilometer below the surface. The secondary payload would examine sub-surface samples of the ice's molecular make-up and any liquid water encountered. Cameras on the secondary payload would give scientists a better visual understanding of what is underneath the ocean's ice crust.

The rover will land near one of Enceladus' Tiger Stripes. The exact landing location can be seen in Figure 3 below. Through use of the JMARS software the slope of the terrain at this location was determined to be 18.8°.

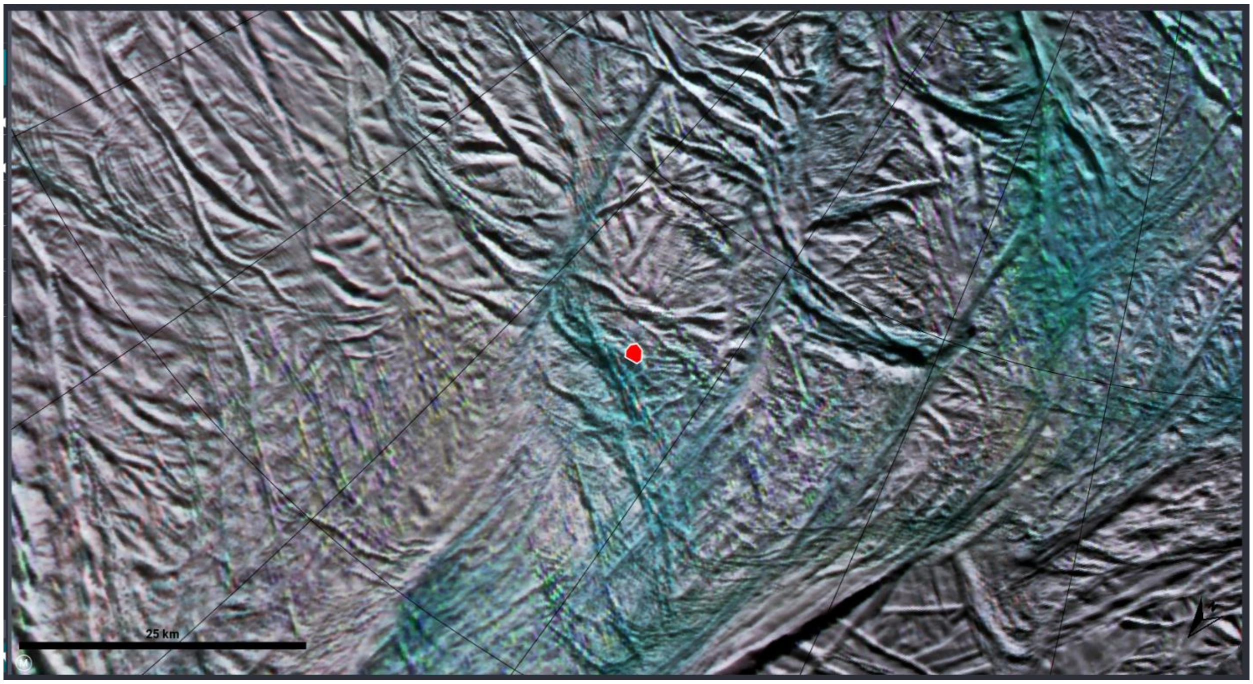


Figure 3. Surface lander location decided based on JMARS software surface exploration

The orbital parameters were determined based on the rover specifics. The dimensions of the rover in the collapsed state is 500 by 720 by 410 mm, and the total weight of the rover is 170 lbs. More precise dimensions of rover components can be seen in Figure 4, the engineering drawings.

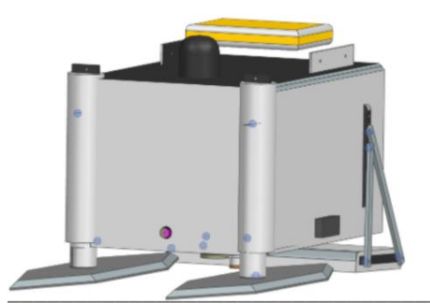


Figure 4. NX CAD assembled rover

The Tiger Stripes will be approached during the summer months. Descent will begin when the orbiter is 140.75 km above the surface and where the velocity is 133 m/s. The entry profile for the payload, or surface lander, is shown in Figure 5. Orbital parameters were determined through use of the FreeFlyer orbital calculation 3-Dimensional software. The proposed entry angle is 35 degrees. A graphical representation of the descent path is shown in Figure 5 below. After condensing it into 2D, the descent of the surface lander can be seen using the Runge-Kutta method in Figure 6. One of the STAR 3A thrusters will push the lander out of orbit. For the first chunk of time, the lander is freely falling only with the force of gravity on it (radiation pressure was ignored). Once it is 5 km above the surface, it hits an assumed atmosphere made of mostly water vapor, where the parachute is then deployed. This parachute does most of the work to slow down the payload and brings it nearly to a stop. The payload will then slowly glide down where the boosters will finally take over to create a smooth landing for the internal components of the payload. During this time, the payload will have traveled a total of 120 km across the surface.

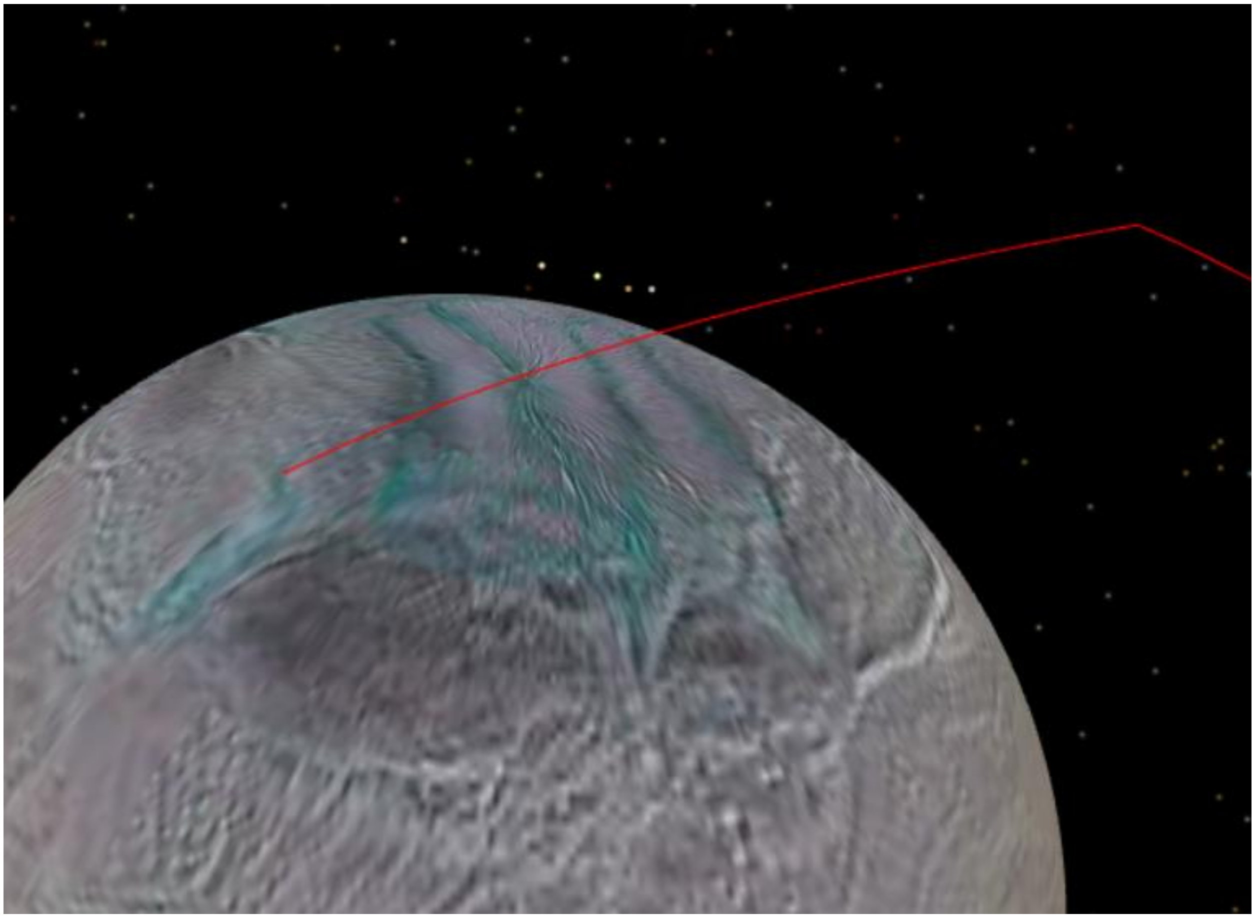


Figure 5. Payload orbit to surface path created using FreeFlyer software

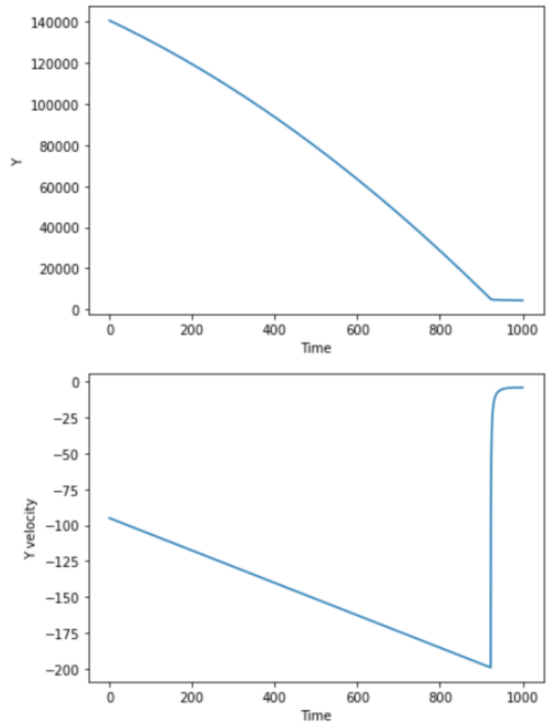


Figure 6. Position and velocity with respect to time condensed to 2D. All units are SI units (meters and seconds)

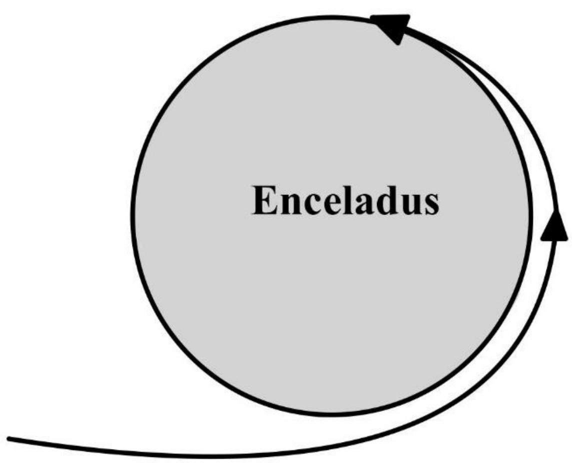


Figure 7. The payload's approach from Earth to Enceladus' surface.

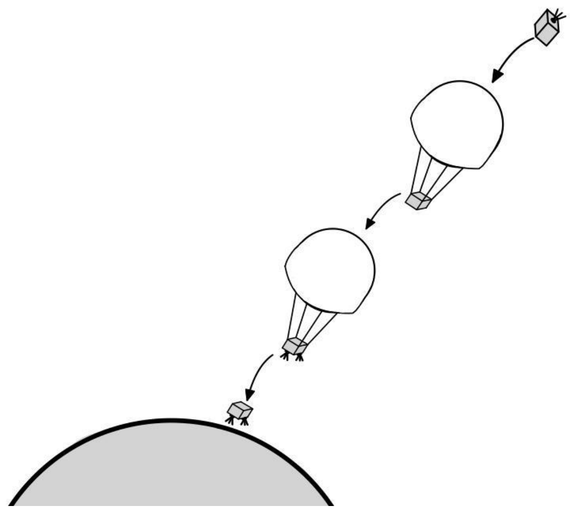


Figure 8. Entry Landing descend landing visual of payload from orbit to surface

1.4. Payload and Science Instrumentation Summary

Seismograph (MEMs)

The Enceladus rover will be equipped with a 11.3x11.3x1.2mm Micro Electro-Mechanical Systems (MEMS) seismometer sensor. A typical seismometer is extremely sensitive to vibrations and requires protection from the extreme environments, while MEMS technology in development is designed to withstand extraordinary conditions such as Enceladus's sub-zero temperatures. The most effective location to mount this sensor is far away from mechanical processes of the rover. Separated from the humming produced from the motors, the MEMS seismometer will be located in the lower front region and extended out by a discrete 10.0x10.0x1.0mm shock absorbent beam. This location will maximize effectiveness of the MEMS seismometer sensor technology while the rover navigates through Enceladus's southern pole.

The MEMs seismograph's purpose is to take seismic readings on the surface of Enceladus and discern the makeup of the core of Enceladus. It is a relatively unobtrusive piece of equipment, measuring 11.3 x 11.3 x 1.2mm.

Spectrograph (APXS)

The 84.0x52.0mm APXS spectrometer will study the chemical make-up from the surface of Enceladus through sampling soil and ice deposits. Primarily this instrument will be located near the base of the rover and positioned for measurements through the suspension system's ability to lower the extraction tool within an acceptable distance. This device will require a temperature-controlled environment provided within the heated cased design. When obtaining samples, the spectrometer will be momentarily exposed to the environment of Enceladus. A narrow probe will extend directly out of the heat shield casing and return within the sealed temperature-controlled rover. The spectrometer will be located in the center lower region of the casing, positioned beneath where samples can easily be positioned for extraction. Noted that the rover suspension is designed to squat within millimeters to the ground, alleviating the use of external measurement arms.

This spectrometer works by taking samples of the soil or crushed rock and using alpha particles detected from radioactive decay and the X-rays with their electromagnetic radiation. With small alpha particles emitted and bounced back from the sample into a detector with some X-rays. The energy distribution of the alphas and X-rays, measured by the detectors, are analyzed to determine the elemental composition.

Imaging (LIDAR, GPR, Stereoscopic)

To allow the rover to collect images, 4 cameras will be mounted to each side of the lander. These cameras will be wide-angle to enable visibility into the fields of view of their adjacent counterparts. This can be managed in two ways: the lens could be placed in a protective housing which protrudes slightly from the body of the lander (as seen with 360° cameras and their lenses), or the lens could be recessed into the body of the lander to avoid protrusions and mechanically controlled to adjust the angle, where it could look up or down to gather the images. Another potential issue could be a light source. Once the lander enters the vent, light may be scarce; the geyser itself may drastically affect visibility. The lander will have a variable light source that can flood the area with different wavelengths of light (UV, IR, visible spectrum, thermal, etc.). The light source could be mounted to the top or bottom of the lander, or close to the lenses of the cameras. The purpose of the variable wavelengths is to gather information, both on the surface and in the vent, of the topography and potentially the composition of the ice.

Power - Alkaline Fuel Cell Battery

The battery chosen was an Alkaline Fuel Cell (AFC). This was selected predominantly since it measures within 1 - 100 kW. It is also operational in <100°C, which will work within the heated body of the rover. This type of battery is most commonly used in the military, as well as space. It can be integrated with a wide range of stable materials; this allows it to stay at a lower cost. The price is around $175 US per kW and the Fuel Cell provides energy for 40000+ hours, which gives ample time for data to be collected.

Communication Systems

The communication systems aboard the rover will provide a path for data to be sent to the Enceladus orbiter and back to Earth. Due to the distance between Enceladus and Earth, the antenna for projecting data to earth will be on the orbiter to save battery power and cargo weight on the rover itself. The rover will be using the PDT-300 X-band Transmitter. This x-band transmitter will provide a frequency range of 8025-8400 MHz. The low bandwidth will only need 56W to operate while transmitting data.

2. Evolution of Project

2.1. Evolution of Descent Maneuver and Lander

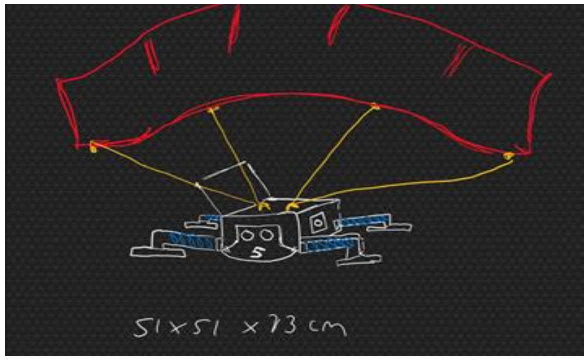


Figure 9. First rover iteration

The first rover design iteration by the engineering team took into consideration the cold, potentially icy surface, of Enceladus as well as its relatively flat surface. The original design incorporated a low center of mass and wide surface area, with a cleat-like grip on the feet to provide a way to stay on top of any snowy terrain encountered without getting buried. The rover was designed with Enceladus' variety of extreme weather systems in mind, particularly the weather condition near the southern poles, which includes active geysers. The contribution to Enceladus' atmosphere and much of Saturn's E-ring is made up of the material erupting from the interior of the moon, and much of the southern surface experiences frequent resurfacing from geyser debris. While exploring the surface of Enceladus, instrumentation will need to be protected from the cold and the resurfacing events. In adaptation to these factors, the rover is designed as a cased, heated box in order to protect the temperature-sensitive equipment. The original design experimented with the idea of having a long cable connected to a climbing payload that would detach from the primary rover to take deep surface measurements within geysers. The secondary payload would have potential to reach beneath the icy crust to explore the subsurface ocean and core directly. This idea requires research and development funding to be feasible due to the weight and volume constraints; the secondary payload idea was scrapped to avoid complexities with communication and hazards while descending into potentially active geysers. This mission could be the first stage of a subsurface endeavor, taking a more cautious approach towards understanding the nature of Enceladus' risks. This payload included the use of landing shocks and a parachute that releases from the top while making its descent.

