NASA L'SPACE Mission Concept Academy

Preliminary Design Review

Enceladus Volatile Explorer (EVE)

Team 12 - Lucynauts

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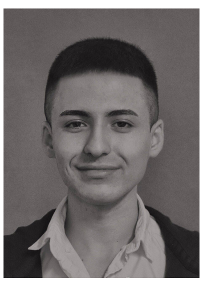
1. Introduction and Summary

1.1 Team Introduction

Project Manager and Research: Caemon Alcantara, New York

Caemon is a Junior in New York Institute of Technology and working on a five-year program to get his Bachelor's and Master's Degree in Mechanical Engineering. He has previous experience with C++, MATLAB, and published his research work on defining a metric for supersonic flights in urban simulations. He is currently learning CAD softwares such as Solidworks and getting a certification in NX.

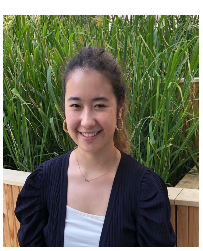


Deputy Project Manager, CAD, and Documentation: Axel Ortega, New York

Axel Ortega is a sophomore studying Mechanical Engineering with a double minor in Architecture and Hispanic Studies at Columbia University in the City of New York. At Columbia, he's the president of the Mexican Students Association, engineering team member of the Columbia Space Initiative, part of the Mechanics Club and executive board member of the Artist Society. He has previous experience in Java, Python, CAD and Creative Suite.

Science Lead and Astronomer: Molly Marie Crock, Ohio

Molly is a student with American Public University studying Astronomy and Mathematics. She has adored numbers since she was a small child and adores the study of being curious in the night sky. Molly also shares her love of space at the local planetarium. She hopes to keep her studies going to fly off to the moon one day.



Business Admin Lead and Budget: Danelya Zholdasbekova, New York

Danelya Zholdasbekova is currently a sophomore studying Finance and Computer Science at Adelphi University New York. At Adelphi she serves as a president for APICS AU supply chain management organization, as well as the fundraising committee chair at Delta Sigma Pi professional fraternity. Danelya finds herself very into astronomy and computer programming.

Engineering Lead and Power Source: Kelsey Cordova, New York

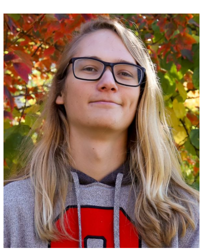
Kelsey Cordova is a senior studying Electrical and Computer Engineering at New York Institute of Technology. She has experience in multiple languages such as MATLAB and Java, as well as SPICE software such as Pspice and Multisim. Her goal is to have the ability to celebrate her passion in STEM and space as a PCB designer in the aerospace industry.

Outreach: Catherine Nguyen, New York

Catherine Nguyen is a junior at Rutgers University-New Brunswick majoring in computer science and English literature. She first became interested in programming sophomore year, when she took her first ever computer science course and found she really enjoyed it! Next summer, she will be combining her love for books and programming by working as a software development intern for Audible, Inc.

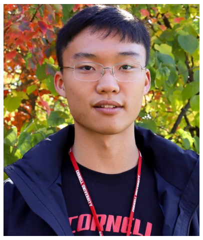
JMARS and Materials: Alina Santander, New York

Alina Santander is a mechatronic engineering student at Vaughn College of Aeronautics and Technology. She is the president of the SWE Club and the Rover Club at her college. She participates in the competition NASA Rover Challenge every year and won relevant prizes in this contest. Her goal is to work in the aerospace field, applying ecology to new technologies.



CAD and Manufacturing: Keaton Haug, New York

Keaton is a sophomore mechanical engineering student at Cornell University. He is a member of the Baja SAE team there, where he learns to design, analyze, and manufacture the suspension systems of an offroad vehicle.



CAD and Manufacturing: Eugene Jeong, New York

Eugene is a sophomore mechanical engineering student at Cornell University. He is also a member of the Baja SAE team there, where he learns to design, analyze, and manufacture the drivetrain systems of an offroad vehicle.

EDL and Propulsion: John Stotz, New York

John is a mechanical engineering student at Rensselaer Polytechnic Institute. He has experience with coding in multiple languages and is currently taking a propulsion system class. He also has previously interned at NASA Jet Propulsion where he helped create CAD models.

1.2 Mission Overview

1.2.1 Mission Statement

Enceladus Volatile Explorer (EVE) will land on the surface of the South Pole of Enceladus near an active Tiger Stripes to gather and record data about the volatiles that exist in Enceladus' atmosphere. NIRVSS Near Infrared Volatile Spectrometer will be inside EVE and will continuously collect information on C02, H20 and H volatiles and surface morphology to further understand the possibility of life on Enceladus. After, it will send back data to Earth utilizing the Deep Space Network technology and onboard communication.

1.2.2 Mission Requirement

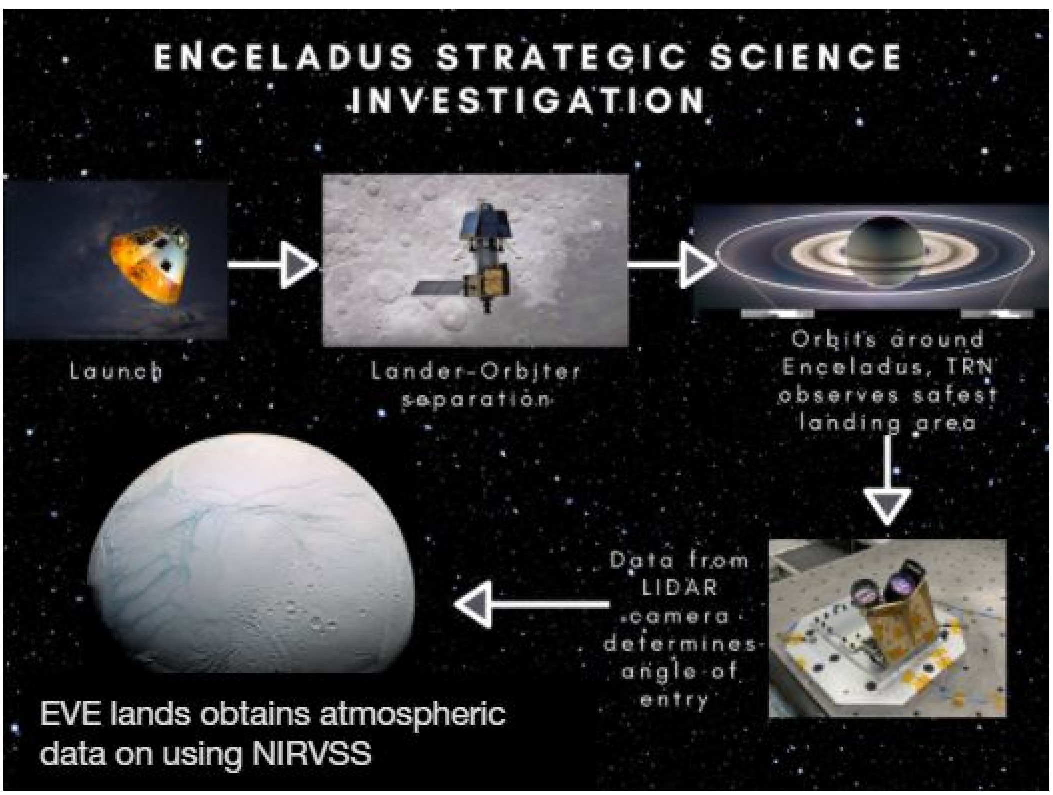
- Mass shall be no more than 77kg (170lbs).
- Volume shall be no more than 51cm x 51cm x 76 cm (20in x 20in x 30in).
- Budget must not pass $400 million.
- EVE shall have legs that can support twice the maximum mass of 77kg and have sensors that can assist in determining a safe landing safely.
- EVE shall be able to hold all the equipment needed to accomplish the mission statement.
- EVE shall be able to operate in its proper working conditions at 273K.

- The science instruments shall be able to record atmospheric data from Enceladus and send it back to Earth

1.2.3 Mission Success Criteria

The first and most important minimum criteria of success will be that EVE's batteries and heater last throughout the journey of traveling to Enceladus. The batteries and heater should remain in working conditions of 273K to utilize the landing equipment as described in our EDL. The second criteria will be that EVE will land with no detrimental damage to the instrumentations inside it's structure. The third criteria will be that NIRVSS will be able to collect data about the volatiles in Enceladus. To be a tremendous success, NIRVSS should collect data with a sensitivity ranging from 1.2 to 4.0 micrometer, a Signal-Noise ratio of less than 100 at 2 and 3 micrometer and confirming water ice to less than 0.25% error. The last criteria will be that more than half of the data is sent successfully from EVE to Earth using the Deep Space Network technology.

1.2.4 Concept of Operations (COO)



1.2.5 Major Milestones and Schedule

The following schedule shows the team's major milestones and missions to Enceladus:

Starting with **Phase A**, the team will conduct the conceptual studies and the preliminary analysis to set a purpose for the mission.

During **Phase B** outlining, schedules, details, and budget will be considered while creating the PDR.

Phase C will start and complete the design with all the required steps.

Phase D will focus on the construction and building of the designs.

Phase E is when the lander EVE has landed and started its mission on Enceladus. A 1-month testing period will be conducted to ensure that the lander is capable of productive operation towards a successful mission.

1.3 Descent Maneuver and Lander Summary

The main challenge of landing EVE on Enceladus is the lack of high resolution photography to find a suitable landing location. The team decides to take a novel approach and to use LIDAR to both generate terrain relative navigation data in-orbit but to instantly use that data as a navigation tool. Since this is a novel approach, the team added an additional requirement to the EDL sequence that EVE must be able to communicate with the orbiter while landing so that if there is an off-nominal landing the team can learn from the data for future missions.

The team developed an EDL sequence as shown in *Figure 1.3.1* to quickly get to the surface so that there would be more battery charge left to accomplish the science mission. The first step is that the EVE detaches from the orbiter and once the orbiter is clear from EVE the orbiter burns to circularize at a height of 234.6 km. Then EVE turns on its TRN system as it descends towards the perigee of its orbit. As it approaches, it burns to cancel out all of its horizontal velocity and enter a circular orbit around the landing site. Then EVE descends towards the surface collecting TRN data and navigating towards a safe site. EVE will freefall from 35 to 10 km and then from 10 km it will burn to reduce the landing zone to a safe area.

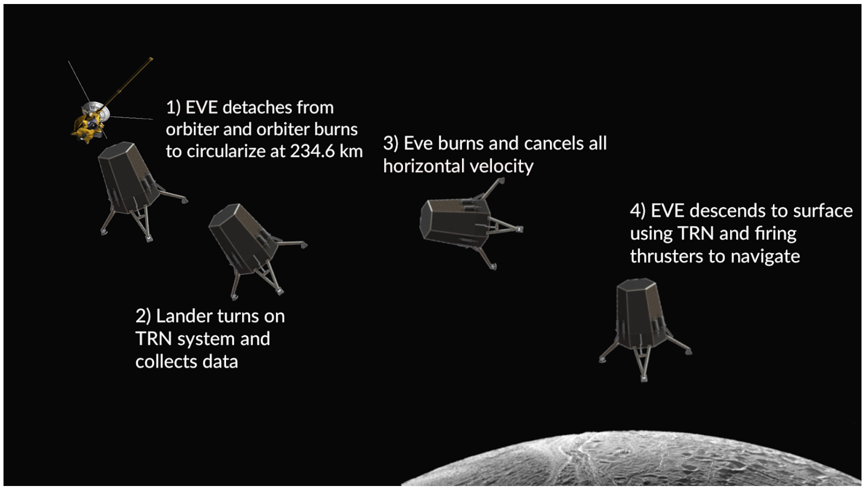


Figure 1.3.1 Primary EDL sequence

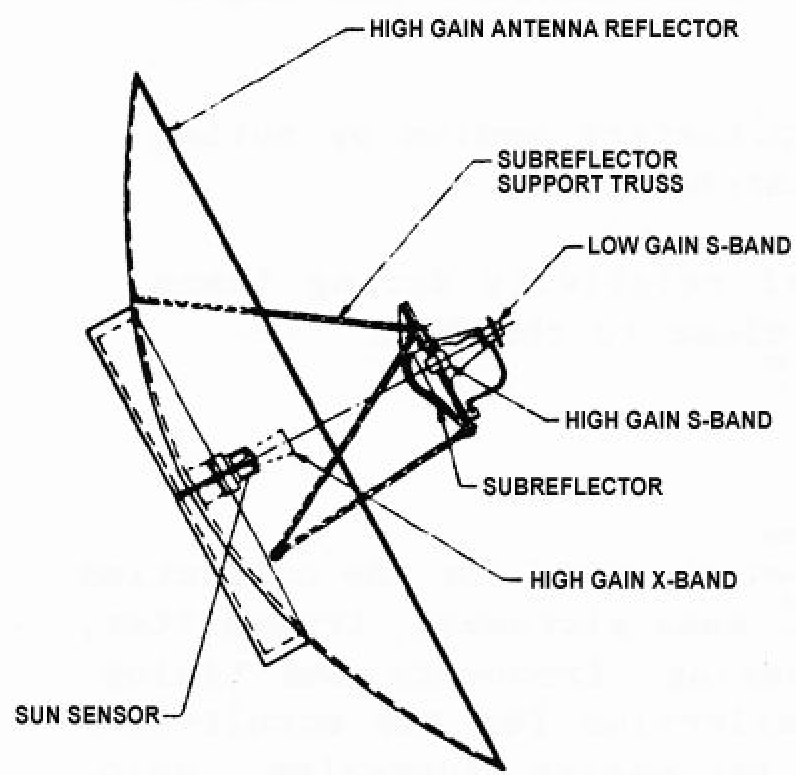
To power the descent, EVE will use 6 MR-103J engines from Rocketdyne. They will be set up so there are 2 engines per side to allow for control since the engines don't gimbal. For the TRN system, EVE will use the 3D Imaging Cubesat Lidar for Asteroid and Planetary Sciences lidar suite and a high-performance spaceflight computer chip to power all of the code necessary for the TRN system.

