NASA L’SPACE Mission Concept
Academy Preliminary Design Review
Enceladus Ground-Based Geyser Observer (EGGO)

Team 44
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1. Introduction and Summary

1.1 Team Introduction

<table>
<thead>
<tr>
<th>Name</th>
<th>Major</th>
<th>Description: School, location, skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devon Taylor</td>
<td>Mechanical Engineering</td>
<td>Pasadena City College, Pasadena. Leadership Engineering and Scientific Knowledge Experience</td>
</tr>
<tr>
<td>Aliza Orjalo</td>
<td>Business Law</td>
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</tr>
<tr>
<td>Austin Duong</td>
<td>Mechanical Engineering</td>
<td>Pasadena City College, Pasadena. Mechanical Engineering. CAD and MATLAB</td>
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</tr>
</tbody>
</table>

Table 1: Team Introductions
1.2 Mission Overview

1.2.1 Mission Statement

The goal of the Enceladus Ground-based Geyser Observer (EGGO), a discovery class mission lander is to explore the southern hemisphere of Enceladus, one of Saturn's moons. Particularly in the tiger stripe region of the Damascus Sulcus, a fissure in the moon’s icy crust which periodically releases oceanic contents in the form of plumes. The lander aims to shed light on the oceanic chemistry and organic compounds contained in the ice geysers by using an inductive coupled plasma mass spectrometry (ICP-MS) and special techniques in situ EGGO will be able to gather data on proteomics and mass to charge ratios to determine the habitability of the oceanic moon and potential biological compounds contained within the plumes.

The significance of studying Enceladus gives a better idea of the habitability of life outside the goldilocks zone. The Goldilocks zone refers to the habitable zone around a star, where the temperature is just right - not too hot and not too cold - for water to exist in liquid form on the surface of the planet.

1.2.2 Mission Requirements

Since the mission aims to reach one of Saturn’s moons and perform research on Enceladus's erupting fissures, the spacecraft travel has to cover quite a significant distance—a minimum of three years for a one-way trip. Without onboard
maintenance, it is vital to the mission’s success to have a highly efficient and sustainable spacecraft throughout the duration. Therefore, the spacecraft must meet the following constraints to ensure a compact and durable design: overall mass is limited to 77kg (170lbs), including EDL components; volume during flight (stowed configuration) must stay within 51cm X 51cm X 76cm (20in x 20in x 30in); and budget is capped at $400M or less.

For the science requirements it is required that the samples collected must be the size of a milliliter in volume in order to be processed by the flow injection analysis chamber (FIAC). The FIAC is required to have an output of 500 samples an hour in order to meet the science expectation of production of at least a thousand samples for the mission duration.

For the ICP-MS it is desired that the resolution should reach at least 6000 to 8000 (unitless). And additionally given the short lifespan of a mission it is expected that the spacecraft produce around 500 samples before expected loss of power.

1.2.3 Mission Success Criteria

In order for the spacecraft to be considered a full mission success it must meet these three criteria: successfully land on the surface, obtain science results, and transmit meaningful interpretable science results.

In order for the Spacecraft to land on the surface successfully the spacecraft must be able to successfully deploy the landing legs and activate the thruster motors prior to landing for surface touchdown.

For a successful mission defined by the science criteria, a significant concentration of biomarkers and specific indicative chemical compounds listed above are the judging criteria whether Enceladus is a potential habitable celestial body and to what degree of life does the moon have. This should be rather easy because of the capability of the mass spectrometer to determine the presence and the amount of chemical compounds and structures and readily quantifiable.

Mission success criteria is defined by the science team as a successful production of at least 500 samples (250 proteomics and 250 mass to charge ratio) and the transmission and confirmation of sample data. The results of the data are not too relevant to success such as the presence of biological life or the lack of. The threshold defined as significant concentration of biomarkers is approximately 100 parts per million molecules. The samples will also be compared to extreme environments on Earth such as hydrothermal vents and other areas where
extremophiles live to determine habitability.

1.2.4 Concept of Operations

Phase I: Launch

The launch of a spacecraft comprises a period of powered flight during which the vehicle rises above Earth's atmosphere and accelerates at least to orbital velocity. Powered flight ends when the rocket's last stage burns out, and the spacecraft separates and continues in freefall. The launch of a spacecraft comprises a period of powered flight during which the vehicle rises above Earth's atmosphere and accelerates at least to orbital velocity. Powered flight ends when the rocket's last stage burns out, and the spacecraft separates and continues in freefall.

Phase II: Transit / Cruise

After launch, the shuttle is commanded to arrange for transit /cruise. The spacecraft can take up to several years to get to Enceladus. During this extended period of time, telemetry can be used to analyze the wellbeing of the shuttle, along with examining how well it survived its dispatch.
Phase III: Orbit

Once the spacecraft encounters Enceladus for the first time, it will undergo a process called the orbit insertion. This process places the spacecraft at precisely the correct location at the correct time to enter the moon's orbit along with controlled deceleration. As the spacecraft’s trajectory is bent by the moon’s gravity, the command sequence aboard the spacecraft should fire its engine and perform a retro-burn to slow down the vehicle. If this were to fail, the spacecraft would continue to fly past Enceladus so the timing of this portion is crucial. However, if the orbit does succeed, the spacecraft can adjust its orbit via aerobraking, and allowing more control for the spacecraft to descend upon the atmosphere.

Phase IV: EDL

Entry, descent, and landing could be the shortest and the most intense part of this mission. The lander will be deployed from the orbiter and use thruster motors to slowly guide the spacecraft to the target landing location. The lander will then use its landing legs to situate it into a stable and upright position.

Phase V: Surface Operations

Once the lander is on its target position, it will use its landing legs to situate itself into a stable and upright position. From there, it will passively gather samples ejected from the plumes from a large funnel-like dish from above. The samples will be collected and melted inside the spacecraft and analyzed by the science instruments. The lander itself must be built with strong insulation to resist the high wind speed and freezing temperatures while gathering data from the plumes. Other than the funnel that collects data, the scientific instruments analyze the particles inside the lander in order to avoid damage from the freezing environment. In order to save energy, the instruments will only be turned on once there have been enough particles gathered in the funnel.

Phase VI: Sending Data

Once sufficient data has been collected, the lander will use a low gain antenna to transmit its data from Enceladus to Earth. Due to the harsh environment, the antenna system will be idle until enough data has been gathered from the falling particles. The data will be received within the Deep Space Network (DSN). The DSN is an international network of facilities managed and operated by JPL and it supports interplanetary spacecraft missions such as this one.
1.2.5 Major Milestone Schedule

In Phase A: The team will create a concept for a self-sustaining spacecraft for a minimum 2.25 year long journey. Spacecraft’s mission is to digestion and analyze plume particulate. The lander will be built with a compact design and include sampling funnel and inductive coupled plasma mass spectrometer to gather data. In this phase key trade studies will be performed to determine the suitable technologies for the mission. The team will study the surface temperature of Enceladus so we can choose the best material that can withstand the cryogenic temperatures.

In Phase B: Definition: In this phase, the team will develop a prototype lander from the system baseline based on the mission requirements and success criteria. It is expected that this might take a majority of a year to evolve a lander design to a sufficient level of maturation. Additionally this phase will be establishing plans of manufacturing and assembly from the prototype lander design. This lander would need to be compact and utilize a durable design with an overall mass limited to 77kg (170lbs), including EDL components; volume during flight (stowed configuration) must stay within 51cm X 51cm X 76cm (20in x 20in x 30in).