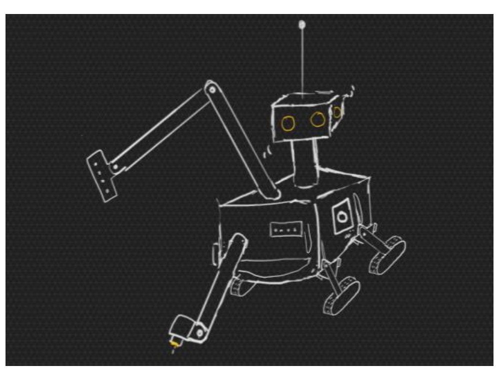


Figure 10. Second rover iteration

The second iteration of the project design introduced extendable measurement arms, treaded tires, and a 360-degree pivot picture and video terminal. This rover evolution discarded the communication cable and geyser descender payload due to the high risk and unknown characteristics of Enceladus's active geysers. This design would be well-equipped to study the surface closely, with two extendable arms that could take direct surface measurements. With all temperature-sensitive equipment sealed in the rover's heated casing, the upper measurement arm would be universal to switch between measurement instruments from a single port. The lower measurement arm would be equipped with the seismometer instrument where the reading can be continuously recorded. The rotatable camera terminal extends out from the inner casing after landing. The 360-degree rotation allows any direction to be viewed at any particular moment. The lenses are cased and reflected through mirror angles to avoid direct contact with the outside conditions. The four treaded wheels would be ideal for solid ice gripping, although if areas of Enceladus' surface contain deep snow, rover maneuverability could become problematic. This factor presented too much risk to the overall maneuverability, and this was replaced with twisting front surface plates and a wide motor-powered track in the back.

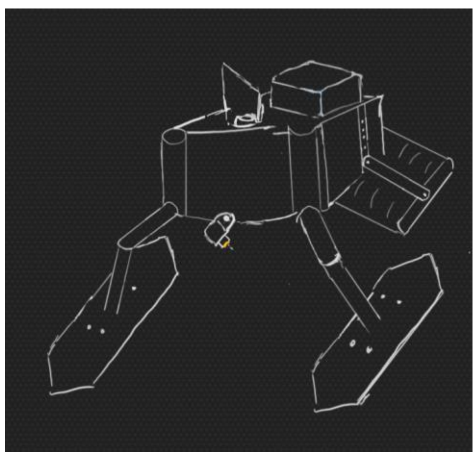


Figure 11. Final rover iteration

The team's final rover design emerged through the elimination process, after consideration of risk mitigation and adaptation to the methods of which data will be collected on Enceladus. The mobility on a variety of surfaces can be accounted for by having a pair of rotatable light-weight sheets and a motor-powered track maneuver from the rear. After discarding the pair of measurement arms, this concept was replaced with underneath compartments, designated to operate as the rover positions low to the surface. This design also protects the instrumentation from any falling ice or core chunks from the active geyser sites. The compartment on the top of the rover will be the rotatable mirror reflection chamber used to indirectly view the outside, without exposing the camera lenses and electrical components to the harsh cold. A lightweight parachute will be used in the landing descent, opening from the top compartment and at contact with Enceladus' surface, the landing will be cushioned with leaf spring and shock absorbers installed on each extendable arm.

Table 1. Below is the decision matrix for each of the rover iterations, showing Rover 3 as the highest-ranking option.

					Totals with Weight
	Maneuverability on Snow	**Maneuverability on Ice**	**Weather Protection**	**Descent Maneuvering**	
	0.2	***0.2***	***0.4***	***0.2***	***1.0***
Rover 1	8	4	7	7	6.6
Rover 2	1	7	6	4	4.8
Rover 3	9	9	9	9	9

2.2. Evolution of Payload and Science Instrumentation

Measurements methods

Collecting physical data on Enceladus requires special attention to the harsh environmental factors. This moon experiences -330°F surface temperatures and potential snow, ice, and debris deposition from geyser activity. A rover exploring the surface is at risk of becoming buried or damaged by constantly falling debris. Originally, measurements pertaining to the makeup of Enceladus's core were designed to be taken directly through a secondary payload. This extension would ideally dive into the subsurface water reservoirs, analyze samples underwater, and transmit data through a cable connection. A safer approach was decided for a first mission to Enceladus due to various unknown hazards that could compromise the mission success.

The second iteration of the rover measurement method was to introduce a pair of extendable probes. In this iteration, a lower beam would be aimed away from the rover, handling the seismometer, and the upper arm would have a connection to the inside heated casing. Inside the rover would be a sealed compartment to hold the electrical components and temperature-sensitive measurement instruments. This idea utilized a universal measurement arm, capable of switching between devices quickly, while minimizing exposure to the outside temperature.

After further consideration of this technique, the thermal casing idea was retained; the extendable arms used in measurements were replaced with a different approach. Adaptations to the overall position of measurement tools were made by positioning all sensors towards the bottom of the heated casing. This made it easier to take direct measurements from the bottom of the rover, while remaining protected from the outside. Removing the measurement arms reduced the risk of having faulty connections and mechanical complexities were avoided.

Maneuverability methods

Maneuverability of the rover was determined based on the overall surface terrain of the southern pole of Enceladus. This mission plans to explore the core makeup of the moon in locations where resurfacing due to weather is frequently experienced. Many unknowns remain as to how the surface will behave at a lower relative gravity and whether or not the ice or snow terrain is dense. In the final iteration, the rover was designed to be adaptive to dense ice and soft snowy terrains by maximizing the surface contact points with the rover's center of mass. In the first iteration of the rover design, the team decided that having four individual legs would maximize mobility and control. The rover sought positioning close to geyser locations where the measurements would be taken by the rover's cable connection.

Eventually, the secondary payload concept was abandoned due to exceeding physical constraints and the amount of risk associated with the first surface lander mission of Enceladus' exploration. The overall mission will be dedicated to exploring the core makeup of Enceladus through collecting surface samples and sample analysis, using protected instrumentation within a heat controlled cased body. When considering the second iteration of the rover's maneuverability, it was crucial to address the need for swift movement across unknown terrain. Four motor-powered tires would allow the rover to move well on a more densely packed, snowy surface, but on more open terrain, the rover would not move efficiently. After the rover's method of data collection was determined and the possibilities of terrain encounters were considered, the final design was determined.

The last iteration of the rover design has a combination of maximized surface connection to the ground, and plenty of power behind the traction motor from the rear. In the event that the rover encounters a sheet of ice or a deep bed of snow, the mission will not be compromised due to immobility. This design also maximizes the safety of the scientific instruments since they will be positioned within the thermal casing of the rover's body. The measurements work in conjunction with the flexible panels and rear power motor to position sensors and sample tools close enough to take direct measurements. This approach is necessary to minimize hazards on Enceladus that may impact the longevity of the instrument's life.

Science Instrumentation

By focusing on the core make up of Enceladus, our instrumentation had to be able to identify elements of the ice, snow, atmosphere, the ground activity, and soil/rock samples. Once the instruments were chosen, research and development was conducted to determine instrument size and necessity.

The first iteration of science instruments included a device like the ChemCam instrument on the Curiosity rover, ice/ground penetrating radar, and seismometers (specifically the Seismic Experiment for Interior Structure or the SEIS). The ChemCam was convenient since it could vaporize rocks within a 27-foot radius, making the movement of our rover conserve energy, at the cost of the laser energy. The SEIS was used on the surface of Mars to measure Mars-quakes, as well as temperature, pressure, wind, and the magnetic field. However, the SEIS instrument was too large to meet our rover dimension requirements. For the ice and ground penetrating radar, the research showed that the entire rover body would need to be utilized in order for the instrument to have enough room to conduct its work.

The second iteration of science instruments included smaller instruments with better defined purposes. Exchanging the ChemCam with the Miniature Thermal Emission Spectrometer or mini-TES. The mini-TES is smaller and requires samples of rock or soil. From the array of seismometers, the MEMs (Micro-Electromechanical System Seismometer) were intriguing due to its small capacity. This would save space inside the rover for other environmental sensors and cameras. The environmental sensors and cameras were also decided on as substitutions for ice/ground penetrating radar. Secondary scientific goals influenced the decision to have more of the environmental sensors (wind, temperature, atm pressure, ect.) rather than ground radar.

The last iteration of the science instrumentation includes the APXS (Alpha Particle X-ray Scanner), MEMs, the high-resolution camera from Perserverance's MastCam-Z, and the TRIS (thermal infrared sensor). The instruments were chosen after extensive research. The APXS was chosen because of its small size and weight. The camera from the MastCam-Z was chosen because of its ability to take high-resolution photos, ultraviolet, and infrared photos. The MEMs are confirmed for the final design. The last instrument that will be incorporated into the rover is the TRIS which will take measurements of the temperature, wind, and atmospheric pressure.

2.3. Evolution of Mission Experiment Plan

The overall mission is to collect data so that questions regarding Enceladus' core makeup can be answered. At first, the method to explore potential life on Enceladus and determine the makeup of the inner core appeared perplexing. It was decided that both categories were too broad to cover in a single surface mission, so the focus began to collect meaningful, conclusive data about one of the two questions. Thus, discovering Enceladus' core makeup became the focus of the mission. Originally, the mission had also utilized a small, secondary payload- a bug-like robot- to study inside of a geyser. The bug would be a subsurface device that would explore the liquid reservoirs directly below the surface. This concept would allow the secondary payload to climb down the walls of an inactive geyser to obtain access to the liquid water reservoirs. This approach would provide astounding progress in the discovery of Enceladus' core components, but the mission would encounter too many unknowns in the process, particularly potential bubble traps in the geyser columns that could present the bug difficulty in climbing the geyser. Ultimately, the secondary payload idea was scrapped for lack of feasibility regarding rover dimension and weight requirements. The last iteration decided to focus on seismic activity, cameras, and spectrometry. These three instruments would provide the most information about the chemical makeup of the core, the porosity, and the relationship with the geysers. The final experiment design focuses on the use of the Alpha Particle X-Ray Spectrometer (APXS), Micro-Electrical-Mechanical Seismometer (MEMs), camera, and Thermal Infrared Sensor (TIRS), Enceladus' chemical makeup, seismic activity, heat, and visual surface will be recorded and analyzed. After further discussion of methods of measurements of collecting data, a more achievable approach was designed by taking surface measurements from seismology and composition of surface materials.

3. Descent Maneuver and Lander Design

The methods used for the rover's descent from orbit to surface will be covered here. Two mechanisms are being used to assist with landing: a parachute and propulsion system. Once on Enceladus's surface, the rover methods for motion and sample collection will be discussed.

3.1. Selection, Design, and Verification

Rover landing mechanisms and lander design are discussed in detail.

3.1.1. System Overview

The lander developed by the engineering team will descend to Enceladus' surface through the use of a single main parachute and a reverse thrust system, the STAR 3A. This will ensure that the lander itself does not suffer any damage and that the instruments are not impaired. Upon approaching Enceladus, the STAR 3A will create a thrust that will push the payload out of orbit, and it will begin to fall to the surface. When the payload reaches 10,000 ft in altitude, as detected by the camera system, the parachute will deploy to slow the payload. As the payload nears 1500 ft, the STAR 3A reverse thrust system will be activated to ensure that the lander has a gentle final descent. Although there is no data yet to confirm this, it can be hypothesized that due to the abundant crypto volcanism, there is a thick atmosphere; therefore, the parachute should work effectively. The reverse thrust system was chosen because it can slow the payload down to a much softer landing than the parachute could alone. It also acts as a backup system for the parachute and is capable of compensating for the parachute if there is less atmosphere than anticipated.

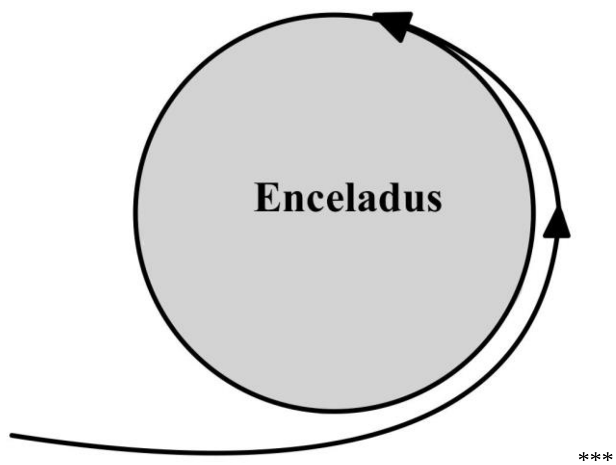


Figure 12. The payload's approach from Earth to Enceladus' surface.

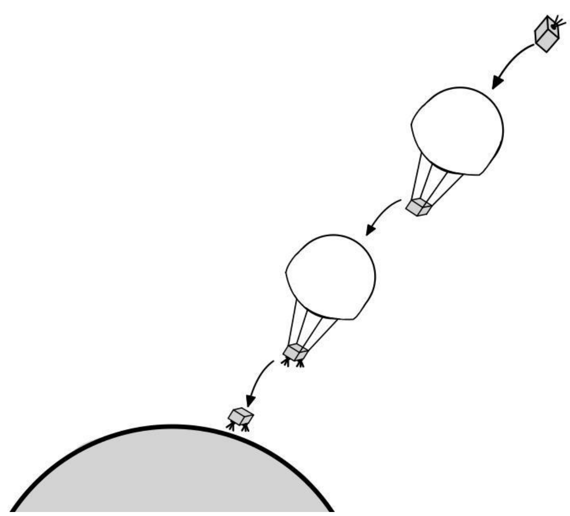


Figure 13. Entry Landing descend landing visual of payload from orbit to surface

This design was the third lander iteration. The rationale for choosing this design is justified in Table 1 of PDR section 2. The criteria for selection of design iterations included maneuverability on snow, maneuverability on ice, weather protection, and descent maneuverability. Because the mission revolves around answering key questions about Enceladus's core, protection of science instruments through the weather protection was weighted more heavily than other categories. Maneuverability for landing, snow, and ice was all considered in the determination of a rover design because very little is known about the atmosphere and surface of Enceladus. These three criteria were all weighted equally. Each rover iteration was ranked and totaled; the rover design that scored the highest based on the decision matrix was iteration three. This rover design incorporated features from the first two designs that will help maximize the success of the mission.

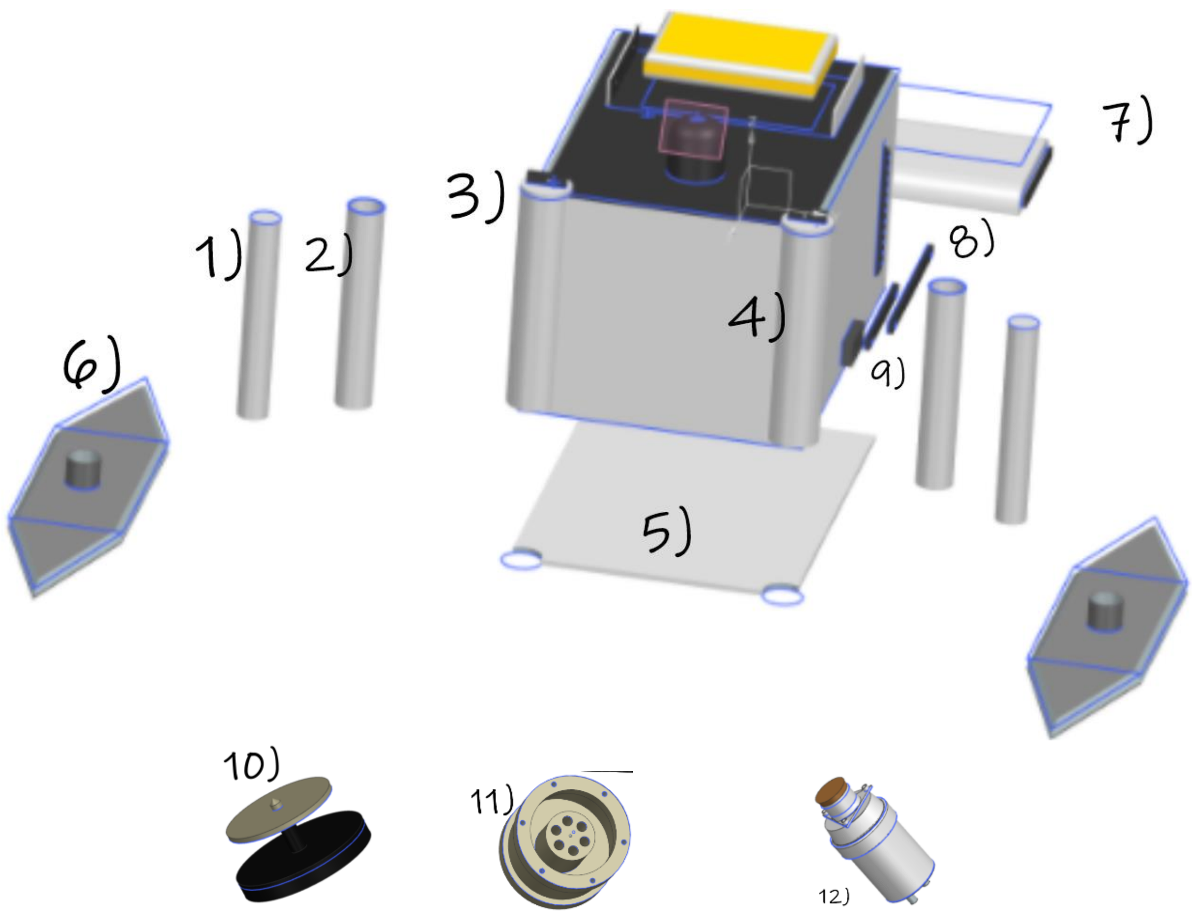


Table 2. Below is a table that shows the dimensions and weight of component from the lander.