Additionally, the team developed a secondary EDL sequence in case the primary EDL sequence requires too much fuel for the lander. This secondary sequence takes longer so it would reduce the time for science on the surface. More details about the secondary landing sequence can be found in Section 3.

1.4. Payload and Science Instrumentation Summary

Inside EVE, the Near Infrared Volatile Spectrometer System (NIRVSS) built by Thermo Fisher Scientific will be utilized to measure CO2, H20 and H volatiles and surface morphology of Enceladus' South Pole. Its features include: operating on external power supply for spectrometer, bracket assembly and lamp to provide light source while in a shadow. It has a mass of 3.57 kilograms with the dimensions of 18*18*18.5 cm. It costs between $5,000-$50,000 and to communicate back to Earth the findings of Enceladus, EVE will be accompanied with a X-Band High Gain Antenna to transmit information directly back to Earth utilizing the Deep Space Network. This is a hexagon shaped antenna at about one foot in diameter with dimensions of 30 cm by 15 cm by 30 cm, costing about $25,000. For a power source, it will be the 55 Ah Lithium Ion Battery, but more research is needed to determine how many batteries will come along. However it has enough space for at least four of them. EVE will also have a Minco's

Thermal-Ribbon surface sensor inside to measure the temperature and works with the High-Performance Spaceflight Computing project (HPSC) to make sure that EVE remains at a constant temperature of 273K. Using the supercomputer, it can turn on and off the Radioisotopes Heater Units (RHU) when the HPSC determines that the internal temperature needs more heating. Additionally, the 3D Imaging Cubesat Lidar for Asteroid and Planetary Sciences (ICLAPS) will be used to record pictures while EVE remains stationary and NIRVSS is analyzing the atmosphere. This LIDAR device has a range of 100km and a 10 degree scanning angle. When powered on, ICLAPS draws 14.3 watts of power. It will be used only for the EDL landing sequence to create the 3D model for the TRN system and also used to navigate EVE while going through the EDL sequence.



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To control EVE throughout the mission, EVE will have a new computer chip from the High-Performance Spaceflight Computing project. This is a NASA project to create a next-generation computer chip which will have 800MHz CPU and 256 MB of RAM and is based on the ARM architecture. The chip will be used for the TRN system to analyze the data from ICLAPS in real time to allow for accurate TRN. When on the surface the chip will switch over to controlling all of the science instruments and communication systems for the remainder of the mission time.

2. Evolution of Project

2.1 Evolution of Descent Maneuver and Lander

Members of the engineering and science teams participated in the planning of descent maneuver and the design of the lander.

The team decided to use JMARS to determine a landing spot. Based on the Enceladus research, an approximation of the landing spot was between the south pole's tiger stripes. The team decided to choose a place with interesting geological activity to collect soil samples and study the terrain for future missions.

Once the landing spot was determined, the design team started developing ideas for the lander. Different specifications were taken to design the lander. It was essential to specify the instruments to be used, since the amount of space is limited. The constraints to take into account were the dimensions, weight, materials, and lander operation.

To land, the team developed an idea similar to what other landers have used in past missions. The team initially considered an inflatable ball similar to what was used on the MER missions, but this was quickly ruled out as it would not allow the precise control of the landing zone needed for Encaldus's hostile terrain. Additionally, an inflatable protection may get punctured or damaged while rolling over the crevices in the south pole. To increase the accuracy of the landing zone the team came up with the idea of using a terrain navigation system to avoid obstacles and to be able to develop a high resolution scan of the tiger stripes. This decision necessitated the addition of the LIDAR system to EVE.

There were multiple different EDL sequences developed throughout the project. The first was a simple direct descent where as soon as EVE detached it would attempt to land. This was ruled out as it would not give enough data for the TRN system. The next idea was a multi-orbit approach where EVE would fly one orbit at its initial condition, orbit again at a lower altitude and then finally attempt landing. The reasoning for this plan was that it would allow one scan of the TRN system at a high altitude and one at a lower altitude which would allow the computer to compare the two measurements and validate the data. This plan however took too long when the decision for EVE to only have battery power was made and had to be reworked. The reworked plan eventually formulated into the secondary EDL sequence with the third orbit cut out. While planning out the secondary EDL sequence, the team also had to adjust the orbiter's orbit to ensure radio communication.

The primary EDL sequence was developed after the determination that getting to the surface quickly would be the best approach as it would allow for the longest battery life on the surface to collect and transmit data. The decision to enter a spiral landing came out of the realization that the EDL sequence would be too quick for the TRN system to get all of the data. It also allows the TRN system to see the surface from different perspectives.

2.2 Evolution of Payload and Science Instrumentation

At first there was discussion on developing different ideas of instruments to use in Enceladus based on which aspect of Enceladus was going to be explored. The concept of exploring the deep waters to search for life was brought up, but with the realization from more research and constraints, it was not possible to bring a drill big enough to make a hole in the ice shells. Furthermore, there was not enough space in the lander to bring a durable enough robot to swim under the pressure the water would press against it. After that, the option of landing in the tiger stripes was discussed, but was quickly denied because the geysers can shoot out water up to 800 mph and EVE would not survive it.

Opting for a landing in between the tiger stripes for safety measures meant that more possibilities were explored. Ground Penetrating Radar and a broadband seismometer was studied for the goal of predicting future shakes on Enceladus and see when would be a good time to land for future missions. IOSPEC miniature spectrometer was also a primary candidate to explore the composition of the atmosphere of Enceladus, but later it was researched that the company no longer developed it and no further information could be found out about it. Weighing the pros and cons of the two types of instruments, spectrometers were chosen for the sake of finding out more about the atmosphere and its composition to see how suitable the environment is for life.

Once the spectrometer was chosen, more spectrometers were explored. However in the end, it was decided that EVE will use a NIRVSS volatile near-infrared spectrometer built by Thermo Fisher Scientific to measure the volatiles CO2, H20, and H and surface morphology of Enceladus' south pole. It is a two part instrument that has a bracket assembly where it holds the instruments to analyze for volatiles and another part, spectrometer module, where it digitalizes and analyzes the results of the bracket assembly records. It will be on continuously after it has landed to measure the volatiles and surface morphology of Enceladus.

High Performance Spaceflight Computing (HPSC) was determined to be the main computer that will compute the ideal landing spots as well as receiving the data of volatile observation in Enceladus' atmosphere from the NIRVSS, sends that data to the

X-band High Gain antenna, and read the data from the Minco's Thermal-Ribbon Surface Sensor to determine whether or not the HPSC should turn on the Radioisotope Heater Unit (RHU) to keep the thermal temperature of 273K.

2.3 Evolution of Mission Experiment Plan

At first the thrill of finding alien life fascinated the team, so the first mission was to be able to drill a hole in the ice shell and explore the water underneath it. With exploring the water, came with the hopes that it could be analyzed enough to see if life could live or if life is potentially living there already. However, with more research, it was discovered that the limitation of the size of EVE will make that sort of mission impossible. This mission had to be revised and then the thought to analyze the water that the geysers were spouting out on the South Pole of Enceladus by the Tiger Stripes was pondered upon. Although, that mission was also dismissed due to the dangers of landing too close to the Tiger Stripes and the size of EVE meant that the lander would be demolished under the geyser's stream of up to 800 mph. After that it was between the two choices of either recording the seismic activity of the Tiger Stripes using a seismometer or analyzing the atmosphere of Enceladus using a spectrometer. Since there wasn't a lot of allotted time for EVE to do more research and analysis, it was determined that the spectrometer should be used because it will take less time to analyze the atmosphere rather than record seismic activity of Tiger Stripes.

3. Descent Maneuver and Lander Design

3.1 Selection, Design, and Verification

3.1.1 System Overview

There are two main requirements during the descent and landing phase of the mission. The first is to successfully land on Enceladus so that the science mission can be carried out and the second is to provide high-resolution scans of the surface of Enceladus even with a landing failure. The second is that there must be capability for uplink throughout the final landing phase. To meet those two requirements two different Entry, Descent, and Landing (EDL) plans were formatted to ensure the most likely outcome of the mission.

The preferred EDL plan starts with the detachment of EVE from the orbiter at the apogee of the orbit. Then as EVE approaches the peerage, it burns to cancel out its horizontal velocity and to enter a circularing pattern starting from a height of 35 km. At this point, it will turn on the TRN system as it slowly falls to the surface in a circular pattern. This will be around the proposed landing location. As EVE descents it will scan the landing site and burn its thrusters to make the landing circle smaller and smaller. This orbit circle will eventually shrink to a point at the moment of landing. If there are any problems the circle will either become larger or shift to a direction. The benefit of such an extreme cancellation of horizontal velocity is that it greatly reduces the time from separation to landing. However, the problem with this method is that it requires a significant amount of fuel to effectively cancel out all horizontal velocity.

Since the team could not verify that the amount of fuel for the primary EDL plan would be feasible, the team also developed a secondary, less fuel intensive EDL plan. However this plan takes about 3 hours longer than the primary plan and thus would be a large drain on the battery. The secondary plan starts the same way, but instead of burning to cancel out all velocity, EVE instead only burns enough to reduce the apogee to a height of 10 km. Additionally, at that time the TRN system is turned on to collect data as EVE flies by the landing area. Then on the new perigee, near the north pole, EVE burns again to circularize at 10 km. Then, as it approaches the landing zone again, it burns to slow down. At this point, it enters final descent and takes a more traditional descending straight landing path to touchdown. The TRN system would be used to guide past any critical obstacles.

Figure 1: Model of EVE, legs folded (left) and extended (right)

EVE consists of a steel frame onto which the six engines will be mounted. EVE has three legs which will be stored in a folded position and extended before the landing. EVE will be covered in composite panels and will house the instruments, fuel, and batteries. A plate with an array of bolt holes will be tabbed into EVE frame onto which instruments and other components will be fastened in a modular fashion.

3.1.2 Subsystem Overview

The EDL sequence is a key factor in the design of EVE and should be explained before any of the subsystems are explained. As stated in 3.1.1, the team has proposed two different EDL sequences for further study and EVE has been designed to work and meet all requirements using either EDL sequence.

The primary EDL sequence is the path that the team would most prefer to use as it lands EVE on the surface quickly which increases the amount of science that the team can accomplish. EDL starts with the detachment of EVE from the orbiter at the apogee of a height of 234.6 km and from this point on EVE is operating on its battery power. Additionally, the orbiter burns to circularize its orbit at 234.6 km to ensure communication during EDL. Once detached, EVE will go through startup procedures including deploying the landing legs and heating the engines. Once approaching perigee, the engines will fire to cancel out all horizontal velocity and to start to transition the orbit into a circle around the landing zone. At this point the TRN system is activated and begins to collect data. Then the thrusters are fired to slow down EVE and to keep it in a circle. The descent rate is limited by the coverage of the orbiter's antennas and it gives approximately 1 hour and 30 minutes for the descent and landing which means the average downward velocity has to be 6.48 m/s. However instead of keeping at the velocity, EVE will be in freefall between 35 km and 10 km in its spiraling pattern gathering data about the landing zone. As it approaches 10 km, it will fire its thrusters to slow down to 5 m/s and start to narrow the spiral. At 5 km, EVE will pick a 100 m landing zone and begin to slow down. Then it will land at a speed of 1 m/s.

This EDL sequence allows EVE to have a large time viewing the landing site and to increase the chance of the TRN system to successfully find a safe landing point. However the challenge is that to cancel out all velocity takes a lot of fuel and to keep EVE circularizing takes even more fuel. Since the margins for this sequence was tight, the team pursued another EDL sequence in case in a later phase the primary EDL sequence was ruled to be infeasible.