In Phase C & D: Designs & Development: For this phase, the team will begin building and creating systems that will come together to operate as a lander which will explore ocean chemistry and organic compounds contained on the ice geysers. The estimated time for manufacturing is approximately a year and half for complete manufacturing 8 months to a year and a half. To test whether the lander is equipped for impact, our team will conduct shock tests to ensure the protective covering will withstand the launch.

In Phase E: Mission Ops & Data Analysis: The spacecraft once deployed from the orbiter will land safely on the surface of the Enceladus. When it is deployed it will use the onboard scientific instruments to conduct the experiments needed to satisfy this mission science goal. Then it will transmit the necessary science data to the orbiter which will relay the data to science teams on earth to process the results. This cycle will be carried out as many times as needed to satisfy the mission requirements. After sufficiently meeting mission success criteria the spacecraft will cease operations and shutdown and remain on the surface.
1.3 Descent Maneuver and Landing Summary

One of the most important stages of a mission and another planet is the entry, Descent and Landing (EDL) stage. If unsuccessful, the entire mission will be considered unsuccessful. In this paper, a simplified star averaging model is used to simulate the EDL conditions encountered by earlier angles to the planet with model predictions evaluated based on observed measurements.

The lander will launch from the orbiter and use rockets to safely guide itself down toward the surface. Onboard accelerometer data will help manage the use of the rockets to provide balance. The landing gear will then help stabilize it and provide a softer landing once touching the surface.

The presence of an atmosphere was assumed to be so thin and insignificant that it would not affect the lander EDL. Therefore, our cruise will not be equipped with a parachute. We have noticed that Enceladus is mostly covered by fresh, and clean ice, which made it one of the most reflective bodies of the Solar System. Consequently, its surface temperature at noon only reaches −198 °C (−324 °F), far colder than a light-absorbing body would be. Hence, the cruise will not be equipped with a heat shield as well.

One requirement was that the landing site must be close enough to the equator.
This ensures that the lander’s will get maximum direct sunlight keeping the lander warm. The landing spot would be (-34.806°N, 29.714°E). The expected temperature at this location is about 80 Kelvin degrees.

As expected, the Cruise will enter the Entry Interface at an altitude of 35km away from the Enceladus surface with a speed of 177.2m / s. After that, the speed of the cruise will increase gradually because of the attraction of Enceladus. The cruise module is also equipped with an active surface sensing system to precisely orient and guide the landing craft on the appropriate terrain. This sensor will receive surface information of Enceladus and transmit data with the central processor. This Data collection system will be activated when the ship at 4.2km underground collects surface information to ensure landing.

At an altitude of 2.1km from the ground, the speed of the cruise will reach a maximum of 197m /s and the back shell will be separated from the cruise to release the rover. Simultaneously, three thrusts from the rover will be activated ensuring the rover will decelerate to the velocity of 0.75m/s and land on the surface of the enceladus. The EDL state ends when the rover landed on the surface of the enceladus.
Throughout the EDL state, energy is only needed when the Heat Shield is separated and the cruise achieved the velocity of 80-110m/s, and the altitude of 2,100m above the surface of the Enceladus. Based on that data, we can estimate the energy consumption in EDL State of the cruise is as the table below.

<table>
<thead>
<tr>
<th>State</th>
<th>Time needed (mins)</th>
<th>Altitude</th>
<th>Expected Velocity (m/s)</th>
<th>Energy needed (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise Stage Separation</td>
<td>E - 10min</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Cruise Balance Mass Device Separation</td>
<td>E - 7min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry Interface</td>
<td>E + 0</td>
<td>35 km</td>
<td>177.2</td>
<td>0</td>
</tr>
<tr>
<td>Radar Ground Solution and Lander Vision System Solution</td>
<td>E + 164s</td>
<td>4.2 km AGL</td>
<td>196</td>
<td></td>
</tr>
<tr>
<td>Safe Target Selection</td>
<td>E + 175s</td>
<td>2.1 km</td>
<td>197</td>
<td>0</td>
</tr>
<tr>
<td>Mobility Deploy</td>
<td></td>
<td>20.7 - 14.5 m</td>
<td>0.75 m/s</td>
<td></td>
</tr>
<tr>
<td>Touchdown</td>
<td></td>
<td></td>
<td>0.75m/s Vertical</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: EDL Expected Values

The change in kinetics energy of the cruise is equivalent to the energy needed to approach the expected last altitude with the expected velocity.
\[ \Delta KE = \frac{1}{2} m \times (v_{ini}^2 - v_{final}^2) \]
\[ = \frac{1}{2} \times \frac{170\text{lb}}{32.2\text{ft/s}^2} \times \frac{0.4536\text{kg}}{\text{lb}} \times \left[ \left( \frac{197\text{m}}{s} \right)^2 - \left( \frac{0.75\text{m}}{s} \right)^2 \right] \]
\[ = 46.5\text{KJ} \]

Figure 5: Kinetic Energy Calculations

Here below is the graph of altitude and velocity of the cruise vs. time.

![Altitude vs. time graph](image)

Figure 6: Altitude vs. Time Graph

Graph above showing the relationship between altitude vs. time when the cruise approaches the Entry Interface (35km from the ground) to mobility deployment (2.1km from ground). Total time for this period is 175s.
The graph above shows the relationship between velocity vs. time from the cruise approaches the Entry interface (35km from the ground) to mobility deployment (2.1km from ground). The speed of the lander when entering the Entry Interface stage is 177.2m / s, then steadily increases and reaches a maximum of 197m / s at an altitude of 2.1km from the ground. Total time for this stage is 175s.

The graph above shows the relationship between velocity vs altitude from the cruise approaches the Entry Interface (35km above ground) until mobility deployment (2.1km above ground). The speed of the lander when entering the
Entry Interface section is 177.2m / s, then steadily increases and reaches a maximum of 197m / s at an altitude of 2.1km from the ground.

### 1.4 Payload and Science Instrumentation Summary

<table>
<thead>
<tr>
<th>Name</th>
<th>Function/ Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multilayer Insulation (MLI) (passive) Radioisotope Heater Units (active) A single RHU weighs just 42 grams and can fit in a cylindrical enclosure 26 mm in diameter and 32 mm long.</td>
<td>Heating: The MLI consists of multiple thin layers of sheets which is intended to reduce heat loss by thermal radiation. The RHU is a small device which generates heat by radioactive decay.</td>
</tr>
<tr>
<td>Battery Lithium Ion</td>
<td>Powers systems: An eco-friendly and high energy density rechargeable battery</td>
</tr>
<tr>
<td>Antenna Low-Gain Antenna (LGA) 33.5 cm length x 2</td>
<td>Communications: An omnidirectional antenna with a broad radio wave beam width which allows for the signal to promulgate fairly well regardless of the adverse terrain and regions. This allows for efficient communication through mountainous ranges on the moon.</td>
</tr>
<tr>
<td>Inductive coupled plasma mass spectrometry metal-coded affinity tags (MeCAT))</td>
<td>Analyze samples (on filter/capturing object):</td>
</tr>
<tr>
<td>electrothermal vaporization device(EVD) flow injection analysis chamber(FIAC)</td>
<td>Melts sample for the FIAC Prepares and Injects reagent into sample</td>
</tr>
</tbody>
</table>
For the heating system two types of insulation were chosen for this spacecraft. One will be a passive system in which systems would statically retain heat by using multiple layers of heat insulating material. Additionally, the spacecraft is equipped with radioisotope heater units which would be strategically placed around key temperature sensitive areas. Such as the science payload, communication, and onboard computer systems.