Number	***Part***	***Size dimensions***	***Weight CAD (lbs)***
1)	Small Arm (1)	diameter 55mm inner 60mm outer; length 370mm	0.8945

	Small Arm (2)	diameter 55mm inner 60mm outer; length 370mm	0.8945
2)	Large Arm (1)	diameter 60mm inner 65mm outer; length 370mm	1.0651
	Large Arm (2)	diameter 60mm inner 65mm outer; length 370mm	1.0651
3)	Arm Holster (1)	diameter 70mm inner 90mm outer; length 400mm	8.2995
	Arm Holster (2)	diameter 70mm inner 90mm outer; length 400mm	8.2995
4)	Body case	720mmX500mmX500mm; thickness 5mm	37.98
5)	Bottom Panel	720mmX500mm; thickness 10mm	20.03
6)	Foot (1)	200mmX400mm; base 150mm height 200mm; thickness 20mm	14.385
	Foot (2)	200mmX400mm; base 150mm height 200mm; thickness 20mm	14.385
7)	Motor Housing	500mmX265mmX50mm; thickness 5mm	1.486
8)	Large Pin (1)	400mX20mmX10mm	0.4181
	Large Pin (2)	400mX20mmX10mm	0.4181
9)	Small Pin (1)	300mmX20mmX10mm	0.313
	Small Pin (2)	300mmX20mmX10mm	0.313
	Total Weight		110.25
	Instruments	***Size dimensions***	***Weight from Manufacturer (lbs)***
10)	MEMS	11.3mmx11.3mmx1.2mm	0.066
11)	APXS	diameter 84mm; length 52mm	1.0
	TIRS	58mmX63X58mm	0.214
	PanCam	no specific measurements	0.595

	COM	240.2mmX230mmX60mm	6.06
	Parachutes	3.17ft^3	1.0
	Total Weight		8.94
	Electronics	***Size dimensions***	***Weight from Manufacturer (lbs)***
12)	STAR 3A	diameter 3.18 in; length 7.5in	1.96
	Motor	length 46.5mm; diameter 30mm	0.33
	Wiring/Fasteners	Fits in body case	6.0
	200W Fuel Cell	118 x 183 x 94mm (4.6″ x 7.2″ x 3.7″)	4.9
	Electronic heaters	1 inch x 1.3 inches	0.0875
	Total Weight		13.2965
	NET Weight		132.481

The final lander iteration incorporated the most attainable approach towards our scientific measurement purposes and risk mitigation on Enceladus. Due to the unprecedented nature of this mission, the descent and lander systems were chosen to alleviate any risks jeopardizing mission success including unforeseen environmental hazards. When the lander is released from orbit, the payload's entirety will be in a compressed capsule form to reduce the maximum size. The lander is fully equipped with a specialized parachute, an upward propulsion booster, and shock absorbers. The front hydraulic cylindrical arms, and roller track suspension in the rear are by design vertically maneuverable to unfold before making contact with the surface. The rover's descent will be slowed by the increased drag of the parachute, deployment located with opposing respect to the suspension legs. Once stabilized in descent, the shock absorbent arms and rear track will position away from the base of the rover, increasing the overall drag. At this time using the visual communication system tracking, and STAR 3A propulsion from below the lander will autonomously control the descent deviation towards the estimated landing site. In the interest of preserving instrumentation accuracy and the rover's mobility, the landing site was decided carefully. A margin for inaccuracy while approaching the landing site was taken into consideration by choosing a vast level area to explore. While the parachute and extended arms maximize the drag, the propulsion system from the base will allow for the softest and most secure landing possible. Also, accounting for the risk of entanglement with the discarded parachute, the lander will use propulsion to offset the rover position. Once the lander is set on the surface of Enceladus, the rover is fully equipped to perform surface readings and collect samples for analysis. Beyond the initial samples collected, the rover is capable of exploring multiple locations within a feasible distance.

3.1.2. Subsystem Overview

Descent

The lander will be carried to Enceladus' surface by a single parachute and a reverse thrust system. The single parachute will be 20 ft in diameter, it will have 200 ft long strings- from payload attachment to the parachute, and it will be ~1 lb in weight. It will be made of a Kevlar-Nylon material to ensure maximum strength, as well as minimum weight (Orion's Parachute System, pp. 2-3). The reverse thrust system will be a STAR 3A rocket; this option was chosen due to its compact size and effectiveness. The STAR 3A, a Northrop Grumman rocket design, is a transverse impulse rocket system that is 3.18 inches in diameter and 7.5 inches long (NG Propulsion Products Catalog. November 21, 2020). These dimensions do not currently fit within the constraints of our payload, but research and development will be performed to reduce the size of this component so that it meets the requirements. This rocket choice has a small casing and exit cone, which allows a lower propellant weight since there is also a smaller volume available. One STAR 3A will be attached to the top of the payload and two additional ones will be integrated into the bottom. The top STAR 3A will push the payload out of orbit, towards Enceladus' surface and inflate the parachute, and the two STAR 3A rockets on the bottom will allow the payload to slow during descent.

The lander incorporates features designed to withstand the harsh terrain of Enceladus. Most importantly the rover body provides a protective casing from extreme cold conditions. With sensitive payload equipment onboard, the heat-sealed casing will insulate the electronics and instrumentation through the entirety of the journey to Enceladus. Mobility on Enceladus was heavily debated through many iterations of feasible options, finally compromising with track gripping motor contact with the ice and snow and extending rotatable front ski arms. With the motor powered back and steering controls in the front maximizing surface contact with the ground, the rover is avoiding the risk of sinking deep in a less dense snowpack. The mobility of the rover may be compromised by unknown surface factors, so the lander payload is prepared to take immediate samples from the landing site. Directly below the rover, all equipment is shielded and deployable. The below measurement design was agreed upon to lower complications with mechanical complexities and the safety of the equipment exposure to the foreign hazards that Enceladus introduces.

We chose multiple scientific instruments to get the most out of the mission. First, the APXS, is an individual instrument that analyzes chemical elements to process readings. Next MEMs is also a stand-alone instrument, and its purpose is to gather seismic activity. Two separate cameras were added; they have potential to assist each other- one is a single camera from Perseverance's MastCam-Z, and the other is a PanCam. Both cameras in use high-resolution images with different lenses and can take photos at multiple wavelengths and different UV, and IR lights. The last scientific instrument we have is the TIRS (Thermal Infrared sensor), which collects IR electromagnetic radiation. All of these instruments work with the X-Band satellite communication system; the data is provided using a variety of frequency bands. This communicates resilience, data rates, and remote coverage to the rover. Eight Radioisotope Heater Units (RHUs) were also chosen to heat the inside of the rover and keep everything functioning correctly.

3.1.3. Dimensioned CAD Drawing of Entire Assembly

This model shows each component of the rover. The motion devices have been expanded out. The skis act as the motion mechanism, and they are in front and are composed of telescoping pipe. The primary landing equipment, the parachute, is compressed in the yellow box on top. The structural side panels are composed of graphite fiber due to their favorable strength-to-weight ratio. The assembly and fastener components are made of the aluminum 5083 alloy. This alloy was selected for its ability to perform in harsh environments. The overall salt content of the matter erupting from Enceladus' Tiger Stripes has 20 times that of what scientists expected. The salt content of the underwater ocean is predicted to be 0.5 to 2 weight percent salt; this was determined when the Cassini spacecraft flew through the geyser's plumes in 2013 (Bradley, D. The Salty Ocean of Enceladus. 2009.). For reference, the oceans on Earth have approximately a 3.5 weight percent salt content (US Department of Commerce, N. Why is the Ocean Salty? 2008). For this reason, an alloy that can withstand a corrosive environment was selected to help preserve the integrity of the rover design. The 5083 aluminum alloy has good weldability (Aalco – Ferrous and Non-Ferrous Metals Stocklist. https://www.azom.com/article.aspx?ArticleID=2804. Retrieved November 21, 2020). The main welding point on the rover design is the point at which the telescoping legs will join the feet. A structurally-sound design will ensure the overall mission requirements are successfully completed.

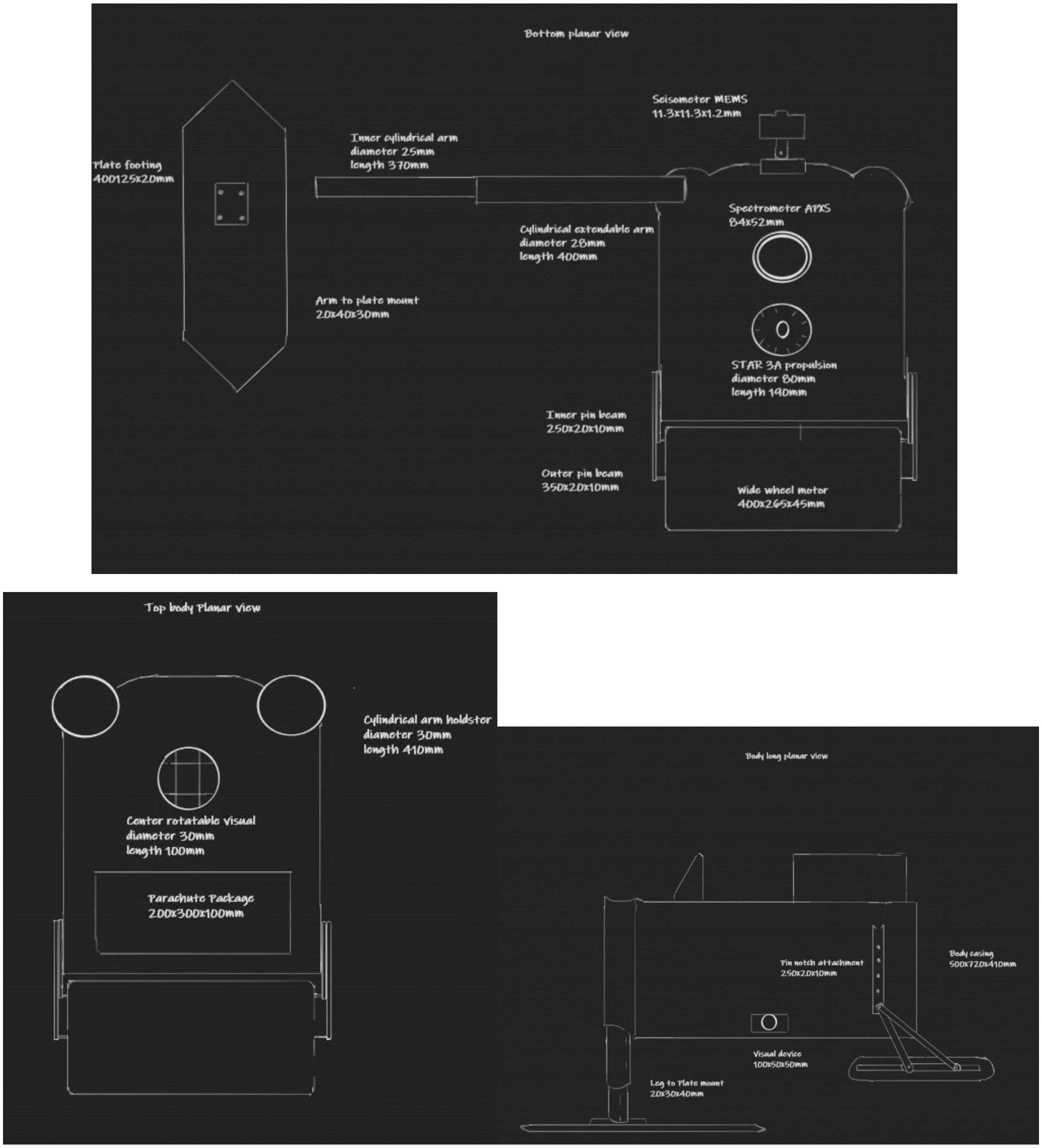


Figure 14. The above image shows the exploded CAD drawing of rover.

The dimension of the rover structure is a 500 by 720 by 410 mm box. When the parachute is fully expanded, the width is 6096 mm (20 feet).

3.1.4. Manufacturing and Integration Plans

The design developed by the engineering team had the underlying concept of having similar components as a snowmobile. The science instruments will be placed in an atmosphere-resistant box, and they will be used in a manner that will keep them safe from environmental hazards such as: extreme cold weather, humidity that might accumulate on the outside of the rover, corrosive salt, and falling core debris. Aluminum 5083 will be bought in bulk and the engineering team will fabricate the metal to design the shape of the instrument box. There will be a custom look-out hatch on the top of the box where the camera will be able to see outside through a set of mirrors similar to what the military uses in their armored vehicles. This will help ensure the safety of the instruments while being able to use the camera to observe the exterior. The timeline of fabrication and design will take place in the first year of the mission, and testing of the integrated systems will be completed in-house during the second year.

It will be ensured that all parts fit together by checking that all small instrumentation connections, such as corner brackets and joints, will be measured correctly and planned out in CAD and 3D modeling before the building process. If possible, the necessary parts will be 3D printed to ensure they are all the correct sizes and will work correctly and fit together.

3.1.5. Verification and Validation Plans

Some of the necessary steps needed to verify that the design will meet the system requirements would be that the rover moves into the testing process immediately after production. Testing is the main key element to make sure it works and is functioning correctly, all the necessary parts of the rover would be gathered, start production and make sure everything is working properly on its own. Then assessments would be conducted on each scientific instrument and test to make sure that each individual part is working as desired. Lastly, the communication system would be connected and each system in the rover would be checked to make sure that the entire rover functions and meets the system requirements. In the end, it would be guaranteed that the design meets the system's capabilities and requirements, that the two-way traceability between the final design of our rover and the system requirements functions, and guarantee that all of the tests performed on the rover are successful. If any system of component fails during these tests, it would be necessary that the requirements are reviewed, that they system or component is re-designed to fix the issues, and that it is developed and tested again until full success is met.

To answer the question, "Did I build the product right", it would be stated that when completing the product- the rover- it was not built based on assumptions. It was built with specific goals and requirements in mind. The team put forth their best effort to ensure that the right product was built and that every possible test was conducted successfully to guarantee that the rover functioned correctly. Even with potential project failures, the team acknowledges their responsibility for the success of the project, and they are confident in their abilities and knowledge as well as in the ability to review their successes and failures which guarantee that it is the right product.

3.1.6. FMEA and Risk Mitigation

Team 28 H2Go Risk Summary						
ID	**Summary**	**L**	**C**	**Trend**	**Approach**	**Risk Statement**
1	Instrument failure	2	5	↓	M	There is little to no redundancy for the lander's instruments. Losing one may prevent the fulfillment of mission goals and requirements. By internalizing many science instruments, the likelihood of instrument failure due to extreme cold temperatures and landing impact has been reduced.
2	Descent parachute failure	1	4	↓	M	Parachute failure during descent would subject lander to higher impact forces than planned for, causing potential failure of multiple systems. By adding a small propulsion system to assist with landing, the parachute system would experience less stress and decrease the likelihood of parachute failure.
3	Damage of structural materials	3	4	↓	M	Exposed structural materials may become subject to corrosion and damage due to extreme cold and the known water, salt, and organic particles coming from Enceladus' geysers. Such damage could potentially immobilize or destroy the lander. By coating these materials and sealing any vulnerable compartments, the potential for failure can be reduced.
4	Decreased battery efficiency	4	4	→	R	The efficiency of the battery can be greatly reduced due to the extreme cold temperatures of Enceladus. Without sufficient battery power, the lander may become effectively dead and unable to fulfil mission requirements. By utilizing a battery with more power than needed and applying a heat reflective coating to the structure around the battery, the lander can remain at optimum operating temperatures and optimize its power priorities.

5	Communication interference	4	3	→	R	Water vapor and other small particles may interfere with the ability of the lander to communicate with the spacecraft and Earth. By increasing the power to the communication system and automating the movement of the lander and the orientation of the lander's antenna, the lander may be able to overcome the interference.
6	Data viability	1	5	→	R	Weather and surface conditions may render the lander unable to return usable data. Falling debris from the geysers may render thermal and visual imaging systems ineffective, whereas surface snow or ice may make the seismometer and spectrometer yield data that cannot be used. Redundancy may not be possible with the scale of this mission, so more research is needed to further understand this risk.
7	Surface maneuverability difficulties	2	2	↓	M	The surface topography is largely inferred, and JMARS resources contain low-resolution information on elevation and angle of the surface. Whether or not the surface is primarily ice or snow is also largely unknown. By incorporating a snow-mobile design and selecting a relatively flat landing site, the lander can safely navigate along the surface.
8	EDL hazards	4	1	→	M	The selected landing site is in relatively close proximity to the geysers, as such geyser activity could present hazards to the landing maneuvers. By implementing sensors or similar adaptive technology, the lander can intelligently determine if the landing is threatened by the geysers and adjust its course accordingly.
9	Poor quality of components	2	4	↓	M	With custom-made or mass-produced components, manufacturing defects can potentially occur. By ordering duplicates of components that present the highest risk, within budget constraints, delays due to quality can be reduced.
10	COVID-19 schedule limitations	4	2	→	M	Due to COVID-19, many businesses have experienced closures and delays to keep their employees and customers safe. To account for this, any long lead items should be ordered as soon as possible.