The second EDL sequence starts with the detachment of EVE from the orbiter, however the orbiter does not burn to circularize its orbit. Both continue down to the perigee at a height of 35 km. At perigee, the orbiter burns to circularize at 35 km, but EVE burns to reduce its apogee to a perigee of 10 km. Additionally, as EVE flys over the landing zone, the TRN system is turned on to collect as much data as possible about the site. As EVE flies away, the computer system uses the time to analyze all of the data and to narrow down a flight path. At the new perigee of 10 km, EVE burns to circularize its orbit. At this point it enters final descent and starts to burn to cancel out its velocity. However, it takes a traditional angled entry to cancel out horizontal and vertical at the same time. The angle would be determined by EVE in orbit for the chosen landing zone. As its falling, EVE also is using its TRN system to adjust to any new data that the TRN system detects. By 1 km, it will have cancelled out all horizontal velocity and started to lower itself down. This descent also targets a landing speed of 1 m/s.

The secondary sequence allows for lower fuel consumption as the hohmann transfers to reduce the spacecraft from its initial orbit to an orbit of 10 km is much more efficient than burning to a halt like in the primary mission. There are significant drawbacks to this sequence, however. The first being that it takes significantly more time for the sequence which would drain the battery significantly more than the primary sequence. The additional time could be used for more advanced analysis of the landing zone if the computer can not do all of the necessary computations in the short timespan in the primary approach. This secondary approach also risks the orbiter as it has to lower its orbit to 35 km to ensure radio communication while landing which puts it at risk of flying through the plume clouds and damaging the orbiter.

For the propulsion system, the team chose to use MR-103J Hydrazine engines from Aerojet Rocketdyne. Each of these engines provide up to 1.13 N of thrust. This means with a total of 6 engines at full power EVE is able to effectively hover or slow down to a near hover depending on the mass. The 103J is currently in development with first flight during 2020, but there are flight heritage with attitude control thrusters on Voyager and the GPS satellites. While not designed for landing engines, the lack of an atmosphere, low gravity and low mass of EVE allow the engines to adapt to this new role. A main downside to the 103J is that there is no thrust vectoring, instead the team decided that placing the engines in a triangle would allow for control as different engines could be fired at different times to provide torque and thus control EVE. However, if needed the small weight of the engines allow for a more traditional horizontal thruster to be added with little impact.

The amount of fuel needed can be estimated based on the delta-V requirements of the EDL sequence. The max delta-V which is for the primary EDL sequence is approximately 300 m/s. From this, the amount of fuel can be calculated based on the effective exhaust velocity of 2111 $\frac{N*kg}{s}$ which was estimated from the thrust and flow rate. This gives a mass of fuel of approximately 9 kg of fuel.

A key subsystem to the success of the EDL sequence is the TRN subsystem which is composed of the camera and image processing. The argest challenge which led to a lot of the design decisions was that the images of Enceladus were not accurate enough to validate that a chosen landing site was safe enough to land. For that reason, the team decided the only way for there to be a high likelihood of success would be some form of

TRN. With TRN, the lander would be able to "see" any obstacles and take the necessary evasive actions to find a safe stop. The ideal TRN would be able to make a decision similar to Apollo 11 where Neil Armstrong and Buzz Aldrin saw the lunar landing site was unsafe and chose to land somewhere else.

Multiple camera systems and software approaches were considered for the TRN system. One of the main factors in the team's decision was the *Overview of Terrain Relative Navigation Approaches for Precise Lunar Landing* report. In this report, it outlines multiple sensors for TRN including a standard camera, altimeter, or imaging LIDAR. Altimeter only provides a position estimate without a velocity estimate and thus does not make reasonable sense to use. The major downside of any method that requires a standard camera is that there need to be adequate lighting conditions which could be a problem with Enceladus due to its distance from the sun or it could be too bright due to the reflectivity of the surface. LIDAR does not have the lighting requirement but both suffer from not having any database for images. However, LIDAR cameras can be used with a shape signature matching for position estimate approach which only requires a 3D map of the surface. While that may initially seem like a problem, the LIDAR could also be used to construct the 3D map. For this reason, the team decided to use LIDAR as it could independently create the data necessary for landing while in-orbit.

This method of creating and using the LIDAR data at the same time is a challenge and has not been attempted in any mission before. Because of this, the EDL path has been planned out so that there is enough time above the landing area to collect data and give enough time for data processing.

The LIDAR system that the team chose to use on EVE was the 3D Imaging Cubesat Lidar for Asteroid and Planetary Sciences (ICLAPS). This LIDAR system was developed as a compact LIDAR system that would be flown as part of a cubesat to image asteroid, comets, or planets. One of the specific applications are topological missions which is what the TRN system needs. The most important feature of ICLAPS is that it has a range resolution of 15cm which means that it can detect the small differences that would outline a rock or a break in the ice that would be hazardous to land on. Additionally ICLAPS has a range of 100km and a 10 degree scanning angle. The range is higher than EVE needs but ICLAPS should be able to function at lower heights. The 10 degree scanning angle allows EVE to "see" to its peripherals which is essential in determining which direction to divert to if necessary. The small form-factor of 2U and small mass of 4kg is helpful for a mission where there is a very small weight and size requirement. ICLAPS requires 14.3 watts of power however it will not be on all of the EDL sequence for either plan so its overall power usage is acceptable.

The other major section of the TRN subsystem is the flight computer. While normally, the computer is important but just follows a preset instruction for this mission the computer must be able to analyze large amounts of data and also be running the TRN subsystem at the same time. For this reason, the mission will require the High-Performance Spaceflight Computing (HPSC) project to be completed so that there are new multicore computer chips rated for long-duration spaceflight. This will allow the computer to be able to do all the necessary computations without a secondary flight computer which would add weight and take up space. While the HPSC project has not been completed so there are no physical chips that the team can choose from, initial papers such as *High Performance Computing Applications in Space with DM Technology* outline initial chips being tested, including a chip called DM-Cube which the team decided to base the expected compute power of eventual fully developed chip on. The DM-Cube is a 800MHz CPU with 256 MB of RAM and 256 MB of flash memory. While this is significantly less than the leading CPU on the market, the team expects it to be fast enough for the necessary calculation. However, the team expects that there would need to be more memory added as all of the TRN data would have to be stored and processed very quickly. In 2017, a DM-Cube was tested on the ISS which showed its radiation tolerances, fault tolerances, and ability to compress and transmit images. With those tests, the program moved to TRL-7 which shows that the system works. However, there were a few anomalies but the DM chip team is working to resolve them.

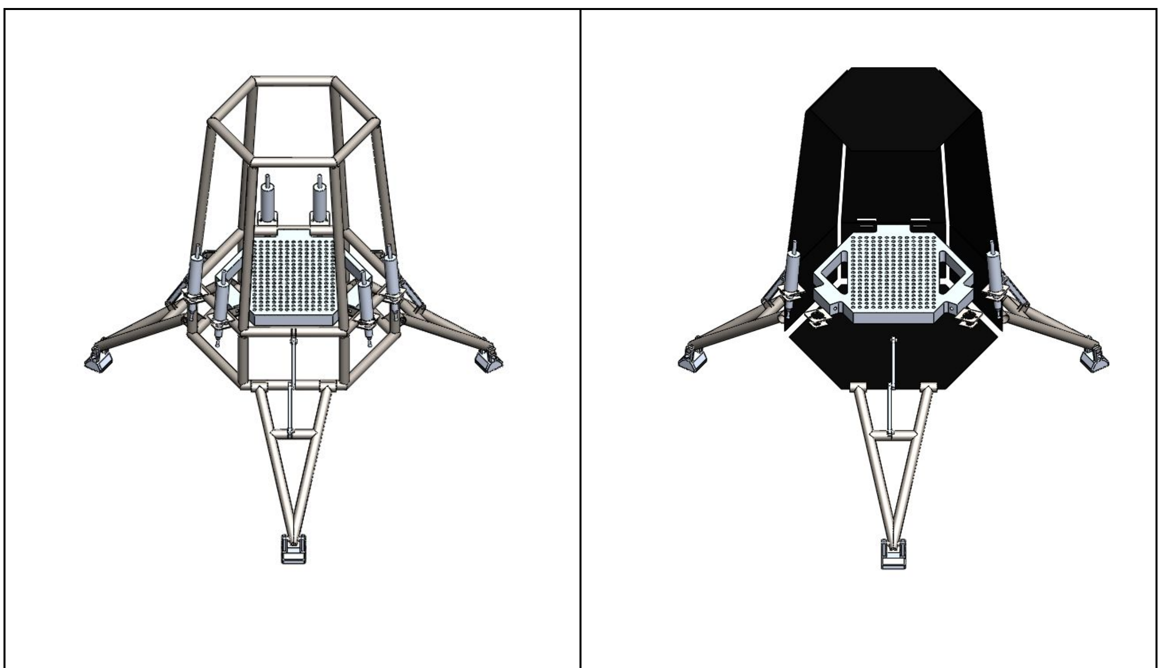


Figure 2: Model of EVE without panels (left), without frame (right)

The frame of EVE takes the shape of a drafted hexagonal prism. The frame is composed of a circular tube AISI 4130 steel weldment. EVE has three legs, which are mounted symmetrically onto frame members, and six engines, which are paired and mounted side-by-side on the frame by two tabs. The engine has a triangular flange with a 3-hole bolt circle, which will be used to constrain the engine to an upper tab. A second lower tab will hold the body of the engine.

The legs of EVE are welded arms consisting of two long members and a cross member. The two long members end in a cup into which a sprag bearing is installed. The sprag bearing will allow the legs to extend downward, but prevent them from folding back. The cross member has tabs for one of two linkages that keep each leg from extending past the maximum desired angle. The far end of the legs have feet, which are tightly fit onto the legs by a pin in the position they would be when landing on a flat surface. The bottoms of the feet will have high traction surfaces to prevent slipping on icy surfaces. The feet can rotate inward and outward to accommodate the terrain. At the frame, the legs are constrained by tabs. The upper linkage is held in another pair of tabs on the frame. The links are connected by pins.

The legs are extended once EVE is released from the orbiter. A set of exploding bolts will hold the legs in the folded position, and triggered electronically when the legs need to be extended. The legs will fall by the force of gravity and from the exploding bolt, at which point they will be fully constrained by the linkages and the sprag bearing.

Inside EVE is a plate with a grid of bolt holes, onto which instruments and other components can be mounted. The plate is held within the frame on three sides by tabs, and is pocketed to reduce weight. The plate is made of 6061 aluminum.

EVE will have 14 exterior body panels to insulate it and cover up the internal components. In case of leg failure, the body panels must be resilient enough to support the weight of EVE. The panels will be secured by Dzus tabs welded onto the frame. The panels will be composed of carbon fiber with aluminum inlay.

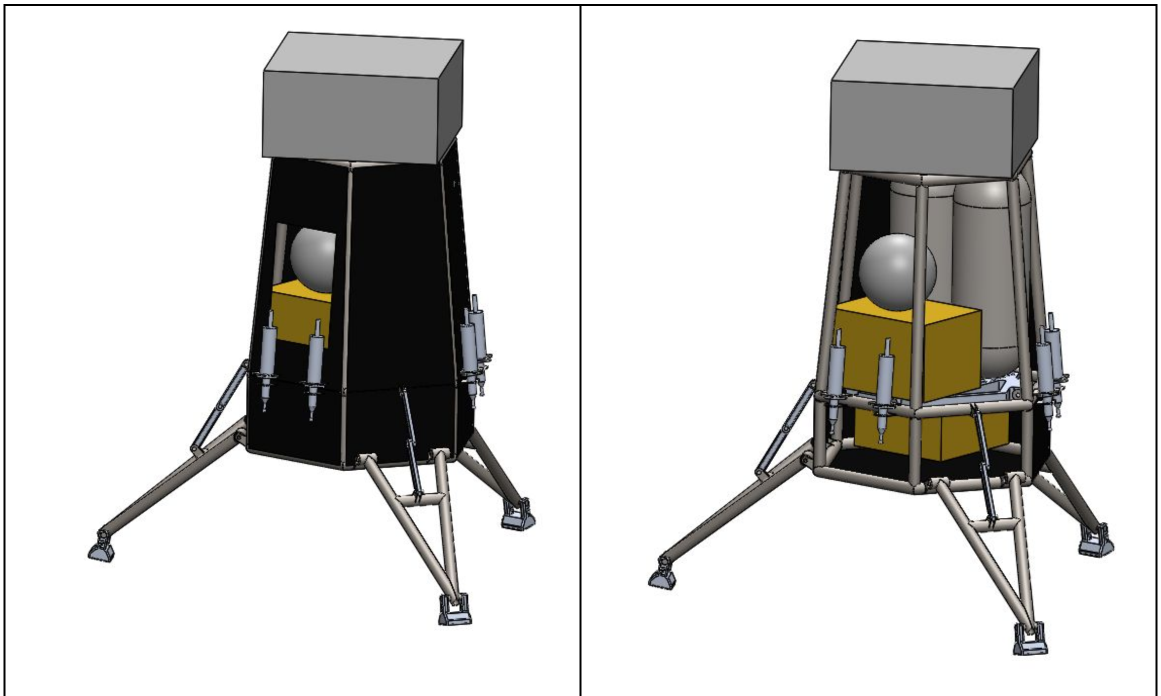


Figure 3: Model of EVE with instrument bounding boxes (left), without panels (right)

Packaging of instruments is demonstrated with bounding boxes. Hydrazine storage is sufficient for 9L in two large tanks and one small tank.