For the batteries from the team’s research it was determined that a very reputable and high-energy-density battery lithium-ion was the clear winner with weight and power density. For the mission based on spacecraft power consumption, the spacecraft will carry 15 kilograms worth of batteries on the lander. For an estimated time of 2 hours and 45 minutes of surface operations.

For communication systems on the Lander it was determined that two low gain antennas will communicate in the ultra high frequency range to the orbiter. These antennas were mainly chosen due to sizing constraints as most of the existing systems would not fit on the spacecraft.

As for the science instrument of choice we chose a high-performance liquid chromatography inductively coupled plasma mass spectrometer due to high performance and accuracy of measurements. Additionally, the system has two step processes prior to ensure sample purification. With metal coded affinity tags it would be easy to identify the key proteins necessary for life. Additionally, this system can run without the reagent allowing it to process samples typical of a normal mass spectrometer and yield mass to charge ratio data.

The electrothermal vaporization device was chosen because we wanted to be able to reduce the sample size to about a milliliter in volume, which would then be processed by the fluid injection chamber, a cheap and effective way output a lot of samples and be able to control the different types of data we would be able to
obtain. As mentioned prior the system is capable of producing proteomics or standard mass to charge ratio data.

For rocket engines the system uses simple thruster engines because the design does not require us to have such high performance engines on a small body that has low gravity. Additionally this system was chosen for its simplicity versus other propulsion systems such as liquid propulsion which would add to mission complexity.

The team decided to go with a custom computer system so that all systems will interface properly because existing space computer systems would not work with the existing design. Additionally when manufacturing it would make it much easier to coordinate because the system would be made in house.

2. Evolution of Project

2.1. Evolution of Descent Maneuver and Lander

Initial idea for the mission concept was a rover is based on the idea of a movable science laboratory which would be able to perform analysis anywhere on the surface. However this idea was turned down because of several reasons: The rover would have difficult navigating terrain such as hill and valleys given the current dimensional requirements. Fitting all the necessary hardware into a constrained size would also be a major challenge, and finally because the chosen power source was not able to make the mission feasible.

Touch and Go (TAGS): This spacecraft idea was a two stage sample gathering method. Initially, as the spacecraft descended, it would gather data, similar to a fly by. Then once it got close to the plume it would capture samples directly from the ejected particles. While the idea seemed creative it posed several challenges. For one, it did not meet the mission requirements of landing on the surface. Additionally, this would only allow the collection of 1 sample and nothing more. However, if this idea was possible, it would have allowed a fast mission with low power requirements. Additionally, with more research and development, more TAGs could be possible.

Lander: This is the team’s final and chosen design. The spacecraft will guide itself and land on the surface of the moon where it will situate and anchor itself. From there, it will passively gather samples from the ejected plumes nearby from the
funnel on top. Compared to the TAG design, the lander is more feasible and more reliable due to the fact that it can capture multiple samples. When compared to the Lander, it deals with the biggest problem of power since the lander only needs to sit idly and turn on when the samples need to be processed.

2.2. Evolution of Payload and Science Instrumentation

The original scientific payload was to be a panoramic camera, an ice core drill and a mass spectrometer. Originally we were going to gather 3 types of scientific data. The first of which would be photography which would be of great geological interest because of the fissures on the surface and being able to examine the imagery could help further theorize the geological structure of the surface. Secondly, from ice core samples we could determine the flow rate of the plume by the thickness of the layers, additionally the ice core sample could be used to feed into the mass spectrometer which would then be analyzed and determine chemical compounds and perhaps biological signatures. However, when reviewing the power constraints having this many instruments was simply not feasible. So for the scientific payload for the second iteration the team went more conservative and went with an ICP-MS and a sampling funnel because of the enormous cost for power-wise and monetary wise of the science payload. It was then realized that by adding a low cost equipment (flow injection analysis chamber) with relatively low power cost, we can automate the sampling process and perform two different kinds of mass spectrometry proteomics, and mass charge ratios. Which led to the current third iteration of the science payload.

2.3. Evolution of Mission Experiment Plan

The first mission iteration was to gather data from different plumes from high altitude and plume particulate from the surface additionally ice samples, and photographs. From these three types of data, we would be able to assess habitability and biotic presence. However, because of mission constraints this was not a viable plan and for the reasons stated prior. So for the second mission iteration the mission focused on gathering data from plumes particulate on a single location for the second iteration with the equipment mentioned in the prior section. With the idea listed above the science team made instruments for the third iteration the team focused on early prebiotic life forms such as proteins and precursor chemical structures indicative of an environment suitable for life.
3. Descent Maneuver and Lander Design

3.1. Selection, Design, and Verification

3.1.1. System Overview

Figure 9: Preliminary Sketch of the Lander
### Table 4: Total Weight of the Lander

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass</th>
<th>Count</th>
<th>Total Mass (lbm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Plate</td>
<td>6.6283</td>
<td>1</td>
<td>6.6283</td>
</tr>
<tr>
<td>Leg</td>
<td>1.1508</td>
<td>6</td>
<td>6.9048</td>
</tr>
<tr>
<td>Hull</td>
<td>11.5305</td>
<td>1</td>
<td>11.5305</td>
</tr>
<tr>
<td>Funnel</td>
<td>20.2069</td>
<td>1</td>
<td>20.2069</td>
</tr>
<tr>
<td>ICP</td>
<td>30</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Rocket</td>
<td>3.74786</td>
<td>3</td>
<td>11.24358</td>
</tr>
<tr>
<td>Flow Injection Analysis Chamber</td>
<td>11.0231</td>
<td>1</td>
<td>11.0231</td>
</tr>
<tr>
<td>Batteries</td>
<td>16.5347</td>
<td>2</td>
<td>33.0693</td>
</tr>
<tr>
<td>Battery Covers</td>
<td>1.814</td>
<td>2</td>
<td>3.628</td>
</tr>
<tr>
<td>OBC</td>
<td>0.264555</td>
<td>1</td>
<td>0.264555</td>
</tr>
<tr>
<td>LG Antennas</td>
<td>~1.3</td>
<td>2</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>~137.129</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>62.20066811 Kg</td>
</tr>
</tbody>
</table>

Figure 14: Top View of Lander
The lander will utilize several monopropellant rockets attached to the base of the spacecraft. Specifically we will use a purchasable monopropellant rocket by the model of MPS-130-1U. These rockets will guide its descent slowly and safely onto the surface of the moon. The chosen monopropellant will be Green (AF-M315E) due to it being strong, effective, and plentiful. Additionally, it gives more thrust compared to hydrazine although it is slightly heavier. The rockets are started by an electrical signal which opens a valve and once the fuel and catalyst come in contact, it ignites. This electrical signal can be activated at a certain elevation or at a specific speed measured by an accelerometer. All of this data will be taken care of by the On-Board Computer; specifically the OBC-P3 Versatile Onboard Computing Platform from Space Inventor.