3.1.7. Performance Characteristics and Predictions

After the rover has reached the surface, the landing equipment will detach from the rover structure. The skis will expand out via the telescoping tubes at the front two corners, and the tread in the rear will fold down. The motion of the rover will begin when the back motor is engaged. Initial rover motion will be autonomous to allow the mitigate surface lander-to-orbiter-to-Earth communication risks involved with the mission.

3.1.8. Confidence and Maturity of Design

The rover design iterations are shown in Table 1. The first iteration was designed assuming that the surface of Enceladus is snow. Snowshoe-like feet at each corner allowed the surface area to disperse and allows the rover to stay atop snow. The second rover iteration was designed assuming that the surface of Enceladus is ice. The tracks at each corner would allow for traction on the ice and quick maneuverability. The second iteration also incorporates sample arms. The third rover iteration combines several of the ideas discussed above. The rover has skis at the front that will allow for maneuverability through snow and a motor-powered tread in the rear for traction on ice. Because Enceladus has rough terrain and the surface density is unknown, this design will be able to maneuver a wide variety of potential surfaces the rover might encounter. To collect surface samples for analysis, the third rover iteration has small arms that will extend from the underside, gather samples, and then bring them back inside the rover for analysis.

The team has designed a rover, with combined abilities and knowledge. This rover has all the instrumentation needed to gather information required to further for knowledge about Enceladus. The rover has been tested and met all requirements and its system has by far passed expectations for each individual instrumentation as well as a whole. Through both failures and successes, we are confident in our ability to meet mission criteria and succeed in our mission.

3.2. Recovery/Redundancy System

A few backup plans for each of our systems include the Pan cam and Camera, which could work together as its own backup system, since they are both high-resolution cameras; if the PanCam fails for whatever reason, it can be substituted with the regular Perseverance’s MastCam-Z. If the APXS ever fails or does not work, it could be replaced with another form of laser that would take spectroscopy and produce narrowband, coherent wavelengths just as well. The MEMs a be replaced with a small seismic activity tool like a small portable seismometer. Lastly, the TIRS (Thermal infrared sensor) could be replaced with a smaller IR sensor, such as a passive infrared sensor, or even upgrade our camera to provide infrared support. If the communication system of X-band happens to not work, the Deep Space Network (DSN) could act as a backup for that main system; this consists of communication facilities around the earth with antennas to help use radio and radar to communicate. This would be coupled with a small high-gain antenna and RLGA antenna, and a RUHF antenna.

3.3. Payload Integration

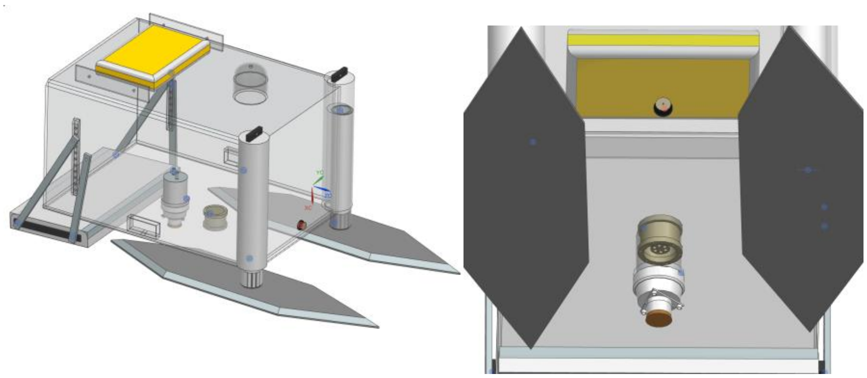


Figure 15. The above images shows CAD models showing interaction between instruments and lander.

Corner brackets as well as telescope tube swivel joints were used to add motions to the rover's legs. Alongside those, are fasteners, hinges, panels, and sliding doors to mount specific instrumentation. The structural side panels keep the base together. Instrumentation will be custom fitted to the internal rover housing for each location. The APXS spectrometer is directed beneath the rover, and ideally completely retractable within the rover's heat casing. The MEMS seismometer's optimal location is in the farthest position from mechanical vibration and discretely located in the lower frontal region. The camera and visual communication center will be located in the topmost region parallel to the parachute equipment. The visual communications will be rotatable and separated by the heat casing through concavity of mirror reflection. This system will be joined with side panel cameras beneath the rover for lower surface images.

4. Payload Design and Science Instrumentation

4.1. Selection, Design, and Verification

4.1.1. System Overview

Camera System

Camera systems on the Enceladus rover will gather images on the surface surrounding the lander using Charge Coupled Device (CCD) cameras. The power usage for the cameras is 3 watts for CCD and electronics, this does require temperature maintenance (NASA: *The Panoramic Camera).*

Micro-Electrical-Mechanical Seismometer (MEMs)

Power usage with the MEMs is 10-15 mW. Seismic data from the surface of Enceladus will be collected, and the power system will send the data back to the orbiter (Dutta Saxena, G., et al. Design, Development, and Testing of MEMs based Seismometer for Space Application. 2013.).

Alpha Proton X-ray Spectrometer (APXS)

The power usage on the APXS will be 5.8 MeV, with the X-ray particles emitting energy of 14.3 and 18.3 keV (Shanmugam, M., et al. Alpha Particle X-Ray Spectrometer (APXS) on-board Chandrayaan-2 Rover. 2014). Data acquisition will be spectra data from the x-ray emissions from pointing a Cm-244 isotope towards the sample. Emissions from the sample will be collected. APXS will work with the power system to conduct its experiments and will send information to the orbiter through the X-band Transmitter (APXS Instrument Information – MSL – Mars Science Laboratory. Retrieved November 27, 2020).

X-band Transmitter (Communication system)

The onboard communication system has a power usage of 56 watts. Data acquisition for this instrument will be conducted by the different instruments aboard the rover, then to transmit this data to the orbiter to be sent to Earth for analysis.

TIRS (Thermal infrared sensor)

Power usage of the TIRS is 1.6 W. The data acquisition for this instrument will collect infrared intensities from the Enceladus surface (Sebastian, E. The MEDA Thermal IR Radiometer For the Mars 2020 Mission. 2020).

The systems involved in maintaining internal instrumentation include the power: a H-200 PEM Fuel cell with 200W power due to its small size, and its price range and power range. For thermal a gold foil on the outside body of the rover was chosen to preserve the heat inside that the battery produces. This keeps body temperature functioning for all systems, since it is extremely sensitive to cold; eight radioisotope heater units were added to keep the inside of the rover functioning correctly.

4.1.2. Subsystem Overview

Camera System

The camera system uses CCD camera sensors and multiple filters to take images at different wavelengths of light, similar to the PanCam on Mars Exploration Rovers. A tube with an angled mirror will reflect light from outside the lander through a color filter and focus the lens to the CCD sensor. This tube will rotate to provide a complete view of the surface around the lander (Bell, J., et al. *About the PanCam*).

MEMs

The MEMs utilize electrostatic spring softening to absorb high levels of shock (Yee, K., et al. MEMs Seismometer-Probing the Interior of Planets. 2019). It will collect seismic readings on the surface of Enceladus.

APXS

The instrument uses Curium-244 as a source of radioactive isotopes, and this will activate the elements within the sample. X-ray emissions will be used to take a spectrometer reading and reveal the abundance of major elements (APXS for Scientists, 2020).

X-Band Transmitter

Communications for the rover will be handled by the PDT-300 X-band Transmitter. It will take the data gathered from other science instruments and send the data to the Enceladus orbiter. The orbiter will then send that information to Earth (Sat Search PDT-300. Product. https://satsearch.co/products/agil-space-pdt-300-x-band-transmitter).

TIRS

TIRS uses thermopiles to measure infrared. Thermopiles convert heat to electricity that can be measured. More heat creates more electricity which can be used to map out IR on Enceladus' surface. TRIS contains 5 thermopiles that cover different bands (with some overlap). Converts approximately 3m^2 of area at a distance of 3.75m. Thermally controlled so sensors are not thrown off (Sebastian, E. The MEDA Thermal IR Radiometer For the Mars 2020 Mission. 2020).

The basic relationship between each of the different systems is that most of the scientific instruments will function single-handedly on their own unless stated otherwise. The rover will run on a 200kW PEM fuel cell which will power all systems including communication systems. The rover's motions will be powered by a motor that will power our main legs and movement functions on the body of the rover. The X-Band communication system will control communication between the rover and earth, as well as communication between inside and outside of the rover's instrumentation. This includes all scientific instruments as well as the parachute, propulsion device, and the rover's main direct movement and controls.

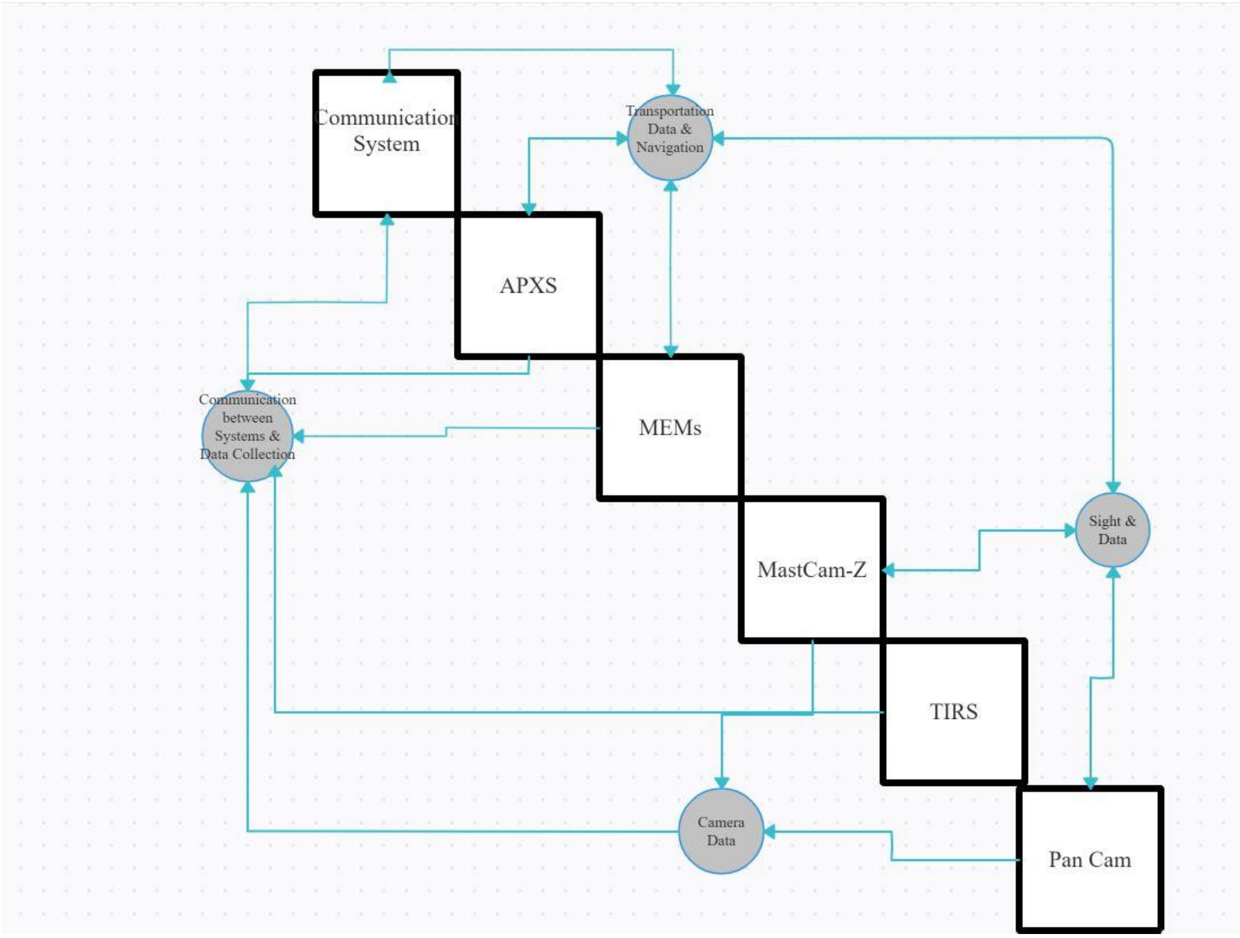


Figure 16. Above is the N2 chart for system integration.

4.1.3. Manufacturing Plan

Camera System

All components can be used commercially or designed by a 3D printer, though it may be cheaper to use COTS (Machine Vision Store, 2020).

MEMs

The manufacturing plan is currently TBD. JPL is currently conducting R&D on this microdevice. It would be better to continue investigating the research already done than to start from scratch (Yee, K., et al. MEMs Seismometer-Probing the Interior of Planets. 2019) (Murphy, P. Universal MEMs Seismometer-Project Introduction. 2018)

APXS

The APXS is built by the Canadian Space Agency. The production of this instrument will be outsourced to them, then shipped to our assembly facility where the whole rover will be put together (Davidson, J. Mars-bound rock analyzer a 'new step' for Canada in Space. 2011).

X-band Transmitter

The PDT-300 X-Band Transmitter comes from AgilSpace (RF Communications. PDT-300 X-Band Transmitter). It is an instrument available from them upon request. This technology is easy to come by because it is used in many cubesats. (Sat Search PDT-300. Product. https://satsearch.co/products/agil-space-pdt-300-x-band-transmitter).

TIRS

Created by Spanish Centro de Astrobiology, it is a part of MEDA (Mars Environmental Dynamics Analyzer) which will be on the Mars 2020 rover. With this technology already developed the Spanish Centro de Astrobiology, will be able to produce this instrument for us (Sebastian, E. The MEDA Thermal IR Radiometer For the Mars 2020 Mission. 2020).

4.1.4. Verification and Validation Plan

Camera System

Verification of the camera systems consists of: ensuring that defects due to manufacturing of the CCD sensor are within quality assurance parameters, determining what defects can cause artifacts in the resulting images and if those need to be adjusted for before or after the image is taken (some artifacts can be accounted for using software after the image has been taken), ensuring that color filters filter out the appropriate wavelength of light before assembly, ensuring that the lens used for focus can result in a focused image, determining if the thermal control system can potentially cause artifacts in the image (heat can affect the CCD's image) (Cumani, C. Introduction to CCD's. 2004), determining if the tube with the angled mirror can provide a clear image, and calibrating the camera for the brightness and the color of the image.

Validation of the camera system will include determining if the camera system can withstand vibrations due to launch and EDL, determining if the camera system can operate within the lander in an extremely cold environment, and determining if the debris from Enceladus' geyser prevents the camera from taking worthwhile images (i.e. icing over the view provided by the mirror, landing site is under whiteout conditions, ect.)

MEMs

The verification plan for the MEMs are as follows: ensuring that defects due to manufacturing are eliminated or within acceptable deviations, determining how a rough landing would possibly affect measurements, and how to account for that in data processing, calibrating sensors for icy conditions (using Antarctica as possible reference) (D'Alessandro, A., et al. A Review of the Capacitive MEMs for Seismology. 2019.) and ensuring that sensors are able to process any data it may receive, no matter how small.

Validation plans for the MEMs set out to determine how weather fluctuations would affect data, and to determine how being buried in show/debris would affect data collection (Dong-Ya, G. We apologize for the inconvenience. Retrieved November 27, 2020).

APXS

Verifying the APXS includes assessing the accuracy of the instrument with quantitative analysis. Sample analysis of compositions will be done to ensure that the samples match original testing.

Validating the APXS requires the data processing and procedural methodology, while the study of the data acquisition time and detection distance on the limit of detection (LOD) of major elements (Dong-Ya, G. We apologize for the inconvenience. Retrieved November 27, 2020).

X-band Transmitter

Verifying the communication system of the x-band transmitter will require checking that the base station is transmitting the correct power for each channel. This will reduce measurement uncertainties. Procedures for the transmitter not meeting design specifications include looking at the signal in the frequency domain and verify that its spectrum appears as expected, performing in-band and out-of-band power measurements, a timing measurement, and determining the error metrics (offsets, phase error, frequency error.)

The validation plan is to iterate through the verification testing so that the x-band transmitter parts are working as expected together. Parts coming from different manufacturers can cause error or failures, hence why testing is integral to this validation (Technologies, A. Agilent Technologies Wireless Test Solutions Application Note 1313. Retrieved January 8, 2002).

TIRS

Verification of the TIRS includes checking each of the 5 channels to make sure they detect in their bands, running TIRS for a while (all channels reporting at once) to make sure it can run and fail within the given accuracies of each channel. Also testing the calibration system remotely to make sure adjustments can be made to any unforeseen problems with the system.