3.1.3 Dimensioned CAD Drawing of Entire Assembly

When the legs are folded, EVE assembly has a bounding box of 52.7cm (20.75”) tall, 43.9cm (17.3”) wide, and 42.4cm (16.7”) deep.

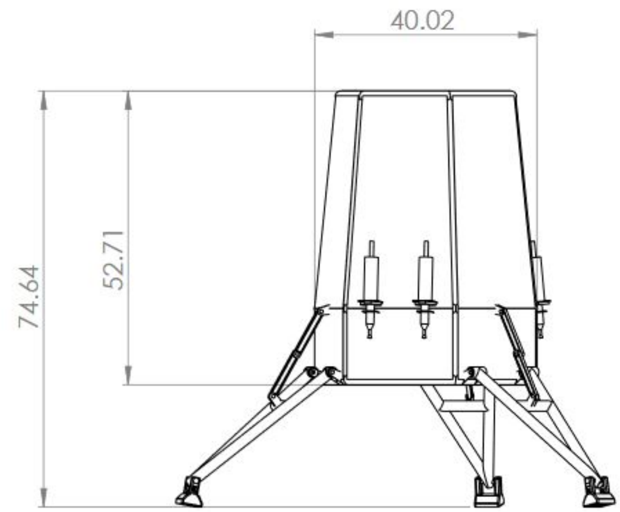


Figure 4: Dimensioned lander, units in centimeters.

3.1.4 Manufacturing and Integration Plans

The frame will be manufactured as one weldment of AISI 4130 circular steel tube of 0.75” outer diameter and 0.065” wall thickness. The cut list is as follows: six of 6.645”, twelve of 8.198”, six of 14.725”, six of 4.625”. The total length of steel needed is 255”. To produce each member of the weldment, a tube notcher with a 0.75” endmill will be used to accurately cut the angles needed.

The cut members will be TIG welded on a fixture plate for the three hexagons. Fixture blocks on a jig plate will be used to support the hexagons vertically, such that the supporting members can be welded on with EVE in a horizontal position.

The engine tabs will be laser cut from 0.0625” (16ga) steel sheet metal and welded onto the frame with the engines on fixture blocks. The leg tabs, link tabs, and shelf tabs will be laser cut from 0.035” (20ga) steel sheet metal and welded on to the frame with another set of fixture blocks and jig plates for the upright lander assembly.

Each leg will consist of weldments of AISI 4130 steel with 0.75” outer diameter and 0.065” wall thickness. The cut list is as follows, for all three legs: 6 of 12.28”, 3 of 3.61”. The total length of steel needed is 85”. Again, the tube notcher will be used to produce the members. These will be TIG welded on fixtures on another jig plate.

The linkages will be manufactured from 6061 aluminum on a CNC milling machine, in two operations for the pockets on each side. The stock will be held in a fixture plate which can be reused. Milling will be done with a carbide ballnose 2-flute endmill and a carbide drill bit. The pins will be purchased as a component off the shelf, but could be manufactured in house if needed.

The feet will be manufactured from 7075 aluminum on a four axis CNC milling machine for 1 operation, and a CNC milling machine for another operation for the bottom. A fixture will be needed to hold the work. Milling will be done with a carbide ballnose 2-flute endmill and a carbide drill bit.

The shelf will be manufactured from 7075 aluminum on a CNC milling machine from a 12” square, 1” thick plate. A router with sufficient travel capability is needed. A fixture plate larger than 1’ square will be needed to hold the work. Milling will be done with a carbide endmill, center drill, and carbide drill bit for clearance to the bolt size used.

The panels will be made as a carbon fiber composite layup, with an aluminum inlay. This will be manufactured from pre-preg carbon fiber and epoxy, using standard oven curing techniques.

Many of the components used in EVE will be existing ones that can be purchased. These include explosive bolts, sprag bearings, fasteners, and Dzus tabs.

Task	Estimated Time
Manufacturing fixtures	1 CNC machinist, 10 hours
Assembling fixtures	1 fabricator, 5 hours
TIG welding frame and legs	1 welder, 16 hours
TIG welding for tabs	1 welder, 6 hours
Laser cutting tabs	1 technician, 2 hours
CNC machining feet	1 CNC machinist, 9 hours
CNC machining linkages	1 CNC machinist, 3 hours
CNC machining shelf	1 CNC machinist, 3 hours
Composite layups	1 technician, 4 hours

Integration will occur during the assembly of EVE. The components are manufactured using fixtures and jig plates in such a way that they will fit together even after welding. The timeline for manufacturing is completing parts in the order of: the frame, plate, legs, tabs, and feet, and installing other components. The entire assembly of EVE will take 180 hours.

3.1.5 Verification and Validation Plans

To validate the TRN subsystem, the team plans on testing the system through the use of a helicopter in a glacier region. To do this the camera equipment and flight computer would be attached to a helicopter and fly to a remote glacier. This glacier would have to be close enough to match the surface conditions of Enceladus. Once at the glacier, the guidance computer would be turned on and it would have to "land" the helicopter. Since there is a large size difference and there is a risk of crashing, the helicopter would not land but the landing spot that the computer system chose would be checked for feasibility. JPL has previously used a similar approach to validate their TRN model for the Mars 2020 mission. A large difference between JPL's use of this method and ours would be the limited resolution of the dataset. With Mars, there are high-resolution images of the landing site so an accurate Earth testing site could be selected but without those for Enceladus, it would be more challenging to find a valid site. This risk could be reduced with multiple tests at different locations however that would increase the cost of the mission.

The engines will be validated by Aerojet Rocketdyne and when fully assembled the heaters and valves will be tested but there will not be a static fire while fully assembled due to the problem of refilling the hydrazine enclosure.

To validate EVE, we will use structural FEA tools. The assemblies to be analyzed are a full assembly, a leg assembly, and the tabs for various loadcases. These loadcases are thrusting acceleration, normal landing, and crash landing impact.

For the normal landing loadcase, we will use the full assembly and leg assemblies in two configurations - one with legs extended and one with legs folded. The maximum stress is expected to be at the legs if they are extended. The crash landing loadcase will also use the full assembly and leg assemblies, but apply loads to simulate EVE impacting in different orientations and at different speeds. The thrusting acceleration loadcases will use the engine tab assembly to determine if they will fail to secure the engines in place.

3.1.6 FMEA and Risk Mitigation

Functions	Failure Modes	Effects	Severity	Causes	Occurrence	Design Controls (Prevention)	Design Controls (Detection)	Determination	RPN	Actions
Extend legs	Exploding bolt fails to trigger	Leg is completely unextended	8	Electronics malfunction	3	Test electronics	Visual from orbiter	1	24	Test exploding bolts and electronic subsystems on the lander
	Sprag bearing sticks	Leg is only partially extended	7	Quality control failure	1	Test bearings before and after installation	Visual from orbiter	1	7	Quality control COTS, ensure bearing fits are to standard
Land	Engines fail	Lander freely falls and crashes	10	Quality control failure	1	Test all six engines	Visual from orbiter	2	20	Quality control engines and test lander on Earth
	Land on terrain protuberance greater than clearance	Bottom of lander is struck forcefully	6	Poor landing site selection	5	Allow sufficient time in EDL for data analysis	Visual from orbiter	1	30	Test TRN and data processing systems on Earth
Protect Contents	Panels are destroyed or fall off	Reduced insulation	5	Engine failure, fastener failure	1	Test panel attachment	Visual from orbiter	1	5	Ensure landing capability and test fasteners
	Fuel tank or plumbing compromised	Fuel is lost, reducing landing capability	9	Quality control failure	3	Test fuel tank and plumbing	Sensor in fuel tank	3	81	Test plumbing and fuel tanks on Earth

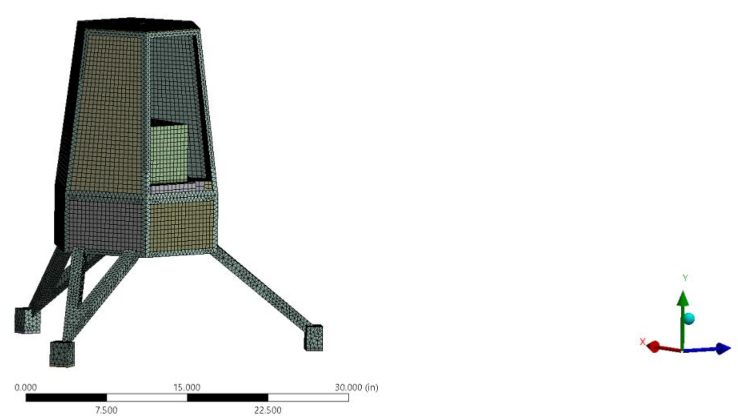
	5					
	4					
Probability	3					
	2		3,4		2	1
	1					
		1	2	3	4	5
				Severity		

Rank	Approach	Risk Title
1	M	Landing failure
2	M	Leg failure to extend
3	M	Leg breakage
4	M	Frame breakage

3.1.7 Performance Characteristics and Predictions

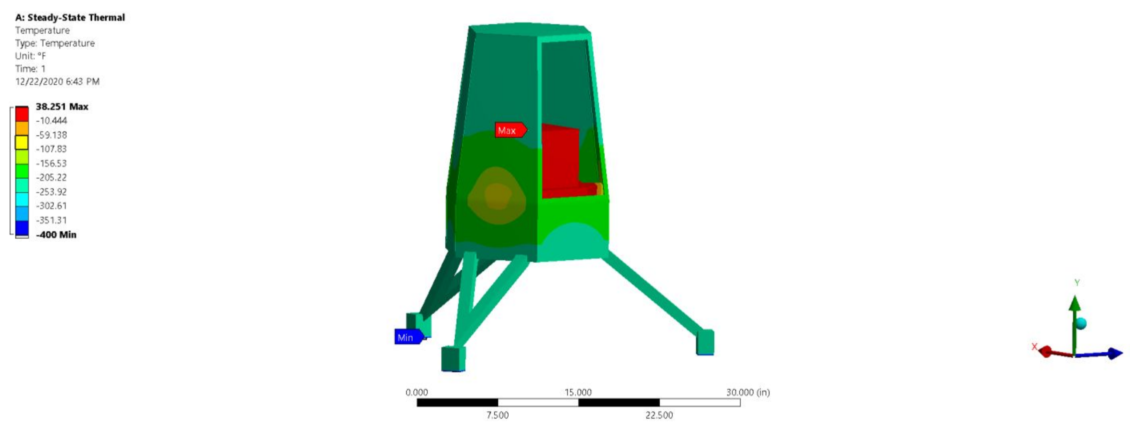
The main performance characteris for the engines will be the thrust outputted by the engine and its ability to throttle. Since Encaldus has no atmosphere the engines would operate in the same conditions as deep space which the MR-103J has previously worked in. ICLAPS will have to be able to determine surface features of an icy surface. This should work because the ice would reflect the LIDAR beams extremely well giving the device a high quality return beam which then could be used to create a good 3D model. The team anticipates however that there will be problems and features that the device may not be prepared for. However there should be enough surrounding data that EVE is able to piece together what the confusing data may be. Additionally testing on Earth data would increase the team's confidence in the system.