Additionally, there will be landing gear on the bottom of the spacecraft, to make sure it can stand upright, and absorb the impact when landing.

Monopropellant rockets were the best option for this mission because a parachute would not work well with the thin atmosphere on Enceladus. Additionally, there is no need for a heat shield due to the thin atmosphere on the moon, compared to Earth’s thicker atmosphere which would generate a large amount of heat upon descent. The rockets also help by making sure the spacecraft can land upright since it will slow the descent velocity.

3.1.2. Subsystem Overview

The descent and landing system is very simple and consists only of the monopropellant rockets and the landing gear. Both systems will be attached directly to the bottom base and will be readily available. The rockets will slow the descent of the spacecraft as well as ensuring that it is upright. This can be done with the combination of telemetry data and the rockets which can propel different amounts of forces to ensure the spacecraft is balanced.

3.1.3 Dimensioned CAD Drawing of Entire Assembly

**Current Height: 29.625 in**
- Baseplate: 2.5 in
- Hull: 15 in
- Funnel: 10 in
- Landing Leg: 2.125 in
**Current Width: 20 in**
- Funnel: 10in Radius = 20 in Diameter
Figure 15: Dimensioned View of Height

Figure 16: Dimensioned View of Bottom Width
3.1.4. Manufacturing and Integration Plans

The overall design can be broken down into 4 major components that need to be manufactured which are: Sample collection funnel, main hull, bottom plate and the landing gear.
The funnel and landing gear will take more precision but overall should be still manufacturable. These parts will need to be outsourced to a manufacturing shop to ensure the parts are created professionally and efficiently. In total the components may take anywhere from 3-6 months to manufacture.

To ensure the parts fit together, an updated CAD model will be used to demonstrate the locations for connecting bolts and/or plates. Additionally, the software can be used to run stress analysis to test the strength of the bolts and connectors to ensure that it meets any standards/requirements.

3.1.5. Verification and Validation Plans

For each of the 4 major components, team members must ensure that the product was manufactured correctly. Additionally, team members should stay in close contact with the manufacturer to ensure that every step taken is correct.
Similarly, for assembly, members must ensure that all parts are correct, such as the specific screws and washers. Several team members should be on standby to make sure that the assembly is correct.

Once the first assembly is made, it will be tested on to see how it handles possible stresses and temperatures. The most important part that needs to be stressed is the landing legs because those pieces will impact with the surface. Ideally, a prototype assembly should be made with all of the major components then there will be a stress test on the assembly as whole. This will allow us to find any physical failure on the components and any connections. Additionally, a stress test in a freezing environment would also be required to ensure that the component can still handle the forces with similar temperatures to Enceladus. A second assembly may need to be made to address changes or to have a new one available for the mission.

Additionally, we should run a physical test that can simulate sample collection from the plumes. This will help ensure that the lander prototype and design is able to collect samples and able to run the samples through the Flow Injection Analysis Chamber and the ICP. Furthermore, we should test the communication systems to make sure it can send the data from the lander to the orbiter based on the maximum distance the orbiter is from the lander. These tests will ensure that the lander can fully complete the mission requirements of collecting and analyzing the samples to gather and send data to the orbiter.

### 3.1.6. FMEA and Risk Mitigation

<table>
<thead>
<tr>
<th>Component and Function</th>
<th>Failure Mode</th>
<th>Cause</th>
<th>Affects</th>
<th>Rating</th>
<th>Recommended Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing Gear: Allow the spacecraft to land</td>
<td>Landing Gear breaks/physical failure</td>
<td>Crash landing on impact with surface</td>
<td>May cause lander to land unevenly</td>
<td>6</td>
<td>1. Review material choice for landing gear to make sure it does not fail 2. Run tests to ensure landing gear and take all the force 3. Apply shock absorbent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>May cause lander to have a rough landing which may break some</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5: FMEA Table of EDL

<table>
<thead>
<tr>
<th>Function</th>
<th>Failure Mode</th>
<th>Impact</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monopropellant Rockets:</td>
<td>Rocket fails to activate</td>
<td>Computer does not send current to activate</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>May cause lander to land unevenly/tip over</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>May cause a harder landing</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Ensure landing gear can withstand extreme forces from a possible freefall</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Ensure failsafe code to make sure it will activate</td>
<td></td>
</tr>
<tr>
<td>Sample Funnel:</td>
<td>Physical damage</td>
<td>1. Crash landing may dislocate funnel</td>
<td>5</td>
</tr>
<tr>
<td>Collect samples from the plumes passively</td>
<td>2. Plum particles may damage funnel</td>
<td>Can cause trouble in collecting samples</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Ensure the sample funnel can withstand some forces from landing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Ensure the funnel can withstand objects falling onto its surface. (No holes but surface damage is okay)</td>
<td></td>
</tr>
<tr>
<td>Hull:</td>
<td>Physical damage / compromised hull</td>
<td>Crash landing may dislocate hull</td>
<td>7</td>
</tr>
<tr>
<td>Protect science instruments</td>
<td></td>
<td>May cause science instruments to freeze</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Run stress tests on the hull to make sure it can withstand impact and other possible forces</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Ensure insulation can handle a small compromise</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.1.7. Performance Characteristics and Predictions

To ensure a good landing the spacecraft utilizes 6 landing legs. Because we went with a hexagon shaped bottom plate one landing leg per side is perfect. The number of landing legs will ensure a wide area of stability so that when the
spacecraft lands, it will not tip over. The hexagonal shape of the allows a large surface area of the hull while also being lighter than a full square. Additionally, the use of 3 rockets will assist in ensuring the same goal. Again, because the bottom plate is a hexagon, using 3 rockets provides symmetry in thrust so that the lander is stable. Arguably 6 rockets could achieve the same goal but that would be too much weight and too much volume used up under the plate. Similarly, while 3 legs would also provide symmetry, 6 legs would be more beneficial in ensuring a more balanced and stabilized lander which is crucial to collecting data. Furthermore, landing legs are lighter than the monopropellant rockets. However, this is an important factor that should be tested in the future to make sure that 3 rockets and 6 legs is a viable option. There is a chance that more rockets will be needed and thus changes will need to be made.

Using accelerometers on the lander underside, the OBC can use this data in relation to rocket propulsion. This will allow the OBC to help the rocket land upright by changing the fuel input in some of the rockets so that the force of the rockets can help balance the lander. This is especially important because plumes may disrupt the landing angle of the lander. Additionally, it is crucial that the lander is somewhat upright in order for it to obtain samples.

The seasons on Enceladus are estimated to be about 7 years each. Unfortunately, the data about the current seasons are not exact, but an article states that the summer season was in 2015. (Byrd, 2015). Thus the lander which may arrive around 2022 or later which would be around the fall season. While seasons may not be a big factor on such a cold and icy moon, it may alter plume activity.

While the lander only has ~2-3 hours of operation, we plan to only turn it on when we want to analyze the samples. This will be based on a time scale where we will turn the lander on at certain time intervals. This will help conserve power in order to run multiple tests with multiple samples.

The largest threat to the descent and landing is the possibility of plumes disrupting the lander’s angle of descent and landing. This can completely throw off the lander and make it land upside down or sideways. This is important to note because the lander’s passive sample collection system needs the lander to be somewhat upright. Thus the use of the rockets in order to balance the lander are vital to a successful landing.