The validation of the TIRS is to evaluate that the instrument will be able to work with the thermal control system to survive Enceladus. Simulating masking out reflected light from the sun so that the instrument only receives IR data from Enceladus' surface (Sebastian, E. The MEDA Thermal IR Radiometer For the Mars 2020 Mission. 2020).

4.1.5. FMEA and Risk Mitigation

Team 28 H2Go Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement
1	Instrument failure	2	5	↓	M	There is little to no redundancy for the lander's instruments. Losing one may prevent the fulfillment of mission goals and requirements. By internalizing many science instruments, the likelihood of instrument failure due to extreme cold temperatures and landing impact has been reduced.
2	Descent parachute failure	1	4	↓	M	Parachute failure during descent would subject lander to higher impact forces than planned for, causing potential failure of multiple systems. By adding a small propulsion system to assist with landing, the parachute system would experience less stress and decrease the likelihood of parachute failure.
3	Damage of structural materials	3	4	↓	M	Exposed structural materials may become subject to corrosion and damage due to extreme cold and the known water, salt, and organic particles coming from Enceladus' geysers. Such damage could potentially immobilize or destroy the lander. By coating these materials and sealing any vulnerable compartments, the potential for failure can be reduced.
4	Decreased battery efficiency	4	4	→	R	The efficiency of the battery can be greatly reduced due to the extreme cold temperatures of Enceladus. Without sufficient battery power, the lander may become effectively dead and unable to fulfill mission requirements. By utilizing a battery with more power than needed and applying a heat reflective coating to the structure around the battery, the lander can remain at optimum operating temperatures and optimize its power priorities.

5	Communication interference	4	3	→	R	Water vapor and other small particles may interfere with the ability of the lander to communicate with the spacecraft and Earth. By increasing the power to the communication system and automating the movement of the lander and the orientation of the lander's antenna, the lander may be able to overcome the interference.
6	Data viability	1	5	→	R	Weather and surface conditions may render the lander unable to return usable data. Falling debris from the geysers may render thermal and visual imaging systems ineffective, whereas surface snow or ice may make the seismometer and spectrometer yield data that cannot be used. Redundancy may not be possible with the scale of this mission, so more research is needed to further understand this risk.
7	Surface maneuverability difficulties	2	2	↓	M	The surface topography is largely inferred, and JMARS resources contain low-resolution information on elevation and angle of the surface. Whether or not the surface is primarily ice or snow is also largely unknown. By incorporating a snow-mobile design and selecting a relatively flat landing site, the lander can safely navigate along the surface.
8	EDL hazards	4	1	→	M	The selected landing site is in relatively close proximity to the geysers, as such geyser activity could present hazards to the landing maneuvers. By implementing sensors or similar adaptive technology, the lander can intelligently determine if the landing is threatened by the geysers and adjust its course accordingly.
9	Poor quality of components	2	4	↓	M	With custom-made or mass-produced components, manufacturing defects can potentially occur. By ordering duplicates of components that present the highest risk, within budget constraints, delays due to quality can be reduced.
10	COVID-19 schedule limitations	4	2	→	M	Due to COVID-19, many businesses have experienced closures and delays to keep their employees and customers safe. To account for this, any long lead items should be ordered as soon in the project as possible.

4.1.6. Performance Characteristics

Camera System

Due to the time of year planned for landing, there should be plenty of light available on the southern pole to aid image taking. CCD's will use a small amount of power, conserving the power needed to operate the lander, saving mass and volume for other vital aspects of the lander. This has been used on the Mars Exploration Rovers, showing they can handle extreme environments if implemented correctly. [PanCam Instrument Site]

MEMs

The MEMs require very little power, which will help conserve lander power (Dutta Saxena, G., et al. Design, Development, and Testing of MEMs based Seismometer for Space Application. 2013.). It is very small, saving space inside the rover (Yee, K., et al. MEMs Seismometer-Probing the Interior of Planets. 2019). It is ultra-shock-absorbent and built to withstand extreme temperatures and environments, as it is designed for icy ocean worlds of the Jovian planets and their moons (Merchant, J. B. MEMs Applications in Seismology. 2009).

APXS

With the assistance the onboard warming box, instruments will be able to function in the extreme cold on Enceladus. The time of year that the mission takes place will not matter for the APXS to perform its sample analysis, and the only challenge will be obtaining the samples. During the winter or when Enceladus is not facing the Sun, the sample on the surface will not be as detectable in the dark. The instrument can withstand up to -35 degrees Celsius, but with the help of the warming box, it will be able to survive the extreme on the surface of Enceladus (Shanmugam, M., et al. Alpha Particle X-Ray Spectrometer (APXS) on-board Chandrayaan-2 Rover. 2014).

Table 2. Transmitter DC input and RF output powers.

	Transmitter S/N001		Transmitter S/N002	
Temperature (°C)	P_{DC} (W)	P_{RF} (W)	P_{DC} (W)	P_{RF} (W)
−30	31.34	4.55	28.87	4.31
−10	31.73	4.83	28.66	4.48
+10	31.76	4.69	28.72	4.47
+25	31.71	5.00	29.57	4.88
+45	30.97	4.71	29.53	4.71
+60	30.97	4.37	29.40	4.20

X-band Transmitter

Temperature variance on the surface of Enceladus can affect the performance of the DC and RF power transmission. The temperature will determine the fluctuation of each transmitter's power. The temperature around the transmitter will be controlled by the warming box (Solan, R. F., et al. An X-Band Telecommunications Transmitter For The Mid-Course Space Experiment. 1993).

TIRS

TIRS is a compact instrument that can be calibrated remotely if it is not performing to the standards on the surface on Enceladus. This instrument will be used in the Mars 2020 mission, meaning that current testing and experimentation is extensive. In varied environments, TIRS can be warmed into its provided temperature range to give reliable results. The current mission will be landing during the summer on Enceladus, so extra power will be reflected by the surface (high albedo) from the Sun. This will require a filter for the excess power to be filtered out to obtain reliable results (Sebastian, E. The MEDA Thermal IR Radiometer For the Mars 2020 Mission. 2020).

4.2. Science Value

4.2.1. Science Payload Objectives

The main goal of Team H_2GO is to examine the Saturnian moon of Enceladus to determine the elemental composition of its core, whether or not it is porous, and to establish whether or not it contributes to the activity of the plumes. To complete this mission, data will be gathered from rocks scattered over the surface and determine if the rock samples originated from the core. The instrument used for this will be the Alpha Particle X-Ray Spectrometer (APXS). The APXS takes samples from the surface soil/rock and analyzes its chemical composition, which will give insight into the core's makeup, and whether or not the inner area of Enceladus has the capabilities to support life. A secondary goal is to avoid potential hazards to the unsullied environment of Enceladus. This will be accomplished by carefully planning the landing site to avoid the most hazards on the surface. The secondary hazard mitigation will consist of cleaning up the waste the mission creates. Any waste created will be cleaned up to avoid creating obstacles for future missions to Enceladus. Imaging data of the moon's surface topography will be collected, as well as potentially gathering images of its subsurface ocean and seismic readings of the core. Using a Micro-Electrical-Mechanical (MEMs) Seismometer, seismic readings will be taken and analyzed to discern the tectonic movements and core makeup of Enceladus. This mission aligns with current decadal goals to understand icy worlds and the potential for how life might develop on other celestial bodies.

4.2.2. Creativity/Originality and Significance

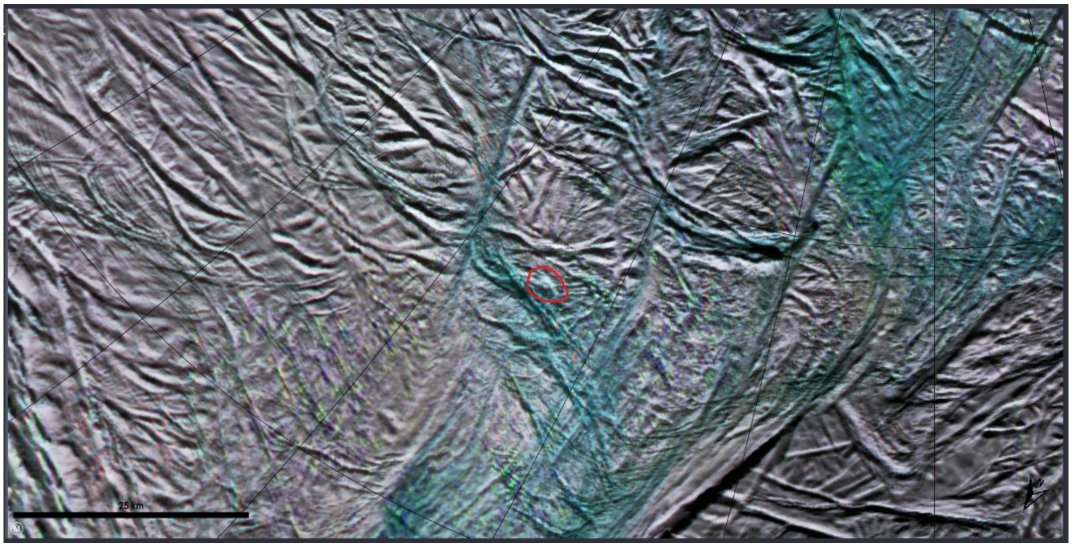


Figure 17. JMARS image showing selected landing site circled in red, located at the coordinates -66.846°N, 34.903°E. It is about 50 km away from the nearest primary geyser.

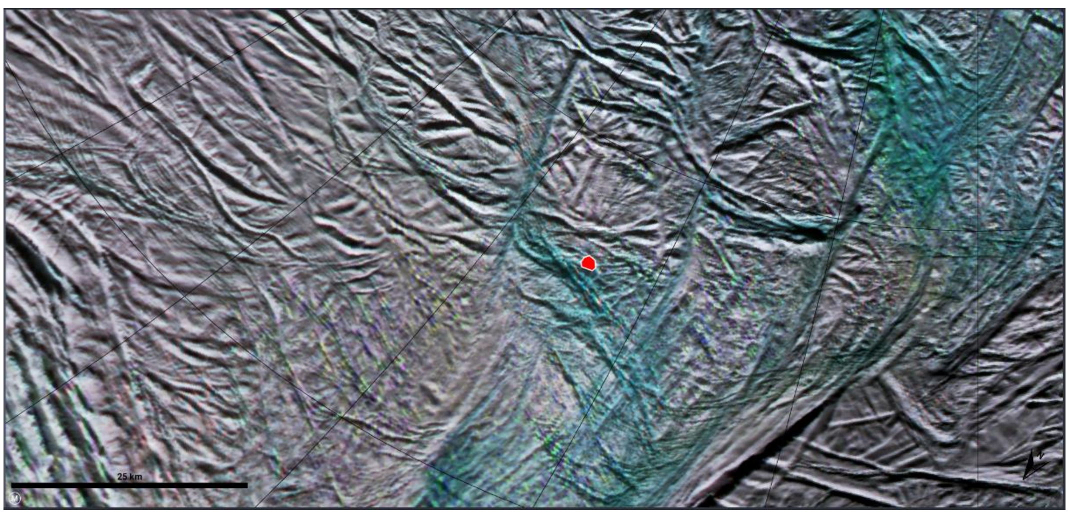


Figure 18. JMARS image showing area of selected landing site. The area within the red circle is 2.025 km^2.

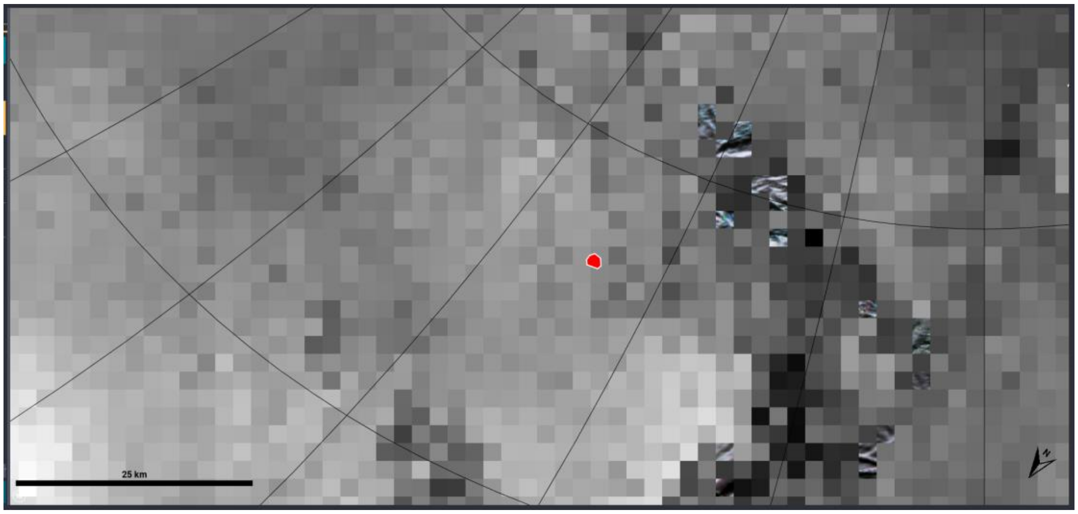


Figure 19. JMARS image showing the elevation of the landing site enclosed in red. Lighter squares indicate higher elevation, and darker squares indicate lower elevation.

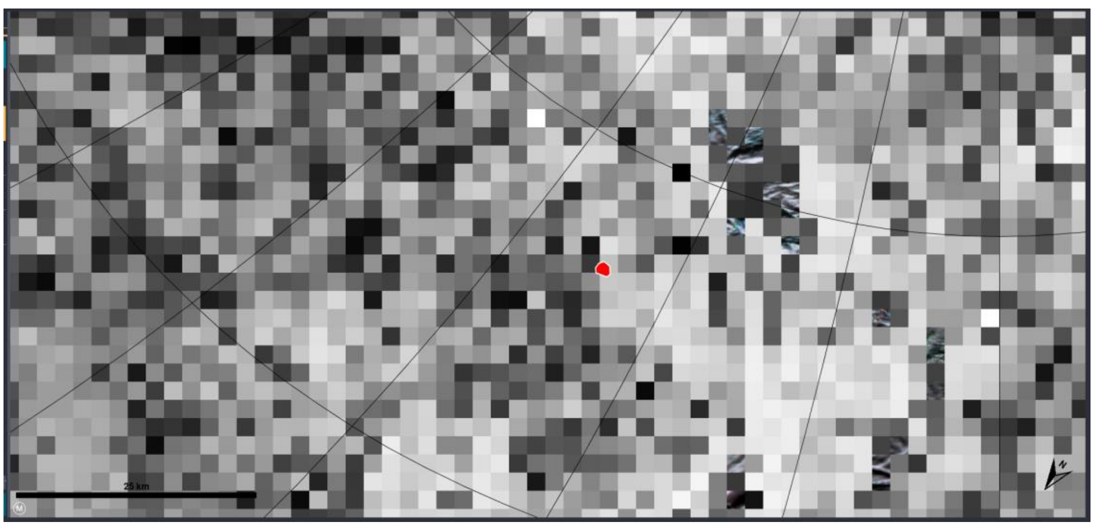


Figure 19. JMARS image showing the slope of the landing site enclosed in red. Brighter squares indicate shallower slopes, and darker squares indicate steeper slopes.

An outstanding question about Enceladus has been what does the core of the moon look like? Initial models of a solid core did not create enough heat to maintain a liquid ocean below the surface, so many switched to a very porous core. These adjusted models were able to create the amount of heat to maintain this ocean leading to some excitement, but in the end they are hypotheses with very little evidence to back them up. By choosing this landing site, the rover will be in an active area that will contain evidence about the core of Enceladus. The light blue areas near the landing site contain sediments from inside of Enceladus shot up by the geysers, including material from the core. The rover is in an optimal position to find this core material and it contains the necessary instruments to discover what the core is made of. With this collected data, the team will be able to weed out any models that do not follow the evidence.

4.2.3. Payload Success Criteria

Camera System

Success for the camera system is to take at least 1024 by 1024-pixel images that are in focus and are adjusted for correct brightness and color. These images will be taken using multiple light filters to provide more information.

Some failure modes include: the images are not in focus, the images are not able to be adjusted for brightness or color, the resolution and image sizes that are too small to allow for scientific observations and conclusions, and the light filters filter out too much/too little/ incorrect wavelength of light.

Taking an image on the surface of Enceladus would be groundbreaking and vital to understand this untouched world. Pictures have never been taken on the surface of Enceladus. The images taken by the lander will provide information on the topography of the surface that can be used to plan for later missions. Different wavelengths of light can provide information about the surface and atmospheric composition, which can be used to draw conclusions about the composition of the core and/or the subsurface sea and this can be utilized plan for future missions. [PanCam Instrument Site].

MEMs

Success for the MEMs means that usable seismic data is collected and able to be analyzed for scientific purposes. The failure modes include, the seismometer fails to collect data, and the data collected cannot be accurately explained, due to the outliers in data that taken cannot be explained by any events that occurred on the surface.

There is a large significance to the projected data collection for this mission. No seismic data has ever been collected on the surface of Enceladus. This would help with the analysis of the geysers. The seismic data could provide revolutionary discoveries about the inner workings of the core of the planet and about the tectonic movement of its icy crust.

APXS

The success of the APXS is determined by the collecting of elemental data it relays back to earth. The failures on this instrument include that data acquisition was not successful, a failed door/sample opening, and a sequencing data error.