To estimate the steady state thermal properties of the lander, ANSYS was used to produce temperature and total heat flux solutions for the lander. A simplified model of the lander was made, shown meshed below:

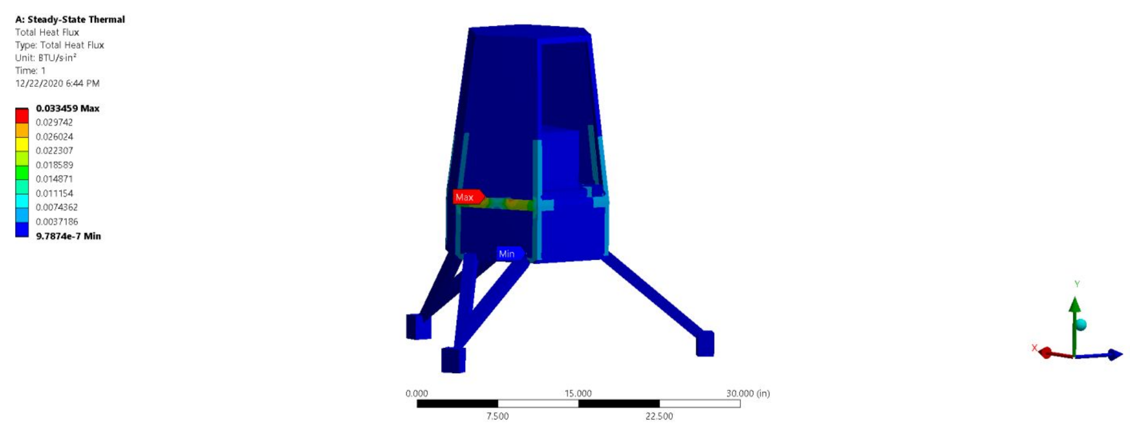


To model the cold conditions of the lander, a constant temperature matching the surface temperature of Enceladus was applied to the bottom of the feet of the lander, radiation with an emissivity of 0.88 was applied to all faces except the outsides of the panels, to which radiation with an emissivity of 0.12 was applied. Finally, an internal heat generation was applied to a box representing the heat generating components of the lander. After several iterations with various insulators placed between bodies, a total heat generation of 125 W was determined to be appropriate to keep the instruments above 273 K in the cold condition. The setup is shown below:

The temperature solution is as follows:



The total heat flux solution is as follows:



Some components were added to the lander to improve the thermal properties, including ertalyte insulators placed between connections between the instrument and the shelf, and the shelf and the frame. Aerogel was placed at the contact points with the surface. Some weaknesses of the model are that the frame, legs, and connections are not modeled accurately.

3.1.8 Confidence and Maturity of Design

- The TRN system would need to be fully developed from scratch and tested through the use of helicopters
- The engines have been proven to work in deep space and are fully mature. Minimal testing needed
- The legs of the lander have changed from a complex telescoping crush design to a simpler design that has fewer interfacing parts, reducing the risk of failure
- The lander can be landed on Earth using the thrusters to test flight dynamics and to determine loadcases. Since the acceleration on Earth far exceeds that on Enceladus, the loadcases derived will be very conservative.
- The lander can also be dropped to get more loadcases.
- Electronic and mechanical systems like the explosive bolts and leg release and locking can be tested on Earth

3.2 Recovery/Redundancy System

Due to the limited mass, weight, and size of the proposed mission, there are less redundancy systems than regularly expected on a NASA mission to ensure that the mission stays within requirements. However, the ability to attempt to land on Enceladus and collect valuable data in this small form factor is worth the higher risk.

The use of more than one engine per side allows for redundancy as a failure could be balanced by shutting down an engine on either side. However this would impact the burn time which would impact the EDL sequence and contingency plans would need to be developed.

The TRN system can not have redundancy as it would increase the weight and take up too much space. Instead the team would plan for rigorous testing of the software as laid out 3.1.5. This system is the critical failure point of the mission. If the TRN system fails then there is a high chance of failure of the mission but if it succeeds then the chance of success is significant.

If a frame member on EVE breaks, the rest of the frame should still be able to support the internals. The only load the frame bears is the weight of the components inside EVE which should be well below the yield strength of 4130 steel.

The load involved in landing is expected to be very low, as the thrusters will be used to gently lower EVE. The gravity of Enceladus is also low, further reducing the impact loads on the legs. If a leg breaks, or if one or more of the legs fails to extend completely, the acceleration of landing should be further reduced to minimize impact loading. Extra fuel will be carried by EVE to accommodate such adjustments.

3.3 Payload Integration

All parts of the payload, including instruments, battery, fuel tank, plumbing, and will be bolted to the shelf with brackets, or tabbed onto the frame.

4. Payload Design and Science Instrumentation

4.1. Selection, Design, and Verification

4.1.1. System Overview

Operational at 273K at all times.
Near Infrared Volatile Spectrometer System (NIRVSS) total power: 29.56W
X-band High Gain Antenna: 5W
High-Performance Spaceflight Computing (HPSC): 12-18W
Radioisotope Heater Units: 1W per unit.
13 Ah Lithium-Ion Pouch Cell or 55 Ah Lithium-Ion Cell
3D Imaging Cubesat Lidar for Asteroid and Planetary Sciences (ICLAPS):14.3 W

NIRVSS	Sends atmospheric and temperature data			
Receives atmospheric data	HPSC	Sends atmospheric data		Sends commands to start heating up
	Transmission acknowledgements	X-Band High Gain Antenna		
29.56W	12-18W	5W	55 Ah Lithium Ion Cell	
	Maintains operating temperature			Radioisotope Heater Units (RHU)

4.1.2. Subsystem Overview

EVE will utilize a NIRVSS Near Infrared Volatile Spectrometer built by Thermo Fisher Scientific to measure CO2, H20 and H volatiles and surface morphology of Enceladus' South Pole. NIRVVS comprises three parts: spectrometer, bracket assembly, and lamp and operates 12W, 5.26W, and 12.3W respectively for a total of 29.56W. It has a mass of 3.57 kg with the dimensions 18*18*18.5 cm with a cost between $5,000-$50,000. It has a sensitivity range of 1.2 to 4.0μm and a signal-noise ratio of less than 100 at 2 and 3μm. Its accuracy to radiance is less than 25% as well.

To communicate the data back to Earth, EVE will be accompanied with a X-Band High Gain Antenna to transmit information directly back to Earth utilizing the Deep Space Network. This is a hexagon shaped antenna at about one foot in diameter at about 30 cm by 15 cm by 30 cm, costing about $25,000. This high gain antenna uses two frequency channels to communicate. One is at about 8.4 gigahertz and the other at 2.3 gigahertz. This needs a total of 5W to operate.

The top contender for the battery supply is between the 13 Ah Lithium-Ion Pouch Cell and the 55 Ah Lithium Ion Cell battery. The 13Ah is longer lasting but the 55 Ah has less of a voltage range which would mean less fluctuating energy. EVE will be using both batteries as a power source to meet our goal of 5 hours. Both the 55 Ah and 13 Ah batteries have 12.8x14.1x3.4cm and 11.5x10.1x0.7cm dimensions respectively, it would be easy to add more batteries if needed.

Radioisotope Heater Unit (RHU) can output a heat of 1W when turned on. It has a size of 3.2 cm in length and 2.6 cm in diameter with a mass of 40 grams.

While the HPSC project has not been completed so there are no physical chips that the team can choose from, initial papers such as *High Performance Computing Applications in Space with DM Technology* outline initial chips being tested, including a chip called DM-Cube which the team decided to base the expected compute power of eventual fully developed chip on. The DM-Cube is a 800MHz CPU with 256 MB of RAM and 256 MB of flash memory. It will be capable with working with the rest of the scientific instrument to dictate commands and handle sensitive data. It will need 12-18W to operate.

3D Imaging Cubesat Lidar for Asteroid and Planetary Sciences (ICLAPS) will also be used as a camera as EVE becomes stationary. It will send the pictures and videos it record to HPSC so that NASA can have a close up of the Enceladus surface. It operates on 14.3 W and has a range of less than 100km, a range resolution of 15 cm,

When EVE lands, the battery will stop supplying power to the landing equipment with the exception of ICLAPS and HPSC and start supplying power to the scientific instruments instead. As shown in the N^2 chart, the battery will supply 12-18W to the HPSC and will work with the Minco's Thermal-Ribbon surface sensor to ensure that EVE will remain at an operating temperature of 273K. Once Minco's surface sensor senses that the temperature drops, the HPSC will send a signal that will turn on RHUs and turn it off when the temperature surpasses 273K. The Near Infrared Volatile Spectrometer System (NIRVSS) will then be able to look outside through the quartz glass to record and measure CO2, H20 and H volatiles and surface morphology of Enceladus' South Pole. NIRVSS will send that data back to HPSC and it will be sent to the X-Band High Gain Antenna to send it back to earth.

4.1.3. Manufacturing Plan

All of the payload will be Commercial-Off-The-Shelf (COTS) instrumentation. NIRVSS will be bought from Thermo Fisher Scientific from $5,000 to $50,000. The X-band High Gain Antenna will also be bought at $25,000. The 55 Ah Lithium Ion Cell or the 13 Ah Lithium Pouch Cell will be bought from the same company, Eagle Picher who has numerous histories with working from NASA. The HPSC has not been developed completely but they would be selling it too as it is their project. The 3D Imaging Cubesat Lidar for Asteroid and Planetary Sciences is also being developed by NASA along with Radioisotope Heater Unit (RHU) with no price so far.

4.1.4. Verification and Validation Plan

All instruments will be tested in a similar environment when EVE has landed in Enceladus. The instruments will operate at a 273K temperature with an interval of 10K changes to see how the HPSC, Minco's Thermal-Ribbon surface sensor, and RHU handles the varying change of temperature. The testing will take place in a room with volatiles in the atmosphere so NIRVSS can test it's capabilities under different environments such as having a foggy lens and measuring the accuracy of its data. The HPSC will be tested to see how it can receive and send data to the Antenna and RHU.

4.1.5. FMEA and Risk Mitigation

Functions	Failure Modes	Effects	Severity	Causes	Occurence	Design Controls (Prevention)	Design Controls (Detection)	Determination	RPN	Actions
Analyze Volatiles	Spectrometer module not working	No volatile to measure	9	Faulty Wiring	3	Double check wiring	Not measuring volatiles correctly	1	27	Make sure the wirings are done right
	Lens break	Inaccurate measure of	7	Rough Landing	5	Secure the NIRVSS with	Loosely secured	1	35	Test the security

		volatiles				bubble wrap	NIRVSS			of the NIRVSS by strong vibration
Sending out data	Not sending out data to HPSC	No data sent out from EVE	10	Broken antenna	2	Test Antenna	Testing it's output	3	60	Test antenna
Heating up EVE	Not heating up	Instruments will freeze and stop working	10	Manufac ture error	1	Test RHU	Not heating up	2	20	Test RHU
Powering up all instruments	Failure to provide power	EVE will stop working	10	Faulty Wiring	3	Double check wiring	No current passing through wirings	1	30	Make sure the wirings are done right
Sensing the temperature	Failure to sense change in temperature from 273K	HPSC won't notice the difference	5	Faulty Wiring or make	1	Double check wiring and test the sensor	Fails to detech temperatur e changes	1	5	Test the sensor
Computing and dictating functions	Failure to communicate with RHU	EVE will have lower temperature	5	Faulty Wiring or code	2	Test wires and program	Can't communica te with RHU	2	20	Test wiring and code
	Failure to communicate with antennna	No data sent out from EVE	10	Faulty Wiring or code	2	Test wires and program	Can't communica te with antenna	2	40	Test wiring and code
	Failure to communicate with NIRVSS	No volatile data to send out	7	Faulty Wiring or code	2	Test wires and program	Can't communica te with NIRVSS	2	28	Test wiring and code

Risk Plot

	5					
	4					
Probability	3					
	2				2	1
	1			6,7		3,4,5
		1	2	3	4	5
				Severity		

Rank	Approach	Risk Title
1	M	Malfunctioning Spectrometer
2	M	Broken Spectrometer

		Lens
3	M	Faulty Antenna
4	M	Faulty RHU
5	M	Faulty Battery
6	M	Faulty Temperature Sensor
7	M	Faulty Wiring on HPSC

4.1.6. Performance Characteristics

Due to our instruments being a COTS, it's already stated what their working operations are. The working temperature that fits all of the instruments while maintaining efficiency is at 273K. As long as they're all within that temperature range, they are expected to operate as intended.