The team’s location to land in will determine how close we come into contact with the plumes but regardless, we will utilize the rockets to help land upright. Additionally, the location will also determine the particles/samples the lander will
gather as being closer will allow the lander to catch larger particles. However, being closer does also present more risk for the EDL as the plume may disrupt the landing angle.

3.1.8. Confidence and Maturity of Design

The team chose the spacecraft to be a lander due to the multiple constraints placed on the spacecraft. One of the largest factors was energy consumption. A rover would require significantly more power to enable it to maneuver to a plume. Thus that would require larger and heavier batteries. A lander would solve this problem as it only needs to turn on to analyze the samples since it will passively collect the samples. To ensure that the lander can passively collect samples, the design choice was to build a lander that had a funnel at the top to do just that.

As for the landing gear, the team went with landing legs and monopropellant rockets. The rockets will help guide the lander to the surface while attempting to keep it upright. The landing legs are lightweight and will help the lander stay stabilized and upright once it has reached the surface. However, it would be beneficial to consider the different combinations of landing legs and rockets in the future after testing.

There are several important tests that need to be run to validate the design choices. First a thermal test needs to be performed to ensure the lander can withstand very high temperatures and very cold temperatures. Additionally, we need to ensure that the instruments can operate properly under those environments. Another test that should be performed is a simulation of an EDL with some sort of plume-like wind ejector. This will ensure that the rockets can guide the lander upright and that the landing legs can stabilize the lander.

The instruments go through rigorous testing to ensure operation at cryogenic temperatures by testing them in encedulus-like conditions on earth with individual systems and entire components and subassemblies as well. The instruments will be tested through a shake-and-bake test which shakes the instruments to expose potential failure modes. The instruments will also be tested in a vacuum chamber to test its durability in environmental space conditions such as pressure and temperature as well as be tested to cryogenic testing to expose instrument durability in low temperatures.

3.2. Recovery/Redundancy System

The lander will have 2 low gain antennas in case one is broken from the landing. Additionally, low gain antennas will work with a wider range than high gain antennas. The data can be received by both Earth and the Orbiter to ensure successful data
collection. Additionally, data will be transmitted as the samples are analyzed to ensure that no data is lost under the possibility of a power shutoff.

There was the possible idea of having a black box on the lander to contain the data in case of an emergency, but it was deemed unneeded due to the fact that there will be no other spacecraft to come retrieve it. That would take additional money and time that may not be worth it.

3.3. Payload Integration

Most of the science instruments will be contained inside the hull where there will be heating elements to keep all components warm. There will be insulation around the hull to keep the heat in. Additionally the use of several Radioisotope heater units will be used to produce heat to keep the components warm and within operable temperatures.

The bottom plate will house the 3 rockets and any extra fuel that may be needed. Next to the hull, sitting on the bottom plate will be the two batteries that will each have their own casing to shield them from any physical damage and the changing temperatures.

![Figure 19: Inside View of Lander](image)

<table>
<thead>
<tr>
<th>Colored of Object:</th>
<th>Component:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>Inductively Coupled Plasma Mass Spectrometer</td>
</tr>
</tbody>
</table>
As seen from the figure, the FIAC sits directly below the funnel. From there the samples will then be pushed into the ICP below the FIAC. The OBC sits below the FIAC taking a small space and leaving room for the heating elements and where any tubing may go for sample waste. The antennas sit to the side and can protrude through the top to send out signals.

4. Payload Design and Science Instrumentation

4.1. Selection, Design, and Verification

4.1.1. System Overview

The following tables illustrate the components that use power and generate power as well as lists the system type, system name, power cost, and description of components.

<table>
<thead>
<tr>
<th>System Type</th>
<th>System Name</th>
<th>Power Cost (Watts per hour)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>Onboard Computer systems</td>
<td>50</td>
<td>Interprets commands and data</td>
</tr>
<tr>
<td></td>
<td>Power source</td>
<td>-3000</td>
<td>Lithium batteries</td>
</tr>
<tr>
<td>Thermal</td>
<td>Multiple Layer Insulation</td>
<td>0</td>
<td>A passive system of insulation</td>
</tr>
<tr>
<td></td>
<td>Radioisotope heater units</td>
<td>0</td>
<td>Active system using radioactive decay</td>
</tr>
<tr>
<td>Comms</td>
<td>Dual low gain Antenna</td>
<td>20</td>
<td>Communication systems</td>
</tr>
<tr>
<td>Science</td>
<td>Electrothermal vaporization funnel</td>
<td>5</td>
<td>A gravity fed funnel that liquidised</td>
</tr>
</tbody>
</table>
For power systems we decided to use a high energy density but lightweight power source and through research was able to determine that lithium ion batteries rated at 200 watt hours per kilogram of batteries. This determined to be suitable for the mission requirements. The spacecraft needs about 15 kg worth of batteries to operate for an estimated 2 hours and 45 mins based on the table of power consumption.

For thermal systems the team decided to go with an approach that would allow the spacecraft to retain heat in the spacecraft but without having to power them. And based on research it was decided to use radioisotopic heating units and multi-layer insulation around temperature sensitive instruments and hardware would be the best way to keep temperature sensitive equipment safe.

For communication systems the dual low gain antenna system is expected to pull at most no more than 20 watts per hour when in use. Like with most space systems hardware on the lander when not in use, it will remain in idle mode to minimize current draw. The dual low gain antenna was chosen mainly because of sizing constraints due to other communications systems such as high gain antenna would not simply fit on the lander and could cause stability issues.

For science systems it's a three-step data acquisition process starting with the electrothermal vaporization funnel which has a pressure sensor which will then turn on a thermal circuit melting the plume particulate allowing the funnel to trickle down the liquid sample into the fluid injection analysis chamber. A parastasis pump will gradually pump the sample into a mixing coil mixing with a reagent(MECAT) and introduce the sample into the ICP-MS which will perform analysis on the sample. However if the system is running normal to perform mass to charge ratio it will pump the sample directly into the ICP-MS without the reagent.

For the inductive coupled plasma mass spectrometer it operates by vaporizing a small sample and ionizing the gases which pass through a series of interference cones which will separate unwanted particles, and race down hyperbolic poles and

| Flow Injection Analysis Chamber | 20 | Prepares samples for use |
| ICP MS | 1000[1,2] | Measure mass to charge ratio/proteomics |

Table 7: System Overview
collide with the detector unit.

Once sample data has been obtained it will then be transferred to the onboard computer system which will then interpret the results and then relay the results via dual low gain antennas which will communicate them to the orbiter.

![Flow of Command/Power](image)

**Figure 20: Flow of Command/Power**

Following the logical flow of command first is the power system which provides power via lithium batteries to the entire lander systems. Power is provided to the payload instruments (the three step process); the main source of power consumption on the spacecraft would be the ICP-MS. When the ICP-MS has gathered data it will send data to the science data to the onboard computers (data handling) which will then translate and send the data to the communications systems which will then relay the results to the Orbiter.

4.1.2. Subsystem Overview

For guidance systems the onboard computer system will act as an onboard avionics system to guide the spacecraft to the surface and will use the three thruster motors to slow the descent enough that the landing legs can be deployed onto the surface of the moon. Additionally, the onboard computer system will also help
facilitate other systems such as communicating with the science instruments to start/stop it.