Sample analysis has never been taken of any of the rocky substances on the surface before and using APXS will be able to show the prominent elements on Enceladus. The composition of elements will show whether or not the core is porous or even active.

X-band Transmitter

Successful use of the transmitter will be when the system relays information correctly and with the correct amount of data in the average configured data range.

Some failures that could happen include the signal varying due to surface conditions, temperature/atmospheric interference, and data miscalculations. To mitigate this, preliminary testing on Earth for each instrument will be performed to determine a base level of data that can be used to calculate variance.

X-band transmitter is the communication system on the rover that will send information to Earth. Without this system, none of the data can be communicated back to Earth for analysis and interpretation. Without this instrument the data would be unattainable.

TIRS

The success of TIRS will report data from the expected errors that can be analyzed to learn about the internal structure of Enceladus. Instrument failures include calibration issues, detectors degrade over time, slips of support plate (means no thermal control).

IR data on the surface can lead to key data about what happens under the ice. Since the widely accepted hypothesis for Enceladus's heat is tidal heating, discontinuities in IR power can provide experimental proof of this or disprove it (highly unlikely). Mapping IR readings can be used to develop a shape for the core and the power measurements can be used to determine a material.

4.2.4. Experimental Logic, Approach, and Method of Investigation

Surface sample data will be collected at incremental distances from the landing point to the geyser of interest. The landing for the rover is shown in Figure 3 of PDR section 1. The relative slope of the land in this area was determined to be 14.8° through analysis using the remote sensing JMARs software. This slope was relatively shallow compared to other regions of the surface. Because of this, the rover will maneuver towards a potential geyser from the point of landing while collecting various surface samples along the way. This landing site is approximately 1 km from the geyser, so a collection of data would occur about every 100 meters while the lander is moving towards the geyser.

Camera Systems

The camera systems will be operational during Entry Descent and Landing, first taking an image of its calibration target, then rotating the angled mirror to take images from multiple angles of the descent, pausing after each rotation to place a different color filter over the lens. After the lander has made contact with the surface of Enceladus, the mirror will pause rotation and the color filters will reset to the filter that allows all light to hit the CCD, then the mirror will pause rotation and the color filters will reset to the filter that allows all light to hit the CCD, then the mirror will reorient to allow for the calibration target to be viewed under the surface conditions of Enceladus. After the filter has been reset, the mirror will resume rotating and pause after each full rotation to change the color filter. When the lander is moving, the mirror will be rotated to a front-facing position, to aid with navigation. When a potential target for the spectrometer is identified, the mirror will then rotate to a position that best aids the lander in maneuvering to a position for the spectrometer to perform its functions. The camera system should also be able to synchronize its image taken with the data sampling of the thermal imaging system, to create a thermal map of the area surrounding the lander.

MEMs

The MEMs will not be deployed until after landing. The instrument can be operated remotely, so the rover will drop the seismometer on the surface after landing and it does not need to stay with the rover. The seismometer collects data constantly and independently of the rover, sending data to the orbiter above.

APXS

The APXS will acquire samples through a robotics arm, which will harvest samples from the surface of Enceladus. The samples will be crushed and put between two glass inspectors that will then expose the sample to Curium Isotope 244. After curium is excited to alpha particles, the sample will emit x-ray particles that will then be measured if they are in a range of 1-25 keV. The spectrometer will then gather the data and send it back to Earth through the x-band transmitter and the orbiter (APXS Instrument Information – MSL – Mars Science Laboratory. Retrieved November 27, 2020).

TIRS

TIRS will be deployed after landing on Enceladus. Measurements will be sent to the orbiter and back to Earth to determine if the system is calibrated correctly, if not, the data will be analyzed to find where it went wrong and adjusted accordingly so that it returns reliable data. The instrument acts similarly to a camera, except it only measures infrared. TIRS can also take measurements as the rover is moving, which would be preferred to find an IR power gradient. If not, it can be used in a small area periodically in different zones.

4.2.5. Testing and Calibration Measurements

The calibration of scientific instruments will be performed after the lander has reached the surface and detached the landing equipment. Some instrument calibration will occur during descent, such as camera calibration. A preliminary plan for the calibration of each instrument is discussed below. The calibration data will be comminuted back to Earth through the orbital communication system to verify instrument functionality prior to surface data collection begins.

Camera Systems

The calibration target for the camera system will be an object mounted either internally or externally that is both exposed to the light conditions on Enceladus and visible to the camera system. This object will have materials that reflect known wavelengths of light on it, so that the images taken may be adjusted later for the correct color. The target will also have a raised surface that can allow for a shadow to be cast, so that the brightness of the image may be corrected after the image has been taken (NASA: *Calibration Targets*). (inspiration for this target is taken from the target used for the PanCam on Mars Exploration Rovers)

During descent, the camera system will image the calibration target before further images are taken. After the lander has made contact, the camera system will reference the calibration target after the filters have been reset, so the brightness and color of the images can be adjusted for the light conditions on the surface.

As the lander moves, after the filters have gone through a full rotation, the camera system will reference the calibration target if there are no conflicts with the other instruments. This will allow for the brightness and the color of the images to be adjusted as the conditions on the surface of Enceladus change.

MEMs

The MEMs will be calibrated using comparable Earth data. The instrument will be tested on Earth to make note of natural fluctuations and errors in the instrument, which will be accounted for when on the surface of Enceladus.

APXS

In-flight calibration is not needed for the APXS. There will be a target plate with multiple sample sheets for the APXS to analyze when landed on the surface. The fluorescence of the samples will provide monitoring of gain and offset of the instrument. If there is variation, it will determine the possible sample contamination. If there is deviation from ground calibration of the instrument, it can be quantified with calibration plate observations, where these corrections will be applied to the analysis. The elements on the calibration plate are Ai, SS, Cu, Ti.(Shanmugam, M., et al. Alpha Particle X-Ray Spectrometer (APXS) on-board Chandrayaan-2 Rover. 2014).

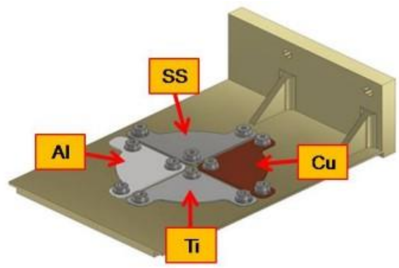


Figure 20. The above image shows the schematic representation of 4 metallic calibration targets used on APXS.

X-band Transmitter

Pre-flight testing will take place on Earth. There will be a spectrum analyzer test and a vector signal analyzer to ensure the proper calibration and signal of the transmitter. Testing for in-band and out-of-band measurements will be taken. In-flight calibration will be done to ensure that the communication system is operating. Calibration at this time will be used to determine a baseline transmission signal. Once on the ground, the rover will send another signal to determine a safe landing. This signal will also be measured and calibrated to ensure that correct data will be recorded. (Technologies, A. Agilent Technologies Wireless Test Solutions Application Note 1313. Retrieved January 8, 2002).

TIRS

The TIRS will be calibrated before, but if data is not correct, it can be calibrated after the landing on Enceladus. It has a calibration plate that uses two heaters and an RDT (resistance temperature detector) to calibrate the precision.

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

Camera System

For precision, the light filters should allow light of their corresponding colors within +/- 5nm or better.

The repeatability of the camera systems will be due to the rotation of the mirror; many images will be taken at different wavelengths of light. With the precision of the filters, the images can be used to support the conclusions of the spectrometer regarding the composition of the surface. The accuracy of this information will be verified on the surface using the calibration target. Referencing the known colors on the target will ensure that the correct wavelengths of light are being viewed so the conclusions based on what is viewed can be made with accuracy.

In the event that the camera system fails, images already taken will be stored in the memory onboard the lander. These can be saved for later communications or sent immediately to ascertain the status of the mission. If no images have been taken prior to the instrument failure, topographical information may be able to be inferred from the thermal imaging system and surface composition may be determined using the spectrometer.

MEMs

The precision for the MEMs is currently under development at NASA’s microdevices lab at JPL. Reputability is ensured by the fact that the MEMs will constantly be collecting data. In the event of seismometer failure, the lander/orbiter will have already collected data from the MEMs before the failure. The MEMs are not mission-critical, as it will not stop the rover from moving and collecting other data, so failure would be a great loss of seismic data, but not detrimental to the lander itself.

APXS

Precision of the APXS instrument will be adjusted based on the calibration measurements. The accuracy of each element is to fall less than 15wt. % at 30mm with 30 minutes of data acquisition time.

There is no recovery plan for these samples yet. The samples will be stored inside the rover as collection takes place. Should astronauts go to Enceladus, they can pick up the rover and retrieve the samples. The recovery plan will continue being developed over the course of the mission.

Should the APXS fail, the TIRS, as well as the Camera system, will be able to take visuals of the surface that can be used for spectroscopy analysis on Earth. The camera system will have many images in different wavelengths, so some significant data can still be collected, although the APXS can get more precise measurements of the element compositions.

X-band transmitter

Noise floor distortion should be at least 10 dB below the distortion of the signal being measured for accuracy. Frequencies for this instrument are 8025-8400 MHz; any radio frequency chosen should fall within these parameters [Agile Space].

There are procedures to do a recovery on an analog signal by filter out the unwanted frequency components and resending the signal (Technologies, A. Agilent Technologies Wireless Test Solutions Application Note 1313. Retrieved January 8, 2002).

TIRS

Accuracies are given to testing. [Source: https://www.hou.usra.edu/meetings/lpsc2020/pdf/1269.pdf]

Since TIRS is essentially a camera, some areas will overlap when it is collecting data; these overlapped areas will be analyzed to ensure precision.

Data will be transmitted via electromagnetic radiation, so as long as there are no system failures for communication, data will be collected.

If TIRS fails, the cameras may be used as backup. The camera can detect IR with a filter so it can be used like TIRS as long as it is not navigating in the visible spectrum. TIRS also contains 5 channels, so if 1 fails, there are still 4 channels left. Some coverage will be lost on the IR spectrum, but TIRS will still function.

Table 3. The above table shows the best current estimate of the TIRS channels performance.

Channel	*Dynamic range*	*Accuracy*[1]	*Resolution*
IR1 [W/m^2]	3.5-180	±1.7 to 6.2	±0.18
IR2[K]	173-293	±3.7	±0.45
IR3[W/m^2]	0-230	±3.7 to 9.5	±0.1
IR4[W/m^2]	50-420	±1.2 to 3	±0.1
IR5[K]	173-293	±0.7	±0.08

[1] *Variation depends on thermal scenario (diurnal and seasonal variation).*

4.2.7. Expected Data & Analysis

Cameras

Example of a CCD image from opportunity rover: [http://pancam.sese.asu.edu/images/True/Sol055B_P2542_1_True_RAD.jpg].

Example image of CCD image from Spirit rover: [http://pancam.sese.asu.edu/images/True/Sol063A_P2532_1_True_RAD.jpg].

Figure 21. The image on the left is an example image from the Spirit rover and the image on the right is an example image from the Opportunity rover.

The expected similarities to the camera system are the image quality, and the expected differences are brightness and color. As Enceladus' surface is primarily white and very reflective, the images from the lander would gather images that are both brighter and less colorful than the images above taken from the Mars Exploration Rovers Opportunity and Spirit. Since the CCD camera system for the lander takes inspiration from the PanCam system used for both rovers, image quality is expected to be similar to, if not better than the example images.

The images gathered from the lander would be analyzed to find any irregularities or unexpected colors on the surface. As the surface is understood to be water ice, noticing any differences in color can help to inform how the ice has formed or what impurities may be present. With the accuracy of the filters of +/- 5 nm, inferences can be made as to how the ice around the lander is composed, inferences that can support or supplement the data from the other science instruments.

MEMs

As this is the same system as the MEMs seismometer, the data should look similar, if not the same. An expected difference is in the actual data itself. Not much is known about Enceladus' seismic activity, so the data could be suprising when collected. The data collected would be averaged over time to look for any irregularities and outliers. Since Enceladus is so different from terrestrial worlds, there is really no comparison that can be made between terrestrial seismometer data and data from Enceladus. The expected error for this seismometer is anticipated to be very small. Preliminary tests on Earth would be conducted to see how certain events affect data reading, so scientists can effectively interpret data fluctuations when they appear.

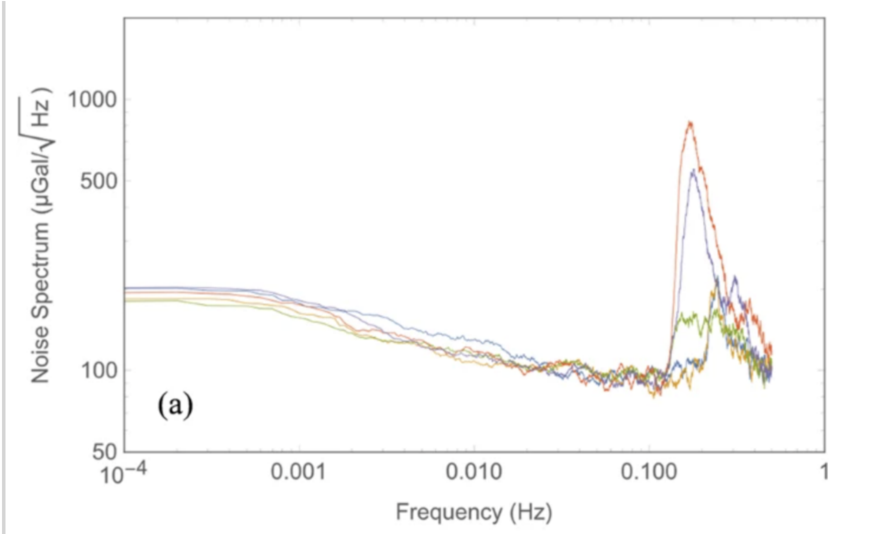


Figure 21. Above is sample data from a MEMs seismometer in Bristol, UK. (Mustafazade, A., et al. A Vibrating Beam MEMs Accelerometer for Gravity and Seismic Measurements. 2020.)

APXS

The sample data is taken of a sample of granite that was acquired with alpha radiation. The expected sample on Enceladus would include more heavy metals, such as Iron, Silver, or Nickle. These elements are present in the sample shown. Analysis of the data will be charted to show different elements present in the sample. Allowing discussion of the type of rock precedent on the surface. Information about the landing site can be determined based off on the samples that are taken. If there is rock or ice, the APXS will tell us what ice/rock is made of. As stated before, error calculation will be taken with inflight calibration, then will adjust the data set accordingly (Shanmugam, M., et al. Alpha Particle X-Ray Spectrometer (APXS) on-board Chandrayaan-2 Rover. 2014).

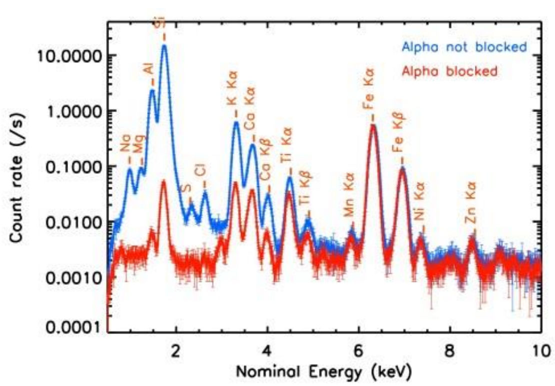


Figure 22. The above image shows the APXS spectra of granite sample and spectra acquired with alpha radiation from source blocked using a thin plastic sheet.

X-band Transmitter

The measurement will be the frequency range and relative amplitude. The analysis of this data will be the frequency range and relative amplitude. The analysis of this data would be over time to measure if the frequencies vary at all. Conclusions around this would be made regarding if the communication systems were working properly or needed to be tuned. By analyzing this data, records of the telemetry with other instruments will be present (Solan, R. F., et al. An X-Band Telecommunications Transmitter For The Mid-Course Space Experiment. 1993).

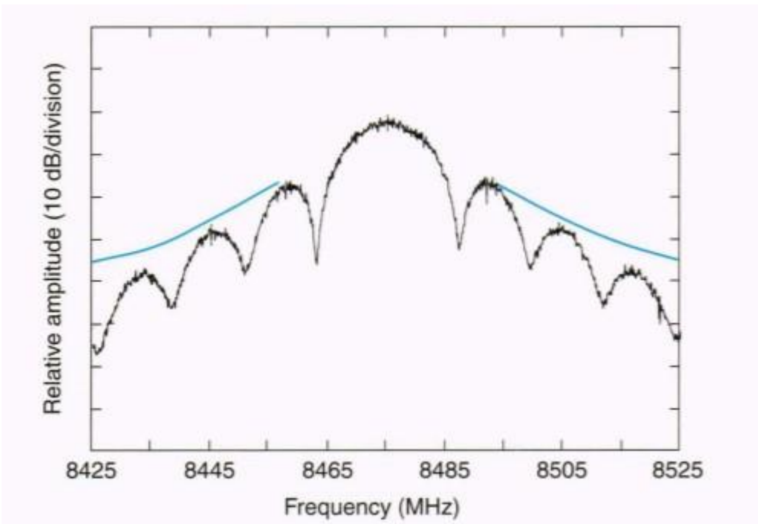


Figure 23. The above image shows the typical output spectrum for random modulation (black) with the spectral limit of the National Telecommunications and Information Administration superimposed(blue).