4.2. Science Value

4.2.1. Science Payload Objectives

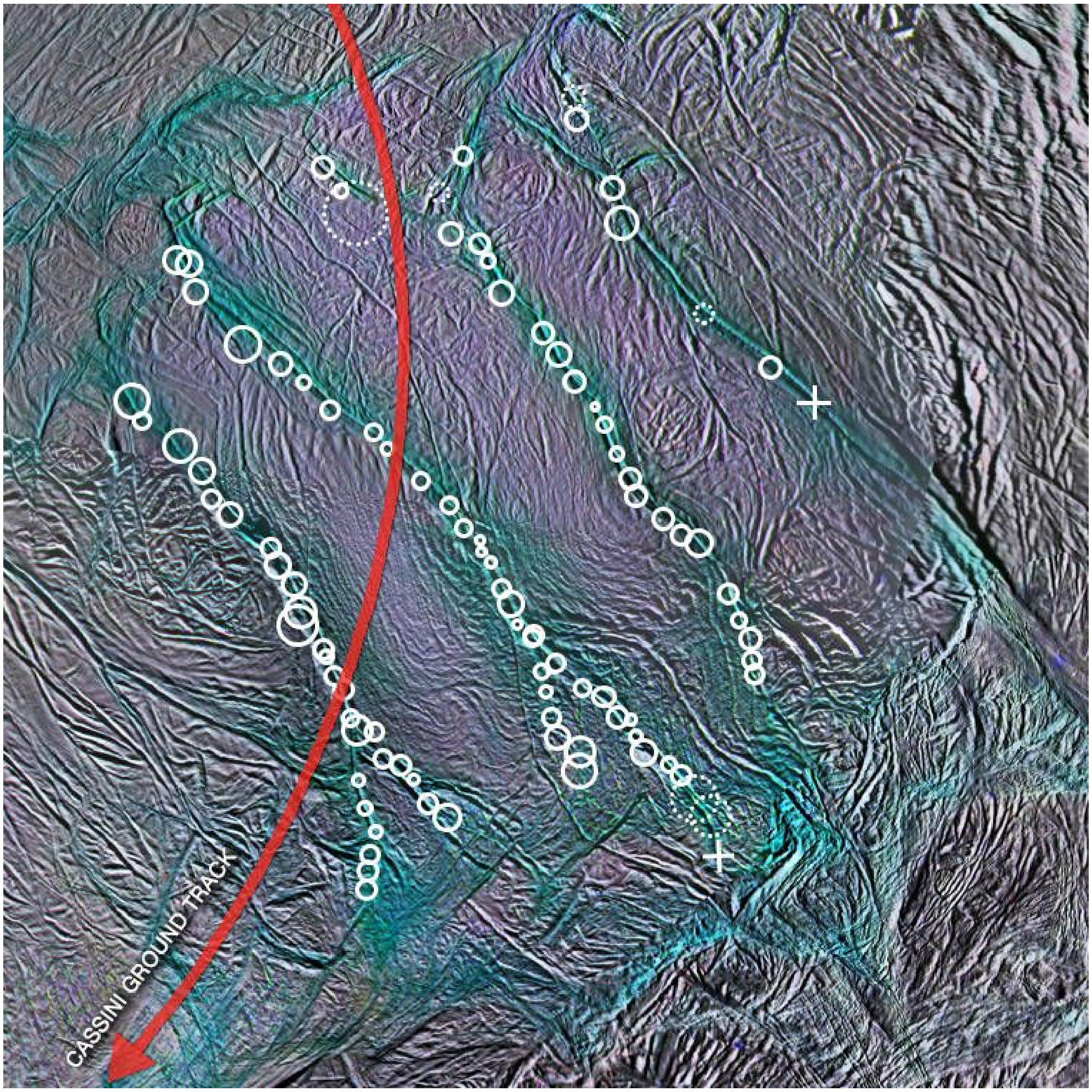
To begin, restated below is the mission statement for the lander and orbiter being sent to do research upon Enceladus.

Enceladus Volatile Explorer (EVE) will land on the surface of the South Pole of Enceladus near an active Tiger Stripes to gather and record data about the volatiles that exist in Enceladus' atmosphere. NIRVSS Near Infrared Volatile Spectrometer will be inside EVE and will continuously collect information on C02, H20 and H volatiles and surface morphology to further understand the possibility of life on Enceladus. After, it will send back data to Earth utilizing the Deep Space Network technology and onboard communication.

The first and most important minimum criteria of success will be that EVE's batteries and heater last throughout the journey of traveling to Enceladus. The batteries and heater should remain in working conditions to utilize the landing equipment as described in our EDL. The second criteria will be that EVE will land with no detrimental damage to the instrumentations inside it's structure. The third criteria will be that NIRVSS will be able to collect data about the volatiles in Enceladus. To be a tremendous success, NIRVSS should collect data with a sensitivity ranging from 1.2 to 4.0 micrometer, a Signal-Noise ratio of less than 100 at 2 and 3 micrometer and confirming water ice to less than 0.25% error. The last criteria will be that more than half of the data is sent successfully from EVE to Earth using the Deep Space Network technology.

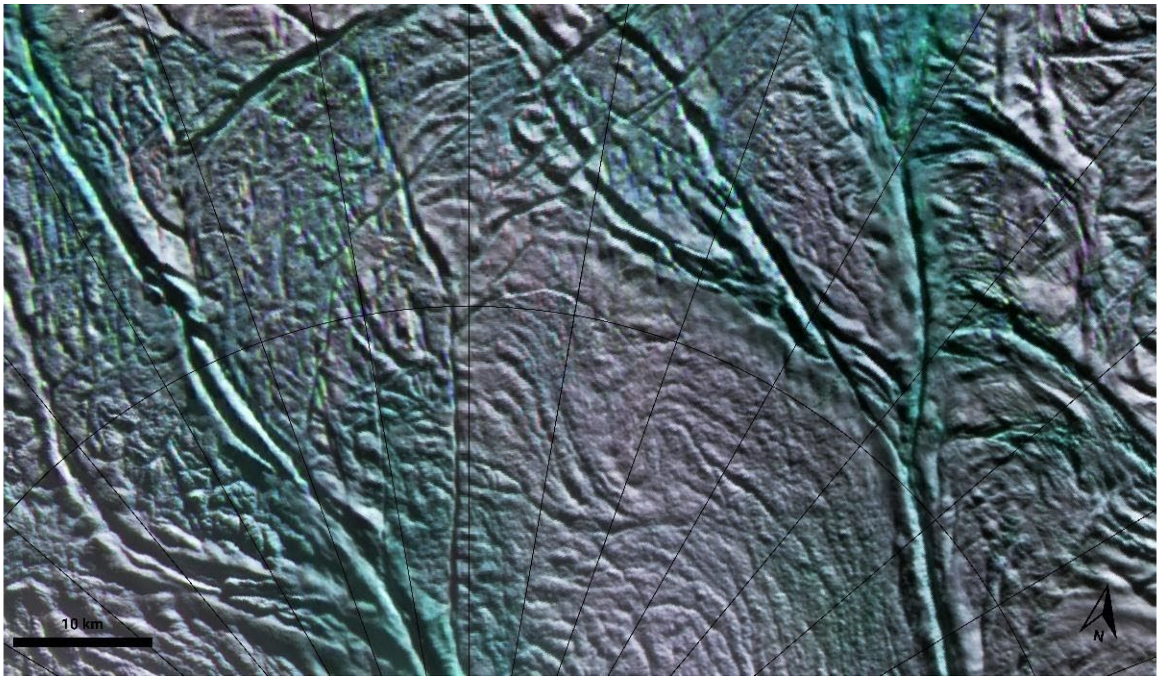
The main objective for the lander on Enceladus would be to find life. However, if upon the first mission, life is not discovered, EVE will be the one to research the volatiles on and around Enceladus' water vapor atmosphere. It is thought that Enceladus' thick icy crust hides a deep ocean where life may be present. With EVE's spectrometer, collecting information on CO2, H20 and H volatiles that could be present in the atmosphere, can bring about understanding on the possibility of life existing on the Saturn moon. Finding a landing on the South Pole region will detect future landing conditions for larger missions in the future to better understand safe landing where Enceladus is more or less active.

4.2.2. Creativity/Originality and Significance



EVE will be landing on the South Pole of Enceladus between the Tiger Stripes. Above is a photo using JMARS to depict an accurate representation of the area designated for the lander to land. This area was decided upon due to the fact that there is interesting geological activity in regards to the geysers located on this area. These geysers can shoot at about 800 mph and are made up of 98% water, traces of ammonia, carbon dioxide, carbon monoxide, hydrogen, methane and organics hundreds of miles into space. These Tiger Stripes are about 130 km long and are shown in the photo by the white circles back to back along the lines of Enceladus. The geysers shoot up volatiles that will help with further understanding of possibility of life as well as safe places to best land in future missions.

Below is a zoomed in photo of the specific lander spot on Enceladus.



This image is zoomed in x64. There is a range of 7 km^2 for the reason that the terrain is consistent. EVE's coordinates will be approximated: -81.805°N, 10.863°E.

[1] https://jmars.asu.edu/

4.2.3. Payload Success Criteria

The NRVSS is responsible for primarily studying the volatiles in the atmosphere of Enceladus. Enceladus is said to be a moon where life has the potential to exist. Upon Enceladus are geysers that gust out volatiles including CO2 and H20, two needed elements of survival. With the spectrometer being able to further access what the volatiles consist of and the consistency of environmental chemicals, a better comprehension of if survival is possible upon the moon for life as we know it to be able to exist, will be able to be researched upon further. The spectrometer will also provide information on if the area that EVE landed on is active with geyser activity to study and where more active areas to research are located for a future mission of exploration on Enceladus.

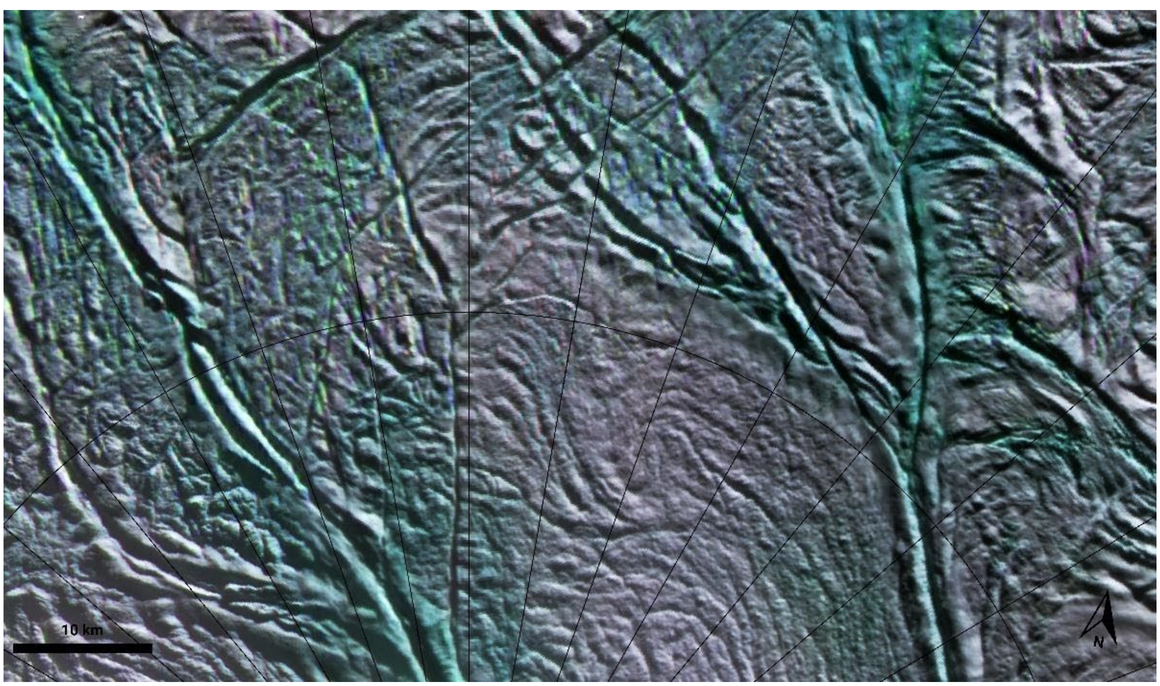
If the spectrometer were to become damaged upon impact, the scientific instrumentation would not end up accurately supporting research needed for the mission statement to remain successful. With proper preparation in safety, the spectrometer will remain safe on it's landing.

The NIRVSS Near Infrared Volatile Spectrometer will collect data by observing light emitted and absorbed from the substances being observed. The spectrometer is successful due to the fact that it can collect data regardless of if substances are located in or out of direct sunlight using its own light with Near Infrared Reflectance.

With the X-Band High-Gain Antenna located upon the lander, communication will be directed directly back to Earth utilizing the Deep Space Network. This antenna is steerable and has the ability to point it's radio beam in any specific direction needed for communication which is convenient as EVE does not need to change her position for accuracy of communication, just the antenna needs to be steered. The beam focus on a high gain antenna will allow for high rates of data back to Earth. With eliminating the antenna transmitting data to the orbiter from the lander itself, a quick message will be relayed directly back to Earth.

To be successful, EVE will land near an active Tiger Stripe and collect volatile information of the atmosphere full of water vapor and send this information back to Earth directly with the high beam antenna. The mission is simplistic, and will give an understanding of the amount of volatiles coming from the possible ocean beneath the Enceladus crust as well as the geysers eruption and what those contain.

4.2.4. Experimental Logic, Approach, and Method of Investigation



Using JMARS, a landing spot for EVE was determined based on the closeness of geysers near it. The geysers on Enceladus erupt from what is thought to be a possible ocean below the thick icy crust on the moon. The geysers contain 98% water, traces of ammonia, carbon dioxide, carbon monoxide, hydrogen, methane and organics. It is instrumental that EVE land near these active areas to best find volatile rich areas, but not too close to be destroyed by heavy blows.

EVE will not be making observations during descent, however will be making observations upon landing. The NIRVSS Near Infrared Volatile Spectrometer holds the instruments to analyze for volatiles and another part, spectrometer module, where it digitalizes and analyzes the results of the bracket assembly records. It will be on continuously after it has landed to measure the volatiles and surface morphology of Enceladus.

These results will be transferred from the spectrometer and sent back to Earth via the X-Band High-Gain antenna. The antenna is able to use a frequency of about 7 to 8 gigahertz and provide data to Earth's Deep Space Network Antennas for collection and further research.