Thermals systems will consist of two systems. Passive multilayer insulation and an active system utilizing radioisotope heater units strategically placed around the spacecraft to maximize heat in critical areas. Key areas which are temperature sensitive are: science instruments, computer systems, and communication devices. For heating the spacecraft will use multilayer insulation technology and will use Radioisotope heater units to actively heat instruments and hardware that are sensitive to the cryogenic temperature of the moon.

Our science instruments can be broken up into three components, one for processing, refining, and analysing samples. Below is a brief overview:

Electrothermal vaporization chamber is a funnel plated in conductive metal that will process samples to break them down into sufficient sample size by thermally breaking down the plume particulate so that it can be properly processed by the FIAC.

![Figure 21: FIAC System](Image courtesy of ScienceDirect.com)

FIAC, the flow analysis injection chamber is a process, in which microliters of samples are suspended in a carrier fluid(Matrix) and are mixed with a reagent in this case MeCAT for proteomics. However, if instruments wanted to perform simply just mass spectrometer data the sample would be pumped through without the carrier fluid or reagent. Which would then be analyzed by the mass spectrometer.

For the main science instrument payload the lander will use a quadrupole ICP-MS to measure biological matter and inorganic matter. By varying radio frequencies and voltage to a precise amount particular ions of a specific mass charge ratio can make their way to the detector while others will collide with the
poles on the side. The instrument will gather the data and send the results to the orbit which will then relay it to earth.

Figure 22: ICP System
(Image courtesy of University of Texas at Austin)

The spacecraft will be equipped with two telescopic low gain antennas to communicate with the orbiter in the ultra high frequency band between the 300 megahertz and 3 gigahertz range which will transmit science data.
Above is a model heat flow map of the cold case for the lander on Enceladus.

Majority of the heat losses is through the large hexagonal metal plate on which the landing legs are attached to. The Lander is contacting the surface by 6 points so it would be an estimated -0.66W by heat of conductance, it is also important to note that the heat loss per side is -2.9W on the shorter side while the larger sides facing the viewer is an estimated -5.1W per side. It is important to note that the internal temperature of the lander system will be kept at 265 Kelvin(17.33°F) which sounds extraordinary low but that comes with several benefits such as not having to refrigerate the chemical compounds needed for analysis because of the colder temperatures and not having to have as many heating systems to keep a spacecraft at a higher temperature for example on the lander reducing overall weight of the spacecraft.
Figure 24: Hot Case Heat Analysis

Above is a model heat flow map of the hot case for the lander on Enceladus. The majority of the heat losses through the large hexagonal metal plate on which the landing legs are attached to, but heat loss is significantly less than the cold case due to the less extreme temperatures.

4.1.3. Manufacturing Plan

After the spacecraft has been designed for manufacturing our approach will be to buy off the shelf commercially available units when possible. However when it comes to custom components such as the spacecraft instruments, the ICP-MS will be the responsibilities of trusted manufacturers such as Spectro or Agilent with a good track record who would complete the contracts in a timely record. The manufacturers work closely with the design teams to ensure the quality of manufactured products are up to mission standards while producing and developing the science instruments.

For the funnel, the manufacturing plan is quite simple: It will be a single piece of metal that meets the design requirements withstanding the cold temperatures.
without fatiguing. The manufacturing method will be using additive manufacturing technology (also known as 3D printing) to reduce waste and part fatigue which could potentially increase the part strength.

FIAC will consist of a peristaltic pump, an injector, and a mixing coil that will all be made in house at the jet propulsion laboratory and made of materials such as Polyvinylidene fluoride, a thermoplastic that can withstand the environment of Enceladus and meets mission requirements. Materials such as these can withstand extreme temperatures and have low off gassing and have seen application in the aerospace field. It is expected to be of ease to manufacture and no specialty machinery is necessary to make it other than traditional machinery equipment such as computer numerical control machines, circuit boards fabricators and for the MeCAT a reputable manufacturer in Germany by the name of Proteome Factory in Berlin Germany[4] for use of biomarkers for absolute quantification of proteins.

For the Inductive coupled plasma Mass spectrometer, since this is such a specialty product to make it will be outsourced to manufacturers such a Spectro which have a well established track record in producing performance mass spectrometer instruments. One area of concern is the hyperbolic rods for the quadrupole icp-ms because even the slightest deviation from design tolerances can cause issues such as improper measurements or particles not being able to reach the detector.

More material that is important for the science instruments are the chemical compounds that we will acquire is the argon gas needed for the ICP-MS must be at least 99.999% purity for proper usage.

The circuitry would be custom made in house at a circuit fabrication facility and the computer systems would be assembled in house at the spacecraft Assembly Building in the Jet Propulsion Laboratory, in Pasadena California.

4.1.4. Verification and Validation Plan

The team would follow up closely with the manufacturers to make sure that Geometric Dimensioning and Tolerancing are within acceptable levels and follow lean six sigma protocols to ensure parts are manufactured to the highest quality possible.

For the assembly process the team would verify design requirements and triple check with the design team that manufactured hardware conforms to mission standards and objectives. Systems will also be tested at the component level and with Enceladus like conditions, additionally in vacuum chambers and vibrational
testing as well as acoustic testing to ensure all systems can operate and can withstand the forces of launch and landing on Enceladus.

For specific tests for instruments an example would be for inductive coupled plasma mass spectrometers. The test would be measuring Quadrupole Peak Hop (Slew) Speed, which would be the maximum rate the ICP-MS can jump (valence shells) of 160 amu without loss of accuracy to an acceptable degree. This would be one of many tests to ensure instruments run smoothly in cryogenic conditions. As well as testing the FIAC and the sampling funnel to ensure confidence in systems operation.

Reviewers will validate the current existing assemblies and systems are in conformance to missions and internal standards and perform the necessary steps needed at every step of the manufacturing process to ensure mission success.

4.1.5. FMEA and Risk Mitigation

The following table include an FMEA and risk plot regarding the payload systems as the tables show evidence that sufficient analysis has been conducted to find the most likely points of failure, how they will affect the rest of the lander and mission objectives and how the team plans to address these risks by adding a “recommended actions” section.

<table>
<thead>
<tr>
<th>Component and Function</th>
<th>Failure Mode</th>
<th>Cause</th>
<th>Effect</th>
<th>Rating</th>
<th>Recommended Actions</th>
</tr>
</thead>
</table>
| Sample funnel          | Heating      | Electrical | Samples can not melt | Catastrophic | 1. Make a redundancy system  
2. Check wiring before launch |
| FIAC                   | Pumps        | Frozen samples and pipes | Not able to process sample | Catastrophic | 1. Material selection  
2. Redundant heating systems |
4.1.6. Performance Characteristics

The estimated time of landing on the surface is estimated to fall/winter, the design team and engineering team will make accommodations on the necessary design requirements and expected environmental conditions based on existing enceladus data.

The main concern is the cryogenic temperatures of Enceladus because normal instruments do not operate at such conditions. But, there are some exceptions such as the gases needed for the icp, mass spectrometry such as argon which need to be kept as such temperatures. However, most of the instruments as stated before do not operate at such low temperatures that is why our design incorporates a passive multiple layer insulation system(Aluminized mylar and Kapton) which covers the temperature sensitive parts such as the FIAC and the ICP-MS instrument. Additionally, radioisotope heating units will be strategically
placed to optimize heating for temperature sensitive hardware and instruments such as communication devices and onboard computers.