TIRS

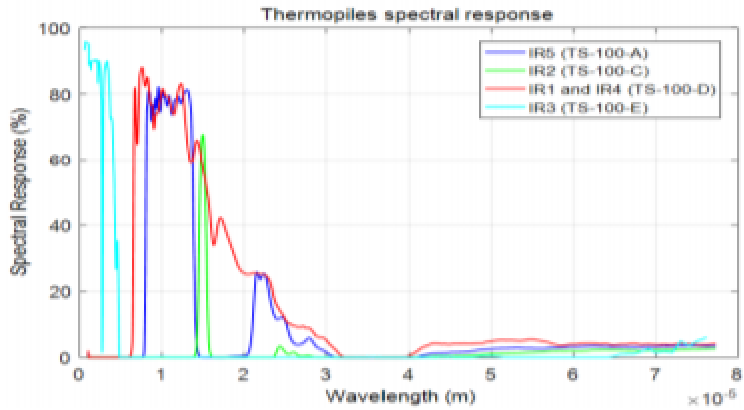


Figure 24. The image above displays the Thermopiles Spectral Response graph.

Although this is not a direct measurement of power, it shows how the power will change based on wavelength and how it should be adjusted. Each channel has a certain band it covers, so the data will be used from the ones that fall within Enceladus's power output. Because channels overlap, multiple channels can be used to make sure data has relatively low uncertainty. The data will look different in that we will likely be plotting a plane where the x,y position is where it is on the surface and it will be colored by the intensity. This way we can see how power changes with position. This can be seen with the picture below, but the resolution of the rover's camera will be much better, similar to the picture below. The general idea of how the IR map of Enceladus looks, but by mapping out the IR power in higher resolution than the picture above, much more can be discovered to find out what is happening on a local scale (VIMS Team. Enceladus in Infrared. 2020).

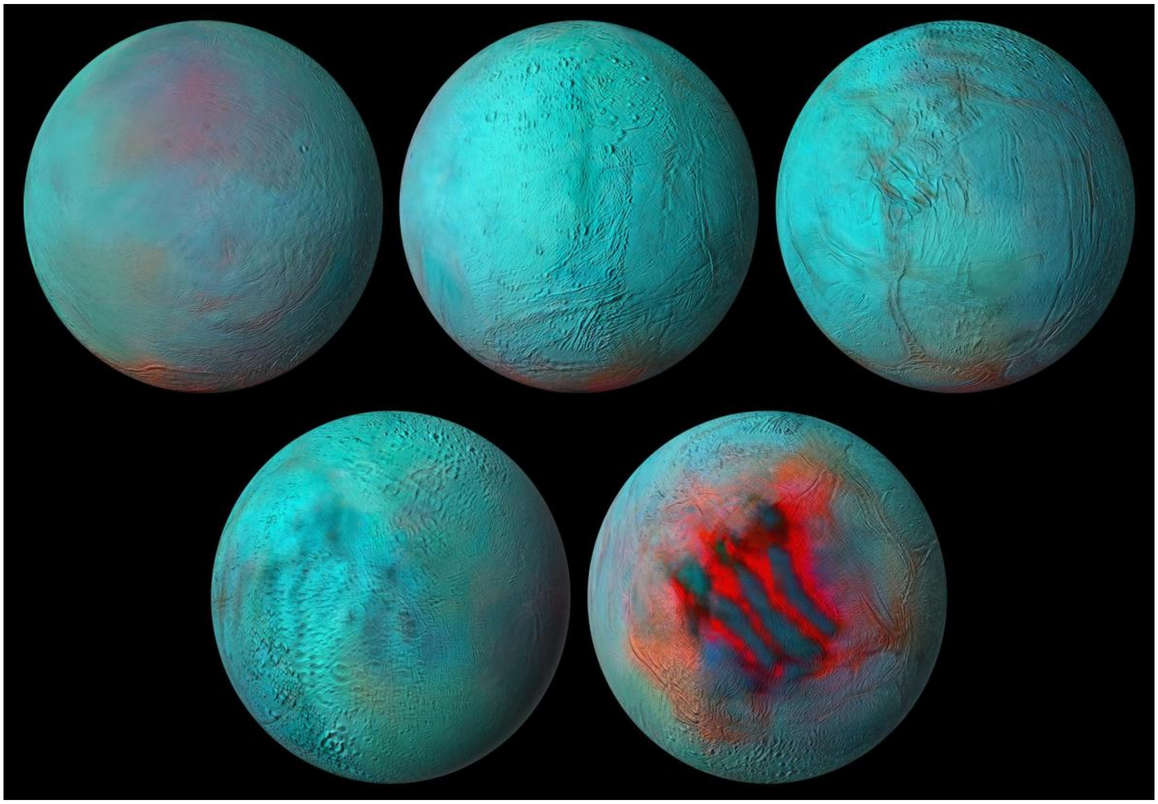


Figure 25. The above image shows the quality of the image that will be taken by the rover's camera.

5. Safety (Science/ engineering)

Mission safety includes the personnel safety and safety of the surface lander. To increase the chances of a safe mission, risks were considered and mitigation ideas for each risk were compiled. This section discusses personnel and environmental hazards.

5.1. Personnel Safety

5.1.1. Safety Officer: Andrew Headley

Andrew Headley served as the team's safety facilitator. Maintaining appropriate safety measures and policies is crucial to ensure that the mission is completed safely and successfully. The Office of Safety and Mission Assurance (OSMA) and NASA Online Directives Information System (NODIS) were investigated to ascertain the parameters required to conduct a safe lander mission to Enceladus.

5.1.2. List of Personnel Hazards

Manufacturing elements include hazardous materials such as solders and any batteries used, which primarily pose a safety violation at their disposal. Potential risks within manufacturing techniques predominantly involve the assembly and transportation of the lander and its parts. With a maximum potential weight of 77kg (170lb), the rover structure or rover components may require heavy lifting equipment. The assembly process may require dynamic manipulation of the lander or its parts, creating a hazardous working environment. Additionally, assembly risks such as welding, or other manufacturing techniques, will have to follow a mandatory safety procedure. The project phase involving the testing of components also has an array of potential risks. Hazardous materials, such as the batteries, present the danger of failure during testing or at any stage of the mission. Risks that can lead to individual health or environmental hazards are especially important. Experimental devices, particularly ones utilizing lights, lenses, or high-powered lasers, present a health hazard as well. Testing techniques create a risk for equipment failure during the testing of parts, electronic systems, or experimental devices. The operational failure of any components during testing could result in physical, injurious risks for the individual. These can be caused by a variety of incidents, including explosions, flying debris, etc. There is always the risk of unforeseen incidents that may arise during any stage of the manufacturing or testing processes.

5.1.3. Hazard Mitigation

Personnel hazard mitigation can be enforced by strictly following Occupational Safety and Health Administration (OSHA) of the United. States Department of Labor requirements, which include personal protective equipment (PPE), appropriate signage declaring risks, safety data sheets (SDS) for anything requiring special attention (tools, materials, chemicals, etc.), and safety training and certification. PPE can be detailed by wearing safety glasses at all times and when necessary, using chemical-resistant or cut-resistant gloves, using respirators/particulate filters, and wearing hard hats. Documentation, periodic team member reviews, and establishing a documented reporting system will ensure that there are minimum risks and there is incident traceability. There will be documented safety procedures for all processes. Routine and random periodic team members' safety reviews will help guarantee that safety standards are being met and upheld. Traceability and accountability will be maintained between all departments and individuals. It must also be considered which specific risks require voluntary consent from personnel. Isolated testing locations can be arranged to test any potentially dangerous components so that if incidents arise with the isolated component, the primary assembly and manufacturing location are not compromised. Quality assurance will ensure that all the parts are within specified quality standards, preventing potential failures as a result of quality. Environmental protection of the surroundings should follow the appropriate Environmental Protection Agency's (EPA) guidelines, especially when it comes to proper disposal of hazardous waste. Establishing a reporting system for waste disposal and other EPA guidelines will guarantee an environment where employees feel comfortable raising their concerns and know how to report safety concerns at any stage of the mission. COVID-19 poses a potentially serious risk, especially to personnel and to the timeline of the mission. All personnel should take the precaution of wearing a face mask at all times, social distancing, sanitizing, getting a COVID-19 test if any symptoms arise, and quarantining if the employee tests positive for the virus or if the employee has been in contact with an individual who has tested positive.

5.2 – Lander/Payload Safety

5.2.1 – Environmental Hazards

Failure due to operating temperature is of concern. The surface of Enceladus is extremely cold throughout the year with an average temperature of -330 degrees Fahrenheit. The terrain is icy and known to stretch and crack from geyser activity. There is a chance that the lander may fall, become crushed by moving ice, or get stuck during operation. Mobility precautions will be considered to ensure the continuation of the mission. With the geysers' constant activity, there is potential for failure due to the inability to operate. The rover may become covered in ice/water vapor. The heat produced by the battery within the lander could melt the ice and prevent such conditions. The landing site will be viable for the mission's scientific experiments, and the surface will be clear of any complications that might affect the lander's performance The lander's lifespan will require enough power to complete all scientific goals. The design of the lander must provide a method to "break the chain of contact" with Enceladus, to avoid potential contamination of a body that holds the potential for life. The mission must account for future missions to Enceladus and current missions on the path to Enceladus to avoid potential collisions. In the event of lander failure (i.e., explosion, disintegration, etc.), as much information as possible must be collected on any resulting debris. NPR 8020.12 Section 5.1.5, “In the context of missions to icy satellites, ‘contamination’ is defined as the introduction of a single viable terrestrial microorganism into a liquid-water environment.” The potential of bringing any Earth-originating microorganisms on the lander is of utmost concern, and the probability of inadvertent contamination must be less than $1*10^{-4}$. After the lander completes its functions, what happens to the lander, and the results of any experiments performed is of concern. Precautions will be taken to ensure minimum contamination between the rover and Enceladus.

5.2.2 – Environmental Hazard Mitigation

Test lander/payload equipment

During the assembly and testing mission phases, cleanroom technology will be utilized in combination with decontamination techniques to avoid potential microbial contamination. The probability of contaminating Enceladus will be determined while accounting for any possible scenario of microbial life surviving on the lander. The team will remain aware of how the lander is to be assembled to ensure that all components are properly decontaminated. Facilities will be monitored that handle any part of the lander so that potential contaminants can be accounted for. The team will ensure that parts and the assembly are up to quality assurance standards and attempt to replicate environmental conditions on Enceladus. Environmental simulations will be performed on scientific equipment, rover materials, and the fully assembled rover to ensure that mission goals will be achieved in the extreme environment. Atmospheric salt content, falling debris, and extreme cold will all be considered for environmental testing. During the data collection phase, maintaining documents for a periodic review of the lander as it is in contact with Enceladus will be completed. During the life of the mission, the team will make sure the lander is not causing harm to or contaminating Enceladus’ potential surface or subsurface organisms.

Precautions

The rover’s operating temperature ensures that all components can work at the established mission standards in Enceladus’ extreme environment. The thermal control system controls the flow of heat to ensure mission success through proper functionality of scientific instrumentation and rover motion equipment. Structural integrity ensures the lander can safely land on Enceladus and have protection from falling debris to successfully fulfill mission objectives. Entry descent landing process complications will be taken into consideration. The landing procedures will be calculated maneuvers that will ensure the safety of the lander.

6. Activity Plan

6.1 Budget

NASA L'SPACE Mission Concept Academy Budget - H_2GO

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Cumulative Total
PERSONNEL				
Science Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 960,000.00
Engineering Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 960,000.00
Administrative Team	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 480,000.00
Total Salaries	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 2,400,000.00
Total ERE	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 669,840.00
TOTAL PERSONNEL	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 3,069,840.00
TRAVEL				
Total Flights Cost	$ -	$ 2,890.00	$ -	$ 2,890.00
Total Hotel Cost	$ -	$ 18,600.00	$ -	$ 18,600.00
Total Transportation Cost	$ -	$ 3,884.00	$ -	$ 3,884.00
Total Per Diem Cost	$ -	$ 22,290.00	$ -	$ 22,290.00
Total Travel Costs	$ -	$ 47,664.00	$ -	$ 47,664.00
OTHER DIRECT COSTS				
Total Outsourced Manufacturing Cost	$ -	$ -	$ -	$ -
|> Science Instrumentation	$17,809,145	$ -	$ -	$ 17,809,145.00
|> Other COTS Components	$ -	$ -	$ -	$ -
Total In-House Manufacturing Cost	$ -	$ -	$ -	$ -
|> Materials and Supplies	$190,338.57	$ -	$ -	$ 190,338.57
Total Equipment Cost	$ -	$ -	$ -	$ -
|> Manufacturing Facility Cost	$ -	$ -	$ -	$ -
|> Test Facility Cost	$ -	$ -	$ -	$ -
In-House Manufacturing Margin	$ -	$ -	$ -	$ -
Total Direct Costs	$ 19,022,763.57	$ 1,070,944.00	$ 1,023,280.00	$ 21,116,987.57
Total MTDC	$ 19,022,763.57	$ 1,070,944.00	$ 1,023,280.00	$ 21,116,987.57
FINAL COST CALCULATIONS				
Total F&A	$ 1,902,276.36	$ 107,094.40	$ 102,328.00	$ 2,111,698.76
Total Projected Cost	$ 20,925,039.93	$ 1,178,038.40	$ 1,125,608.00	$ 23,228,686.33
Total Cost Margin	$ 6,277,511.98	$ 353,411.52	$ 337,682.40	$ 6,968,605.90
Total Project Cost	$ 27,202,551.91	$ 1,531,449.92	$ 1,463,290.40	$ 30,197,292.23

Figure 26. The above image shows the budget allotted to each system of the rover and to personnel arrangements for the mission.

6.1.1 Admin Budget

The administrative budget shall cover all employee wages and the business trip costs to Cape Canaveral for the launch of the lander. The mission will take 3 years for completion, and all team members will be dedicated full-time employees throughout the course of the mission.

Travel	& Salaries	ERE	Flights	Hotel	Per Diem	Car Rental & fuel	Total
Andrew Headley	$240,000	$67,200	$230	$1,860	$2,229		$311,519
Calli Veautor	$240,000	$67,200	$385	$1,860	$2,229	$971	$312,645
Jake Horstmann	$240,000	$67,200	$385	$1,860	$2,229		$311,674
Jessica Clarke	$240,000	$67,200	$230	$1,860	$2,229	$971	$312,490
Karson Tice	$240,000	$67,200	$344	$1,860	$2,229		$311,633
Kathleen Sullivan	$240,000	$67,200	$230	$1,860	$2,229		$311,519
Madilyn Fesenmaier	$240,000	$67,200	$132	$1,860	$2,229	$971	$312,392
Madison Clark	$240,000	$67,200	$344	$1,860	$2,229		$311,633
Mysaruh Massoud	$240,000	$67,200	$266	$1,860	$2,229	$971	$312,526
Nick Wright	$240,000	$67,200	$344	$1,860	$2,229		$311,633
Total	$2,400,000	$672,000	$2,890	$18,600	$22,290	$3,884	$3,119,664
				TownePlace suites Marriot	$135/day	4 Full Size Cars	
				4815 Helen Hauser Blvd	15 days	4 over the age of 25	
				Titusville, FL, 32780	2 travel days at 75% $102	Fuel estimated at $20/day	
				15 days, Kg Sz 1 bdrm		for 17 days	
				$124/night			

Figure 27. The image above shows wages paid to each employee over the course of the mission.

6.1.2 Science Budget:

1	Instrument	Price	Reference	
2	APXS	$17,800,000	https://www.cbc.ca/news/technology/mars-bound-rock-analyzer-a-new-step-for-canada-in-space-1.1007601#:~:text=The%20cost%20of%20building%20APXS,of%20operation%2C%20was%20%2417.8%20million.	
3	MastCam-Z	$9,145	1,208 * 4 N (TotalMass)^0.43 * 17.4 Watts (TotalMaxPwr)^0.50	https://mars.nasa.gov/mars2020/spacecraft/instruments/mastcam-z/
4	TIRS	Unable to find the thermal mass of the TIRS	569 * ThermMass^0.55	
5	MEMS Seismometer		Still being invented will need to contact NASA to be updated when the instrument will be ready for use. The instrument will be very essential to the success of the mission.	
6	Total	$17,809,145		

Figure 28. The above image shows the science budget.