4.2.5. Testing and Calibration Measurements

Once EVE is landed on the surface of Enceladus, collection of volatiles will be done near the landing sight. The density of volatiles researched in the past regarding organic materials were about 20 denser than predicted. Comparison to the volatiles discovered in geysers in prior times, from the volatiles found including 98% water, traces of ammonia, carbon dioxide, carbon monoxide, hydrogen, methane and organics and the density will be used as a control. If the spectrometer is able to accurately identify elements previously discovered as well as a composition near previously detected, the spectrometer will go on to provide information on new substances or deeper understanding of the atmosphere with trust in its abilities.

The NIRVSS Near Infrared Volatile Spectrometer also has a longwave calibration sensor with infrared flux which will research surface temperature from below 100 K to positive or negative 5 K.

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

The spectrometer precision accuracy is at less than 25% in regards to radiance. The spectrometer range is 1.2 to 4.0 micrometers on sensitivity. The Signal to Noise ratio is greater than 100 at 2 and 3 micrometers and water to ice is below .25%.

The X-Band High-Gain Antenna will transmit data faster than an antenna signaling back to an orbiter, to Earth. Using X band in radio frequency at 7 to 8 gigahertz, the antenna will transmit 160/500 bits her second to the Deep Space Network's 112 foot antennas or 800/3000 bits per second to the 230 foot diameter antennas.

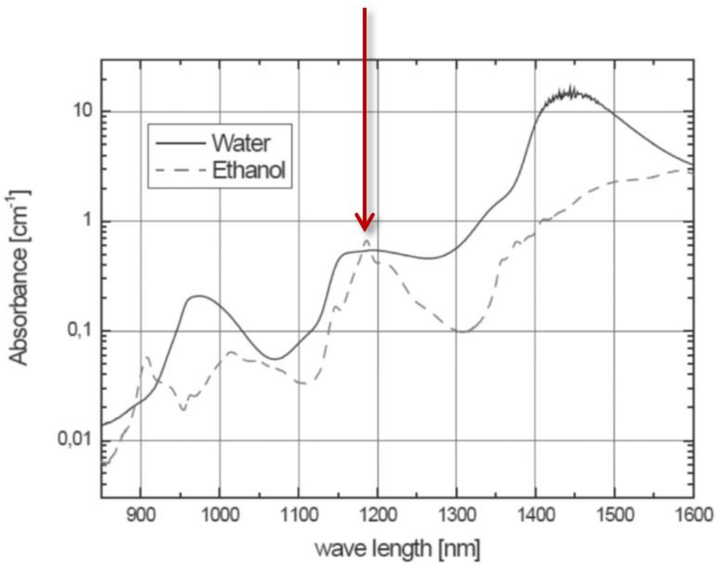
Accuracy will be determined by the identity of volatiles researched corresponding to the research done with Enceladus water vapors within the atmosphere previously and volatiles released from geyser activity in the past. If new volatiles are discovered, they will be inspected upon relation to existence with other volatiles in the Enceladus' atmosphere on Earth through the laboratory to understand how they coincide in the ocean underneath the crust of Enceladus together and what they form when combined. With little discovery upon Enceladus to begin with, any information found and researched will be substantial to further understandings on what life could be like and what the atmosphere of Enceladus is like.

If the spectrometer is unable to perform duties needed to understand the environment of the Saturn moon, then information will be successfully given to Earth with the understanding that two smaller instruments will be needed to fit on the lander as a primary and back up in the future. If the spectrometer is unable to give data needed to better understand volatiles, then in the next mission to Enceladus, preparation for a different scientific instrument will be needed.

Spectrometers measure the precise information needed and with the safety of descent and landing, EVE will explore safely and successfully.

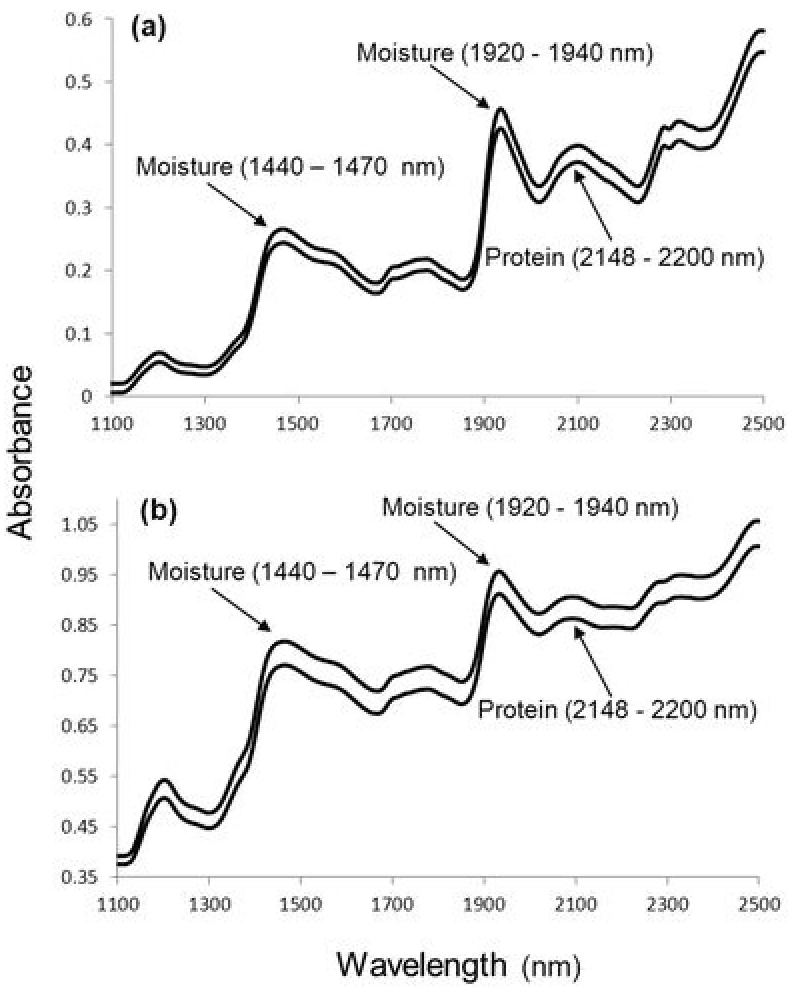
4.2.7. Expected Data & Analysis

The NIRVSS Near Infrared Volatile Spectrometer will observe light that is emitted or absorbed from substances to understand their composition. By understanding the composition of volatiles on Enceladus, an understanding of what the atmosphere is made of, the ocean underneath the surface of crust is made of and the possibility of life, will be better grasped to further research.



https://wiki.anton-paar.com/en/near-infrared-spectroscopy-nir/

This is an image of a graph relating the image of the water and ethanol being measured within the given wavelengths. By understanding how much CO2, H20, ammonia, carbon monoxide, hydrogen and organics are located and making up the geyser eruptions, a determination of what the ocean below the crust contains, can be estimated. The spectrometer will analyze the data collected from light emission and absorption to transfer to Earth for a measurement to be made and each substance can further be compared.



https://pubs.rsc.org/en/content/articlehtml/2014/cs/c4cs00062e

The spectrometer will also be able to determine moisture which will determine more information on volatiles.

The spectrometer precision accuracy is at less than 25% in regards to radiance. The spectrometer range is 1.2 to 4.0 micrometers on sensitivity. The Signal to Noise ratio is greater than 100 at 2 and 3 micrometers and water to ice is below .25%.

With a deeper understanding of what the geysers eruptions consist of will lead to a more well rounded understanding of what the crust of Enceladus is hiding, the ocean and its contents. If the spectrometer does not find much information in regards to what the atmosphere is made up of, then a landing spot closer to a Tiger Stripe will be needed for the next mission to garner more possibility of collecting volatile information.

The mission is to measure volatiles on a given spot of Enceladus, if a less active spot is researched, then a higher active spot can be determined by where the most information on volatiles was collected in the data. With the spectrometer's collection, and research on Enceladus in a previous mission, Enceladus is estimated to have an ocean of multiple substances. Any substances being analyzed will be helpful in understanding the possibility of life in the moon's ocean.

5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

The safety officer responsibilities will be divided up into two between Catherine Nguyen and John Stotz. Ms. Nguyen will be responsible for the team's personnel safety while Mr. Stotz will be responsible for the lander/payload safety. They have researched OSHA (Occupational Safety and Health Administration) laws for personnel safety and planetary space laws as well as research the elements of Enceladus for the lander/payload safety. Furthermore, they will continuously compare the safety sections of similar space missions PDR to make sure they don't miss anything other safety factors.

5.1.2. List of Personnel Hazards

Hazards could mainly happen in the duration of manufacturing the lander and that could include flying particles, molten metal, liquid chemicals, acids, gases, and potentially dangerous radiation. There are also possible fall hazards that a member may go through if not trained properly. The release of stored energy from a machine or equipment may also be potentially dangerous if not handled correctly. Working with potentially toxic and hazardous substances.

Additionally the use of hydrazine as a fuel poses a hazard as it is a hypergolic which means that when handled the attendant must be properly protected. Additionally, during the launch sequence the flight must not have a risk of spreading hypergolics over any population.

5.1.3. Hazard Mitigation

As per OSHA regulations, the employer shall ensure that each affected employee uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation. The employer shall provide a training program for each employee to make sure they know safety and regulations for the occupational hazards they might face. Furthermore, they need to be certified before working on any professional work that could have potential dangers such as working with fire or hazardous substances. The employer shall also establish a program consisting of energy control procedures, employee training and periodic inspections to ensure that before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energizing, startup or release of stored energy could occur and cause injury, the machine or equipment shall be isolated from the energy source and rendered inoperative. As an added bonus, the building will have ramps and elevators on top of stairs so that it will be disabled friendly and mitigate the risk of getting hurt.

5.2. Lander/Payload Safety

5.2.1. Environmental Hazards

One of the main hazards with a landar to Enceladus is that there is limited research into the material composition of the surface. This means that there is little data to design what impact the lander legs should expect at contact. Also with the limited data about the surface there is fear that the icy surface could be soft or could crack leading to the lander sinking into the surface.

Another hazard with a lander mission to Enceladus is the limited amount of topological data on Enceladus. This means that there is a large danger with choosing a landing zone as once the lander gets to Enceladus and begins to land, the surface may not be what the team expects.

While radiation always poses a risk to satellites, Saturn does not have an intense radiation band that would warrant an increase in radiation protection over regular deep-space missions. However, deep space travel still exposes the craft to solar radiation which can cause issues for electronics thus requiring protection on the craft.

With the goal of the mission to be visiting the south pole region, near the geyser, there is a concern about flying through the plumes. There may be risk as the plumes may have chunks of ice or rock that could damage the spacecraft. The team has no additional preventive measures engineered into the lander to prevent collisions since the team assumed the risk of damane to be low.

When landed on the surface, the lander could also be damaged by materials falling from the plumes. The team has assumed that any damage due to this would be minor and in the case of major damage, it would give data about the composition of the plumes.

ID	Summary	L	C	Tren d	Approach	Risk Statement
1	Landing legs not designed for surface	2	5	Down	M	Since the surface composition is unknown, the legs may not be able to survive the forces. This is being mitigated by overengineering the legs
2	Electronics are damaged by radiation	3	3	Down	M/A	The critical electrical components will be radiation hardened but there may be secondary components which are not
3	EVE collides with plume	1	4	Unch anged	A	While Enceladus has plumes which have particles in it, the chance of damaging the spacecraft has been determined to be small and the team has accepted any risk of damage.
4	Landing spot is not suitable	3	5	Down	R/M	Through the combination of research on the surface of Enceladus and the novel use of the TRN system the risk of attempting a landing at an unsuitable place is being mitigated. The risk still remains high.

5.2.2. Hazard Mitigation

The team designed the lander legs to work with a variety of different surface conditions. The lander pads are wide to spread out the weight of the craft in case the surface is soft. In case the surface is hard the legs have a crush-core inside which can absorb a hard impact on the surface.

The lidar sensor is used during EDL to mitigate the risk of hitting an object or choosing a poor landing location while in EDL. The idea of using data obtained from the spacecraft to determine a suitable landing location without the guide of human input has not been done in a NASA mission to the team's knowledge. Both proposed EDL sequences are designed to give EVE enough time to assess the incoming data from the LIDAR sensor and be able to use the same data to navigate to a safe location. The risk of the software choosing a poor location is mitigated by the pre-selection of a large landing zone that the teams. Using the LIDAR suite to navigate to a safe landing spot, has been tested and is currently being used on Mars 2020. Also on a New Shepard launch, NASA just tested SPLICE which is a TRN system proposed for lunar missions.

To protect the lander against radiation, the team has decided to only use radiation hardened electronics on critical components. Some secondary components may not be radiation harned to cut weight as the mission has a tight weight limit.

With a mission to a planet that may have life, the team will ensure that the lander is constructed and cleaned to planetary protection level of category IVb.