4.2. Science Value

4.2.1. Science Payload Objectives

Our science goals are to collect protein samples as well as to determine the habitability of Enceladus based on mass spectrometer data and proteomics. Specifically we are looking for fibrous proteins which do not easily break down and survive in more rigorous conditions unlike globular proteins. An example fibrous protein we would be searching for would be Actin or Myosin key proteins for life which are proteins typically used for muscle contractions or used as "motors" for smaller creatures such as single cell organisms to move. By determining from the amount of proteins and other biological compounds in a given sample one could potentially determine from that sample if it is suitable for life or infer to what degree of life is possible in the sample. Determining the habitability of Enceladus could shed light on the possibility of other moons existing in such conditions similar to Enceladus making the possibility of a likely candidate for Life much higher because planets would no longer be limited to the Goldilocks zone. The data gathered from the mass spectrometer would be able to analyze the chemical presence of several indicative compounds which would help determine the overall presence of life and habitability of the ocean world.

Specifically the mission focuses more on biological aspects to determine what forms of life or proteins exist in the plumes of Enceladus. What this data should tell the scientific community is to what degree life exists on the moon, be it biological compounds and molecular substances.

4.2.2. Creativity/Originality and Significance

The team’s main objectives are to explore the southern part of Enceladus and explore the Damascus Sulcus during the research phase of the project the team could not find a design remotely similar to the one showcased in this PDR or methods of investigation meaning that the design is truly unique and would provide one of a kind data set for the plume for Ma‘aruf a geyser by Damascus Sulcus, and relatively smooth area to make landing easier. Using JMARS, the area that would serve as the landing spot would be -34.806°N, 29.714°E. Below is the image of the area that would serve as a landing spot.
4.2.3. Payload Success Criteria

Success criteria is:

- Spacecraft instruments make repeatable and accurate measurements and deliver quality data.
- Determination of what level of habitability exists in Enceladus based on chemical-structure and compounds found in plume data
- Infer to what degree life exists based proteins and ms data from plume particulate

Quality data in this context is usable meaningful and interpretable results. Threshold for success is successful data transmission of experimentation results. Whether the results contain finding that would indicate the presence of life is not relevant to success criteria it is the successful transmission of results that count.

However it is necessary to prepare for making sure necessary criteria is fulfilled. With the proper preparation, a groundbreaking discovery can be made. For this mission any "quality" data back would be considered a success because it would be
the first ever surface data from Enceladus that yield proteomics, and would shed light on chemical structures and compounds contained within the plumes providing useful science data for decades to come. There is great scientific interest and value for the scientific community because Enceladus is not the only moon that is warmed by tidal forces in earth's solar system.

4.2.4. Experimental Logic, Approach, and Method of Investigation

First the lander will deploy from the obiter but before deploying the instruments will run specific industry standard calibration techniques such as matrix matched calibration before landing and after touch down and additional standard calibration techniques listed later in this paper. Once the lander has safely landed it will begin testing once the plume particulate lands on the lander via pressure sensor. The sample will be funneled from the passive gravity fed funnel leading to the electro vaporization device which will then liquidate the samples down to a milliliter in volume so that they can be accepted into the flow injection analysis chamber (FIAC) which will prepare the sample for the ICP-MS. For the carrier fluid (Matrix) used to transport the liquid sample in FIAC it was determined that Ammonium ions [5], NH4+ are most suitable for theoretical detection of particles in the parts per billion range when samples mainly consist of salt water. Which is most likely the case from the data gathered from Cassini mission.

For the ICP-MS depending on the mode the instrument will either gather normal mass charge ratio spectrometer data or we will use MeCAT using the bottoms up approach [3] to determine the amount of proteins in a given sample (proteomics). The two data sets can be cross referenced and walked to infer from the two data sets to yield even more information.

JMARS

We picked a region in the South Pole that had relatively flat terrain and based on existing plume data indicates an active plume in the area named Ma’aruf which the lander plans to sample a plume data from.
4.2.5. Testing and Calibration Measurements

The instrumentation systems will be tested during phase D operations on earth in Enceladus like conditions to ensure instrument operations are at satisfactory levels of precision and accuracy. Additionally Instrumentation systems will be tested in situ on the landing site before instrumentation operation for quality assurance.

For calibration the payload the icp-ms instrument will matrix matched calibration[9]. As for a blank sample the lander will take samples of fine plume particulate at high altitude as a comparison to the surface samples to detect “noise” in given samples. For calibration for proteomic the ICP-MS will use specific metal species delivered in precise amounts to serve as an internal standard for measurement detection rate. Some other things to consider are the use of Ammonium ions(NH4+) in the carrier fluid which is a biological compound which
may skew the results that is why while performing calibration the instruments will account for concentration when the “blank” sample test as a baseline.

For the ICP-MS a standard methodology of calibration is by injecting a certain amount of concentration of the analyte and having those expected values compared to actual values in a specific range of concentrations in the parts per million range.

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

Typical ICP-MS instruments measured in nanograms per milliliter of sample and have an accuracy of +/- 5% RSD. As mentioned in prior section the instruments will be calibrated on orbit of Enceladus and again on the surface by injecting a small amount of metal coded Affinity tags prior to the instruments operation for proteomics. We can calibrate the systems by determining the discrepancy in instrumentation measurement and expected instrumentation measurement. As with most ICP-MS instruments the more measurements they make with corrections gradually over time the accuracy and precision of measurements increases.

For most discovery class missions, recovery systems are not a likelihood. That is why the lander will transmit results of the experiments as they are successfully completed.
4.2.7. Expected Data & Analysis

Figure 27: Data figure of a typical ICP MS

In this picture above is a concentration of elements in a point plot curve in a given sample measured in atomic mass units.
Figure 28: Example of a proteomics data figure.

In the figure above we’re looking at the concentration levels of specific proteins and their mass plotted on graphs.

For analysis using the bottoms down approach[3] which would break the proteins into smaller peptides by using a protease such as trypsin to aid the breakdown process. Then inject synthetic peptides with MeCAT tags quantified by the flow injection analysis chamber which is then analysed by the mass spectrometry, or the sample could be run without the reagent and directly head to the mass spectrometry unit.

Typical mass spectrometry data is usually represented in the form of Extensible Markup Language data which will be received by the orbiter. Samples data will be validated and quantified the day that will be presented in matrix like formation.

Depending on the given data set one could interpret the concentration of proteins or by the presence of and concentration of organic molecules in the given sample. Which could be indicative of the basic structures necessary for life or even perhaps signs or evidence of some molecular level of life.

Below is the random standard deviation formula used to determine the accuracy of
the icps ms typically the rsd value is around +/- 5% RSD for particle measurements in the parts per million range is widely accepted as the standard in the scientific community.

\[ s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \]

\[ RSD = \frac{s}{\bar{x}} \]

Figure 29: Random Standard Deviation Formula

Concentrate formula taking the existing concentration of an initial volume of a stock solution.
5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

The Safety Officer for EGGO mission is Aliza Orjalo.

The Safety Officer’s responsibilities include:

- Ensuring that construction of EGGO is carried out safely by maintaining documentation that identifies the materials team members may be utilizing to help understand risks and procedures associated with those materials.

- Verifying that all tests and launches of the lander abide by relevant codes and regulations.