6.1.3 Engineering Budget:

	Component	Price	Reference	
1	Component	Price	Reference	
2	Rover Structural Side Panels	$1,351.59	http://www.graphitestore.com/carbon-fiber-laminate-uni-zero-0-03t?custcol width=4&custcol length=10	
3	Corner Brackets	$140	https://www.grainger.com/product/80-20-Inside-Corner-Bracket-2RCW5	$5.80 x 24
4	Telescoping Tubes & Joints for Telescoping Tubes. 2 skis for front steering.	$6,320	https://www.alibaba.com/product-detail/5005-5052-5083-5182-aluminum-sheet 62248145131.html?spm=a2700.7724857.normalList.14.310d3b1f4pNXsn&s=p&fullFirstScreen=true	3 tons of aluminum 5083 of raw material that will be machined and fabricated by the team. Skis will be fabricated from the 3 tons bought. price included with bulk order of aluminum.
5	Fasteners/hinges/ panels	$42.98	https://www.amazon.com/Chicago-Buttons-Crafting-Fastener-Diameter/dp/B00O8RZ66E/ref=sr 1 9?dchild=1&keywords=gold%2Brivet&qid=1604893470&sr=8-9&th=1	
6	Cryogenic insulation	$290	https://www.amazon.com/Solid-Platinum-Reflective-Insulation-Barrier/dp/B00ZOF7JS2/ref=asc df B00ZOF7JS2/?tag=hyprod-20&linkCode=df0&hvadid=312066930227&hvpos=&hvnetw=g&hvrand=11794852992641417912&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9028705&hvtargid=pla-762094681152&psc=1	500 sq ft
7	Kubota track	$5,295	https://www.atvtracks.net/track-systems/kubota-850-rtv-xg-sidekick-2018-2019-4s1?gclid=CjwKCAiAtK79BRAIEiwA4OskBiM K2Gz0Mo57FMtSJUjTcglQv zhhApL bfVIuDX-ifkVAB1il82xoCaEsQAvD BwE	
8	Motor	$1,600	https://www.maxongroup.com/maxon/view/catalog? ga=2.116104448.781730802.1605144173-1921627844.1605144173& gac=1.229351918.1605144173.CjwKCAiAtK79BRAIEiwA4OskBlsxll4azqJWAvx-Cx3HhhX8knVxydV3G-JPHbV8nlrfY-rf7Z7vQRoCYM8QAvD BwE	
9	Battery	$175,000	https://www.sciencedirect.com/science/article/abs/pii/0378775386800891#:	$175 per KW accounting for a maximum of 1000 KW
10	Parachute	$299	https://www.fibreglast.com/product/kevlar-carbon-hybrid-yellow-1065	5 yard roll
11	Total	$190.338.57		

Figure 29. The image above shows the engineering budget.

6.2. Schedule

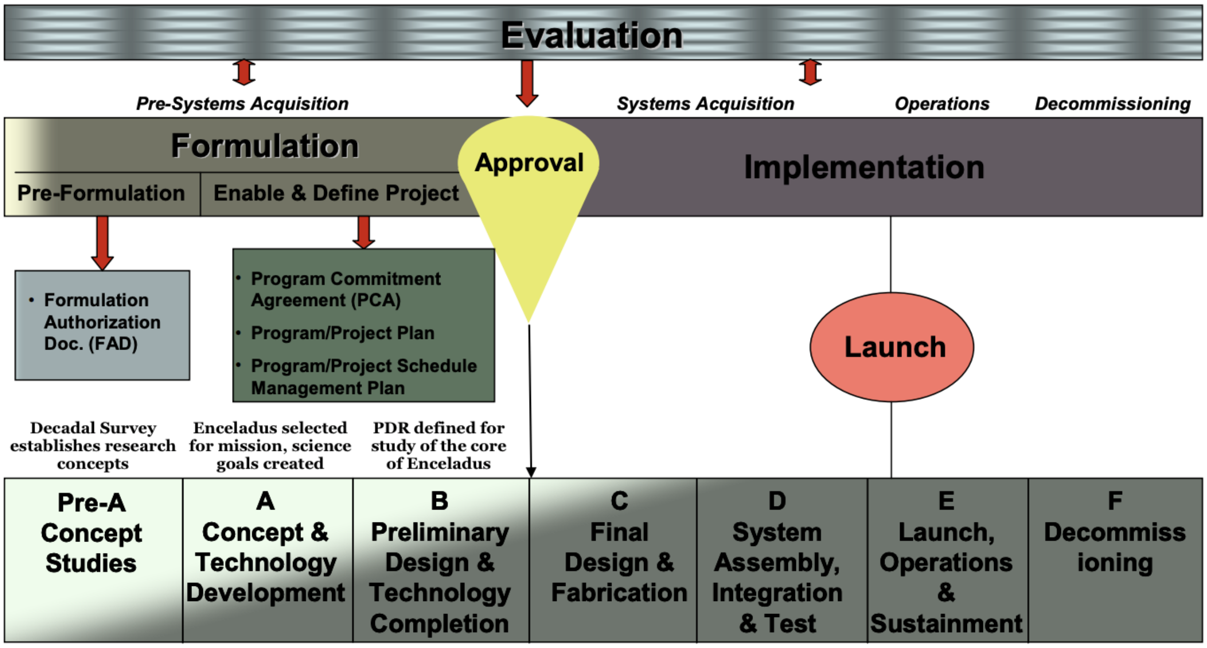


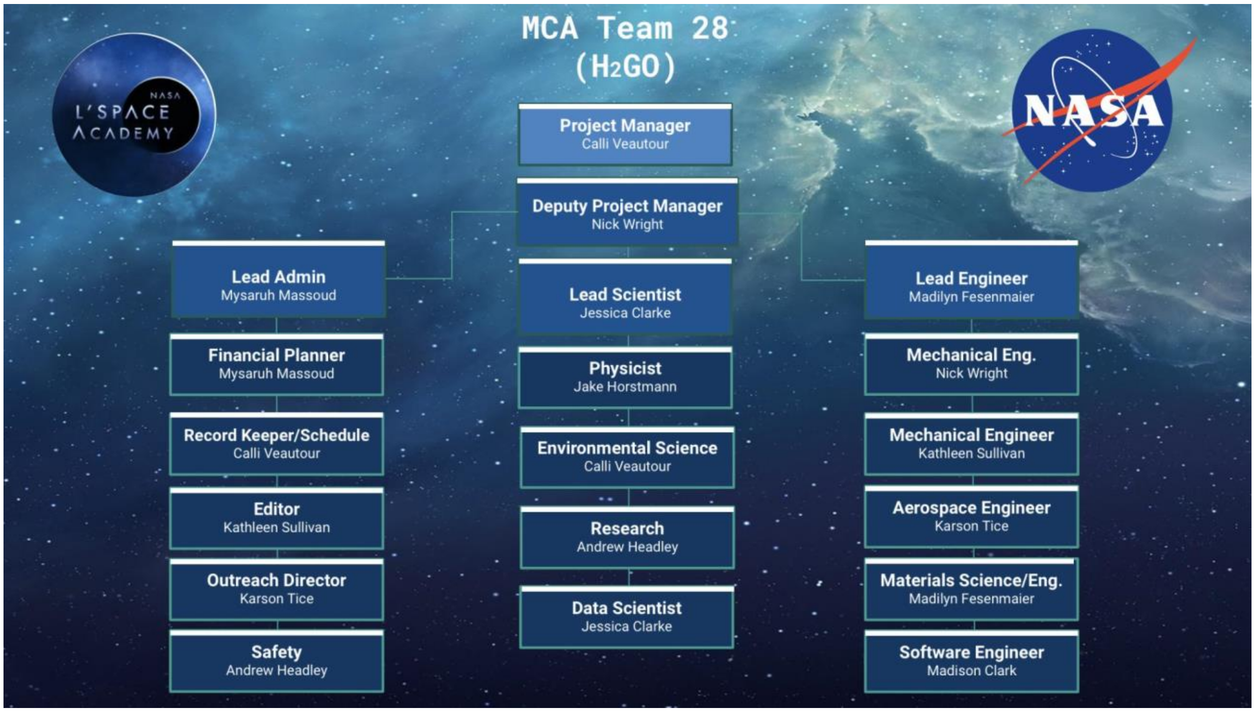
Figure 30. The above image shows the mission process, from the beginning to launch.

6.3. Outreach Summary

The administrative team will reach out to students within their colleges and universities and explain the importance of why mission H_2GO is beneficial for science and society. They will also hold presentations that are open to the public within their schools to inform as many people as possible. The team will also go to K12 schools within their vicinity to introduce the mission to the younger generation, and to inform them about the discovery of water and the possibility of discovering living organisms on Enceladus.

6.4. Program Management Approach

During the second meeting, the team read over each position's description, and each member listed any relevant experience if interested in the job. Once leadership positions were established, each member picked a team to be on: science, engineering, or admin/business. Each team led weekly meetings for their team to make progress on their assigned PDR sections, with a weekly all-team meeting led by the Project Manager (PM) and Deputy Project Manager (DPM). When issues arose during the course of the project, they were either brought to the team leads or the PM/DPM, if the issue needed to be brought higher.



7. Conclusion

Mission Statement

The main goal of Team H_2GO is to examine the Saturnian moon of Enceladus to determine the elemental composition of its core, whether or not it is porous, and to conclude if the core contributes to the activity of the plumes. To complete this mission, data will be gathered using multiple scientific methods. Spectroscopic data of sediments carried up from the core by the geysers will be analyzed to give clues on the composition of the core. Infrared radiation levels and seismic data will be recorded to provide insight into the internal and external structure of Enceladus. Combining these data sources sheds light on the differences between theoretical model data and empirical data.

A secondary goal of the mission is to avoid potential hazards to the unsullied environment of Enceladus. Imaging data of the moon's surface topography will be collected, images of its subsurface ocean will be potentially gathered, and seismograph readings of the core will be taken. This mission aligns with current decadal goals to understand icy worlds and the potential for how life might develop on other celestial bodies.

Lander Overview

The lander will have two main sections: the body and the drivetrain. The body will hold scientific instruments, the alkaline fuel cell (AFC), landing gear (propulsion and parachutes), and the communication system. The drivetrain includes the motor, snow spikes, and sled legs to navigate the snow. Data gathered by the lander will be used to achieve the goals of the mission.

Payload Overview

Within the Payload, there is the AFC, landing gear, communication system, and scientific instruments. The scientific instruments include the Alpha Particle X-Ray Scanner (APXS), Universal Micro-Electrical-Mechanical Seismometer (MEMs), Thermal Infared Sensor (TIRS), MastCam-Z, and the PanCam. The APXS' purpose is to collect materials from the surface of Enceladus and perform spectrographic analysis to determine the chemical composition of the debris, giving clues as to the composition of the core of the planet. The MEMs will take seismic data from the surface, and analyze the possible tectonics, as well as the makeup of the core (similar to how Earth-bound seismologists gleaned the makeup of the inside of Earth using seismic data). The TIRS will measure thermal data on the surface of Enceladus and act as a backup camera of sorts if the camera becomes damaged, allowing the lander to discern its surroundings without a picture made of visible light. The MastCam-Z, currently used on the Mars Perseverance Rover, is the camera system mounted to and used by the lander. It analyzes visible wavelengths of light to generate images for the rover to plot a course around. It will also provide the first surface images of Enceladus, giving insight into surface conditions previously unknown. The PanCam will function in a similar way, giving panoramic images of the surface, so that scientists can analyze surface conditions.

Future Milestones

Given more time and resources, the team would further explore the idea of a “bug” --a small robot equipped with sensors and instruments that would travel into a geyser to study the makeup of it. The main problem encountered was that the majority of geysers on Earth have bubble traps, which are spaces that extend horizontally from the main geyser column. Given that Enceladus' geysers would most likely have a similar structure and that the bug would be climbing the geyser walls, it could get lost in the bubble trap and risk the mission. The idea of a cable/wire attaching it to the rover was played with but dismissed due to the space and sheer amount of cable needed for the bug to make it any measurable distance into a geyser.

CDR Plans

For the Critical Design Review (CDR), we will continue to refine the details of the lander, instrumentation, and administrative tasks, to culminate with final, production-ready detailed designs. The budgeting and cost analysis will be finalized, and specifics accounted for. There will be continued risk assessment on technical and cost fronts, as well as productivity analyses and product specifications. Lastly, the overall concept will constantly be checked against the mission goals to make sure the mission stays on track.

Works Cited

APXS for Scientists. (2020, July 15). Retrieved November 27, 2020, from https://mars.nasa.gov/msl/spacecraft/instruments/apxs/for-scientists/

APXS Instrument Information – MSL – Mars Science Laboratory. (n.d.). Retrieved November 27, 2020, from https://spaceflight101.com/msl/apxs-instrument-information/

Bell, J., Adler, J., Anderson, R., Arneson, H., Bollen, D.M., Chojnacki, M.,…Wolff, M. (n.d.). *About the PanCam*. PanCam Instrument Site. Retrieved from http://pancam.sese.asu.edu/about.html

Bradley, D. (2009, October 31). The Salty Ocean Of Enceladus. Retrieved November 21, 2020, from https://edu.rsc.org/news/the-salty-ocean-of-enceladus/2020921.article

Cumani, C. (July 26, 2004). *Introduction to CCDs*. European Southern Observatory. Retrieved from http://www.eso.org/~ccumani/doc/2004-CCDs-Introduction.ppt

D'Alessandro, A., Scudero, S., & Vitale, G. (2019). A Review of the Capacitive MEMS for Seismology. *Sensors*, *19*(14), 3093.

Davidson, J. (2011, November 26). Mars-bound rock analyzer a 'new step' for Canada in space | CBC News. Retrieved November 27, 2020, from https://www.cbc.ca/news/technology/mars-bound-rock-analyzer-a-new-step-for-canada-in-space-1.1007601

Dong-Ya, G., & All., E. (n.d.). We apologize for the inconvenience... Retrieved November 27, 2020, from https://iopscience.iop.org/article/10.1088/1674-1137/39/7/076002/meta

Dutta Saxena, G., Agarwal, E., Selveraj, P., Thamarai, V., John, J., Arvind, K., Islam, R. (2013) *Design, Development and Testing of MEMS based Seismometer for Space Application.* Laboratory for Electro-Optics Systems. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6637438

Machine Vision Store. (2020). CABR202. Retrieved from https://machinevisionstore.com/catalog/details/31

Merchant, J. B. (2009). *MEMs Applications in Seismology.* Seismic Instrumentation Technology Symposium, Sandia National Laboratories. https://www.iris.edu/hq/instrumentation_meeting/files/pdfs/MEMS_Seismology.pdf

Murphy, P. (2018). *Universal MEMs Seismometer-Project Introduction.* TechPort, NASA. https://techport.nasa.gov/view/94417

Mustafazade, A., Pandit, M., Zhao, C. *et al.* A vibrating beam MEMS accelerometer for gravity and seismic measurements. *Sci Rep* 10, 10415 (2020). https://doi.org/10.1038/s41598-020-67046-x

National Aeronautics and Space Administration. (n.d.). *Calibration Targets*. Mars Exploration Rovers. Retrieved from https://mars.nasa.gov/mer/mission/instruments/calibration-targets/

National Aeronautics and Space Administration. (n.d.). *The Panoramic Camera (PanCam)*. Mars Exploration Rovers. Retrieved from https://mars.nasa.gov/mer/mission/instruments/pancam/

NG Propulsion Products Catalog. (n.d.). Retrieved November 21, 2020, from https://www.northropgrumman.com/wp-content/uploads/NG-Propulsion-Products-Catalog.pdf

Orion's Parachute System (pp. 2-3). (n.d.). National Aeronautics and Space Administration.

RF Communications. (n.d.). PDT-300 X-Band Transmitter [Pamphlet]. Singapore: ST Electronics.

Sat Search PDT-300. (2018, April 14). PRODUCT. Retrieved November 27, 2020, from https://satsearch.co/products/agil-space-pdt-300-x-band-transmitter

Sebastian, E. (2020). The MEDA Thermal IR Radiometer (TIRS) For The Mars 2020 Mission [PDF]. Madrid: Spanish Centro de Astrobiologia. Retrieved November 20, 2020, from https://www.hou.usra.edu/meetings/lpsc2020/pdf/1269.pdf

Shanmugam, M., Murty, S., Acharya, Y., Goyal, S., Patel, A. R., Shah, B., . . . Subrahmanyam, D. (2014). Alpha Particle X-Ray Spectrometer (APXS) on-board Chandrayaan-2 rover. *Advances in Space Research, 54*(10), 1974-1984. doi:10.1016/j.asr.2013.03.011 https://arxiv.org/ftp/arxiv/papers/1910/1910.09232.pdf#:~:text=For%20this%20purpose%2C%20APXS%20uses,%2Dray%20fluorescence%20(XRF)

Sponsored by Aalco - Ferrous and Non-Ferrous Metals StockistApr 19 2005. (2020, October 16). Aluminium Alloys - Aluminium 5083 Properties, Fabrication and Applications. Retrieved November 21, 2020, from https://www.azom.com/article.aspx?ArticleID=2804

Solan, R. F., Bokulic, R. S., & Sinsky, J. H. (1993). An X-Band Telecommunications Transmitter For the Mid-course Space Experiment.. Retrieved 2020, from https://www.jhuapl.edu/Content/techdigest/pdf/V14-N04/14-04-Sloan.pdf

Technologies, A. (n.d.). Agilent Technologies Wireless Test Solutions Application Note 1313. Agilent Technologies, Application Note(1313). Retrieved January 8, 2002, from https://literature.cdn.keysight.com/litweb/pdf/5968-3578E.pdf

US Department of Commerce, N. (2008, November 14). Why is the ocean salty? Retrieved November 21, 2020, from https://oceanservice.noaa.gov/facts/whysalty.html

VIMS Team. (2020, September 24). Enceladus in Infrared. Retrieved November 20, 2020, from https://science.nasa.gov/enceladus-infrared

Yee, K., Badalian, M., Blaes, B., Kedar, S., Toda, R. (2019). MEMs Seismometer-Probing the Interiors of Planets. *NASA Jet Propulsion Laboratory-Microdevices Laboratory*. https://microdevices.jpl.nasa.gov/capabilities/nano-and-micro-systems/mems-seismometer/

Zwicker, M. L., & R. J. (n.d.). Pack Density Limitations of Hybrid Parachutes. Retrieved November 21, 2020.