6. Activity Plan

6.1. Budget

Within our budget 400 million U.S. dollars, we covered personnel, manufacturing, equipment, instruments, and materials costs. We also included the travel for the event launch as well as other required information that was requested. 10 team members within our mission with a personnel salary of $80,000 with 28% ERE benefits; our estimated team trip is planned to last for 6 years (our budget also includes travel, meal, and accomodations for the entire team). Other direct costs include science instruments, components, materials, and facility costs (thermal LIDAR cameras).

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

NASA L'SPACE Mission Concept Academy Budget - *Enceladus Volatile Explorer - EVE*

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Yr 6 Total	Cumulative Total
PERSONNEL							
Science Team	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	**$ 1,440,000.00**
Engineering Team	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	**$ 2,400,000.00**
Administrative Team	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 160,000.00	**$ 960,000.00**
Total Salaries	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 800,000.00	**$ 4,800,000.00**
Total ERE	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 223,280.00	**$ 1,339,680.00**
TOTAL PERSONNEL	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	**$ 6,139,680.00**
TRAVEL							
Total Flights Cost	$ -	$ -	$ -	$ -	$ -	$ 3,455.00	**$ 3,455.00**
Total Hotel Cost	$ -	$ -	$ -	$ -	$ -	$ 2,356.00	**$ 2,356.00**
Total Transportation Cost	$ -	$ -	$ -	$ -	$ -	$ 1,200.00	**$ 1,200.00**
Total Per Diem Cost	$ -	$ -	$ -	$ -	$ -	$ 1,420.00	**$ 1,420.00**
Total Travel Costs	$ -	$ -	$ -	$ -	$ -	$ 8,431.00	**$ 8,431.00**

OTHER DIRECT COSTS							
Total Outsourced Manufact	$ 16,262,000.00	$ 16,262,000.00	$ 16,262,000.00	$ 13,265,000.00	$ 16,262,000.00	$ 16,262,000.00	$ 94,575,000.00
|> Science Instrumentation	$ 13,262,000.00	$ 13,262,000.00	$ 13,262,000.00	$ 13,262,000.00	$ 13,262,000.00	$ 13,262,000.00	$ 79,572,000.00
|> Other COTS Component	$ 3,000,000.00	$ 3,000,000.00	$ 3,000,000.00	$ 3,000.00	$ 3,000,000.00	$ 3,000,000.00	$ 15,003,000.00
Total In-House Manufacturi	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 24,720,000.00
|> Materials and Supplies	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 4,120,000.00	$ 24,720,000.00
Total Equipment Cost	$ 13,600,000.00	$ 13,600,000.00	$ 13,600,000.00	$ 13,600,000.00	$ 13,600,000.00	$ 13,600,000.00	$ 81,600,000.00
|> Manufacturing Facility C	$ 12,000,000.00	$ 12,000,000.00	$ 12,000,000.00	$ 12,000,000.00	$ 12,000,000.00	$ 12,000,000.00	$ 72,000,000.00
|> Test Facility Cost	$ 1,600,000.00	$ 1,600,000.00	$ 1,600,000.00	$ 1,600,000.00	$ 1,600,000.00	$ 1,600,000.00	$ 9,600,000.00
In-House Manufacturing M	$ 8,860,000.00	$ 8,860,000.00	$ 8,860,000.00	$ 8,860,000.00	$ 8,860,000.00	$ 8,860,000.00	$ 53,160,000.00
Total Direct Costs	$ 43,865,280.00	$ 43,865,280.00	$ 43,865,280.00	$ 40,868,280.00	$ 43,865,280.00	$ 43,873,711.00	$ 131,040,000.00
Total MTDC	$ 23,465,280.00	$ 23,465,280.00	$ 23,465,280.00	$ 20,468,280.00	$ 23,465,280.00	$ 23,473,711.00	$ 49,440,000.00
FINAL COST CALCULATIONS							
Total F&A	$ 2,346,528.00	$ 2,346,528.00	$ 2,346,528.00	$ 2,046,828.00	$ 2,346,528.00	$ 2,347,371.10	$ 13,780,311.10
Total Projected Cost	$ 46,211,808.00	$ 46,211,808.00	$ 46,211,808.00	$ 42,915,108.00	$ 46,211,808.00	$ 46,221,082.10	$ 273,983,422.10
Total Cost Margin	$ 13,863,542.40	$ 13,863,542.40	$ 13,863,542.40	$ 12,874,532.40	$ 13,863,542.40	$ 13,866,324.63	$ 82,195,026.63
Total Project Cost	$ 60,075,350.40	$ 60,075,350.40	$ 60,075,350.40	$ 55,789,640.40	$ 60,075,350.40	$ 60,087,406.73	$356,178,448.73
********** Do not change percentages in the boxes below unless mission concept instructions specify otherwise.							
F&A %	10%	10%	10%	10%	10%	10%	
Manufacturing Margin	50%	50%	50%	50%	50%	50%	
Total Cost Margin	30%	30%	30%	30%	30%	30%	
ERE - Staff	28%	28%	28%	28%	28%	28%	

6.2. Schedule

The desired launch date is planned to be around 2028 since the planned trip will take about six years, by our calculations. This is because the alignment of Saturn and Jupiter only happens every 20 years or so. That way, we will be able to get to the final destination by 2035 so that the alignment is estimated to be great for gravitational assist. The following schedule shows the team's missions to Enceladus:

Starting with Phase A, the team will conduct the conceptual studies and the preliminary analysis where it sets a purpose for the mission.

During Phase B outlinings, schedules, details, and budget will be taken into consideration while creating the PDR.

Phase C will start and complete the design with all the required steps.

Phase D will focus on construction and building of the designs.

Phase E is when the lander EVE has landed and started its mission on Enceladus. A 1-month testing period will be conducted in order to ensure that the lander is capable of productive operation towards a successful mission.

Phase	Date	Title	Description	Duration
Pre-A	9/28/2020	Conceptual Study	Theoretical mission assignment	6 months
A:	10/6/2020	Preliminary Analysis	Set purpose for the mission	6 months
B:	9/28/2021	Definition	Schedule and budget for the mission	1 year
C:	9/28/2022	Design	Lander design	1 year
D:	9/28/2024	Development	Lander and instruments assembly	2 years
Launch:	5/10/2028	Desired Launch Date	Rover Launch	1 day
Pre-E	5/11/2035	Testing		1 month
E:	3/10/2035	Operations	Mission on Enceladus, data collection	11 months

6.3. Outreach Summary

Executive Summary: The goal of our team regarding public awareness is to work towards increasing public awareness and appreciation for the sciences. A thorough outreach plan is needed to not only give an overview of what our mission is accomplishing, but also why and how it directly impacts people on earth.

Approach: The outreach team will work on:

- Using resources such as the Internet, Public Affairs Office, publications, engineers, etc.
- Creating partnerships with appropriate outside groups and organizations
- Providing observation opportunities with the public by building a communications network and having talks at local K-12 schools

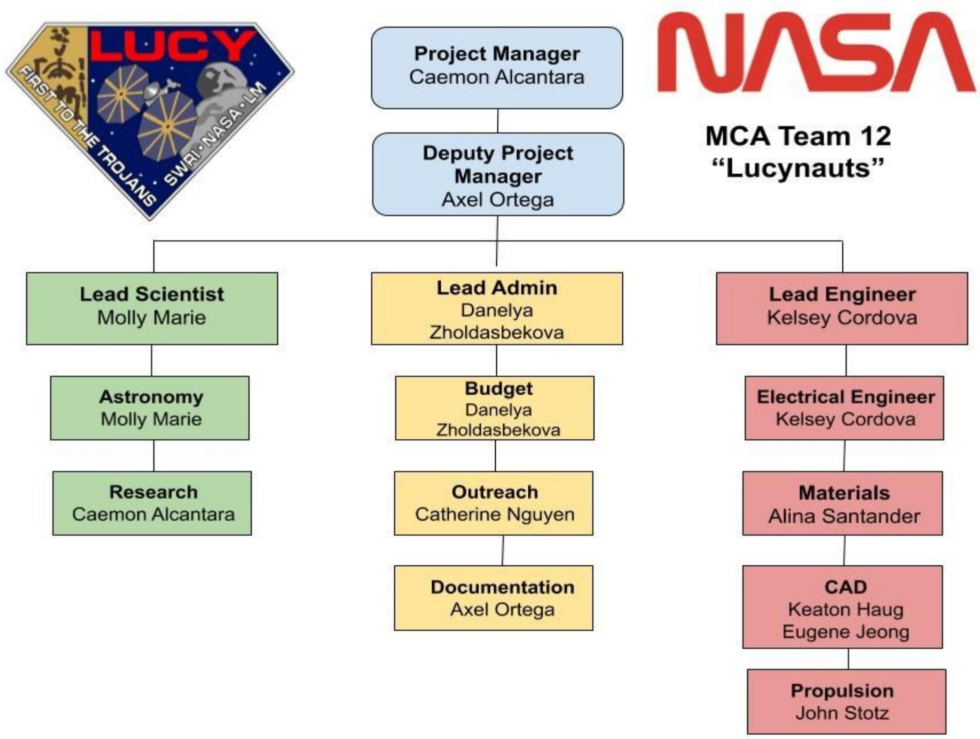
Outreach and Communications Program Plan:

- Draft weekly press releases on the Enceladus mission that can be sent to local K-12 schools, email list of citizens
- Attend local conferences that involve science and space (such as SpaceCom Conference)
- Reach out to local K-12 schools and create programs similar to StarLab, a portable planetarium that engages students on astronomy
- Have Q&A sessions at local K-12 schools with NASA engineers, so that students can ask questions about the mission and get answers directly from the source
- Work with museum programs such as the American Museum of Natural History to create interactive and visual displays of the mission

6.4. Program Management Approach

The team has been organized based mainly where each member thought their individual strengths lied. For instance, anyone with an engineering or similar major decided to be a part of our engineering team. Other team members who are non-STEM majors decided to be in the team of business administration of our project. Team leaders chose to be team leaders if they decided they wanted to be in charge of assigning and taking charge within workloads of the team needs for the project. The mission was approached by gathering as much information on Enceladus as it was possible and by discussing multiple viewpoints and brainstorming where it was thought scientifically to be the best landing spot. The team worked separately but came together before going off into our individual research, studying, designing, and brainstorming as a team while bringing all ideas to each other throughout. Initially, it was hard to decide on a mission objective, however the team ended up finding an objective of exploration to see if the possibility of life thriving in Enceladus' atmosphere is possible. All in all, it took much discussion and thorough understanding of Enceladus' atmosphere and the team's capabilities to conclude on a mission.

A common problem that arose during this time is the lack of time when everyone is available. There was never a time when everyone was able to meet and discuss the project together. In turn, that made it difficult to assign tasks. Furthermore, the team leads also struggled to meet up and communicate since school this semester was more challenging than any previous semesters. This led to an imbalance of task workload between the members as others missed meetings and couldn't help as much. This issue was addressed by making a task and announcement channel on discord so that everyone can see what tasks everyone was doing and how others can help. Additionally, more meetings happened to make sure everyone is on top of their task.



7. Conclusion

To land on Enceladus EVE will use the 3D Imaging Cubesat Lidar for Asteroid and Planetary Science (ICLAPS) to create a 3D map of the surface and will use that map to determine a safe landing spot in real time. There were two different EDL sequences developed. The primary one, which takes less time and more fuel, does not complete a single orbit after detect and instead cancels most horizontal velocity and then falls in a circle around the landing zone. The secondary path orbits once over the landing site and then burns to land on the next pass while taking a shallower attack angle. To power the descent EVE will have 6 MR-103J Hydrazine engines which have been used in previous space missions. EVE's computer will be a chip from NASA's High-Performance Spaceflight Computing project with a clock speed of 800MHz and 256MB of RAM. The chip will be used for both the EDL sequence on on-surface activities.

The mission to study the volatiles in Enceladus' atmosphere using the NIRVSS will be available for other scientists to observe once the data is sent back to Earth using an X-band High Gain Antenna utilizing the Deep Space Network. ICLAPS will be used as a camera when EVE becomes stationary, allowing pictures of the surface of Enceladus to be sent to Earth. Assuming that the landing is safe and remains in operation, the lander will remain at an internal temperature of 273K with the help of Minco's Thermal-Ribbon Surface Sensor, the Radioisotope Heater Unit and the High-Performance Spaceflight Computing (HPSC) project. These will all be powered by either 13 Ah or the 55 Ah Lithium-Ion battery by Eagle Picher.

In the future, the next milestone would be testing how well all the payload and scientific instrumentations work with each other. It would be interesting to see them function as a whole and making tweaks so that they could work with minimal interference with each other and optimizing their performance. After that could be testing them in various environments to check the validity of the instrumentations that were chosen.

If there was more time, ANSYS and FEA would have been more specific and given us more accurate results in simulating the heat map. It would have given us a better idea of how EVE would survive the trip down at Enceladus' surface.

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