- Maintaining team procedures, safety protocols, and hazard analysis

- Directing pre-launch meetings to brief the team on recognizing hazards and to avoid accidents.

The team’s safety during all phases of the mission is the priority. The primary role of the Safety Officer is to ensure the team’s safety by identifying potential hazards that the team may encounter, having the team acknowledge the risks associated with the mission, and overseeing all tests and launches to guarantee that the team is abiding by relevant codes and regulations.
5.1.2. List of Personnel Hazards

Safety concerns undoubtedly will arise throughout the course of the mission, most notably during construction and testing of EGGO. Potential hazards will be reduced by conducting proper training and safety reviews. Operating heavy machinery also raises safety concerns for the team members. To expose team members to minimal possible hazards, it is emphasized that only experienced personnel operate heavy machinery. During the development of the lander, only experienced and certified personnel will carry out the construction and handle hazardous materials.

During the construction and testing phases for example, materials and debris may cause injury to a team member, team members may inhale fumes, come into contact with skin irritants, and be within the vicinity of falling debris. The following list outlines potential personal hazards to which team members may be exposed throughout the mission.

- Inhalation of toxic fumes
- Skin irritation caused by toxic substances and powders
- Electrical hazards such as shocks or burns
- General cuts and irritation
- Tripping hazards
- Contact with foreign object debris

5.1.3. Hazard Mitigation

To ensure that all team members are aware of the risks associated with the mission, the safety documents identifying the materials and the potential hazards will be available electronically on the team’s online forum and provided as a hard copy to all team members at the test site and facilities for the team members to read and use. In addition, it is enforced that only experienced and certified personnel operate heavy machinery and handle hazardous materials to mitigate team members’ exposure to the following hazards:

- Inhalation of toxic fumes
- Skin irritation caused by toxic substances and powders
- Contact with foreign object debris
- Electric hazards such as shocks or burns → shut of batteries, safety switch
- General cuts and irritation
- Tripping hazards
<table>
<thead>
<tr>
<th>Hazard</th>
<th>Effect</th>
<th>Mitigation</th>
<th>Required Safety Equipment</th>
<th>Emergency Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toxic fumes irritation</td>
<td>Inhaled fumes cause damage; toxic substances may cause blindness if eye contact</td>
<td>Work space be ventilated and spacious</td>
<td>- Face masks - Gloves - Protective eyewear (glasses)</td>
<td>- First aid kit - Eye flush station</td>
</tr>
<tr>
<td>Skin irritants - powders</td>
<td>Can irritate skin and may cause burns</td>
<td>Components stores in insulated, separate storage or units and handles with gloves</td>
<td>- Gloves - Protective eyewear</td>
<td>- First aid kit - Eye flush station - Burn kit - Fire extinguisher</td>
</tr>
<tr>
<td>Vehicle debris</td>
<td>Falling debris can injure an onlooker</td>
<td>Team members trained to be aware of surroundings to avoid falling vehicle debris</td>
<td>- Protective eyewear</td>
<td>- First aid kit - Eye flush</td>
</tr>
<tr>
<td>Electrical hazards</td>
<td>Electrical shocks may cause burns and cause internal problems</td>
<td>All team members must know where the power source is located in the event the power needs to be shut off in an emergency; shut off batteries</td>
<td>-Protective gear such as rubber gloves - Use of rubber mats in facilities to prevent conductivity of electricity</td>
<td>-First aid kit -Fire extinguisher</td>
</tr>
<tr>
<td>General cuts and irritation</td>
<td>Cuts can be caused by sharp objects during the development</td>
<td>Protective wear such as gloves must be worn at all times when</td>
<td>- Glasses - Gloves</td>
<td>- First aid kit</td>
</tr>
</tbody>
</table>
Table 9: Human Hazard Mitigation

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Risk Mitigation</th>
<th>N/A</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>and building of the lander</td>
<td>working with sharp object or any irritants and glasses must be worn when operating machinery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tripping hazards</td>
<td>Unkempt workspaces could injure team members as the walk around the facility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintain the cleanliness and organization of the workspace/facility to prevent tripping hazards and fire hazards in the event of an emergency</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

During the construction and testing phases for example, team members may inhale fumes, come into contact with skin irritants, and be within the vicinity of falling debris. To minimize these safety hazards which include inhaling fumes, coming into contact with skin irritants, and being struck by falling debris, the safety team is requiring that all team members wear protective eye gear, respiratory protection, and other necessary personal protective equipment. The construction of the lander will require the work space to have ventilation to mitigate the risk of team members inhaling fumes.

With recent developments of the COVID-19 pandemic, the safety team will be enforcing that masks and gloves be worn at all times while on site and that no more than 10 team members be in the same room at any given time. In an effort to maintain a clean and safe working environment, the safety team will be providing alcohol-based hand rubs containing at least 60 percent alcohol, disinfectants, and disposable towels for team members to use to clean their work surfaces.

The standard establishes the boundaries of the clinical range that exposes the crewmembers to acceptable risk of immune and hematologic disorders. The critical value is defined as the level that represents a significant failure of the
hematopoietic system and is associated with specific clinical morbidity. Evaluation and action by the appropriate health care team are indicated when values reach this level.

Actions that can be taken to facilitate good Immunological or hematological status include implementing a quarantine period before launch; assuring immunizations are current, in accordance with the NASA Crewmember Medical Standards; employing environmental measures to reduce exposure and subsequent sensitization to allergens and particulate matter; and determining whether crewmembers were sensitized to new environmental agents during flight using pre- and post-flight hypersensitivity panels.

During the mission, hematological/immunological values are to remain within normative values established for the general population. Target parameters have to remain outside the critical values, defined as those levels of the target parameters that are associated with specific clinical morbidities.

5.2. Lander/Payload Safety

5.2.1. Environmental Hazards

Several environmental concerns may impact EGGO as the lander will be subjected to mechanical, thermal, as well as other hazards during the launch and landing.

The lander will be subject to the forces of launch such as:
- Mechanical - High wind speeds, changes in atmospheric pressure
- Thermal - Freezing temperatures
- Others - Random Space debris

The very low temperatures will be a large problem as the lander must be able to operate within cryogenic temperatures. It is possible that some science instruments will be unable to operate as well.

Additionally, the plumes could disrupt the trajectory of the lander. This can be detrimental if the lander is rotated in such a way that it is unable to land safely.

5.2.2. Hazard Mitigation

Some Earth-based tests will be different landing rotations. Here we can test how much our lander will rotate and to see if it can land correctly, and still be
operationable. Additionally, the lander should be subjected to below freezing conditions to see how it will operate. Environmental hazards that may impact the testing, launch and landing of EGGO have been analyzed in the following table.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High wind speeds</td>
<td>Launches will be planned and organized in advance according to weather forecasts to avoid high wind speeds that may affect flight pattern</td>
</tr>
<tr>
<td>Freezing temperatures</td>
<td>Components and power sources use elements made of materials that can withstand freezing temperatures to prevent the lander being redirected to earth</td>
</tr>
<tr>
<td>Orbital debris</td>
<td>Analyze the probability that the lander will collide with space debris and make changes to the flight plan in accordance with the probability of collision</td>
</tr>
</tbody>
</table>

Table 10: Environmental Hazard Mitigation

6. Activity Plan

6.1. Budget

The budget of the entire mission consists of 400 million which will be allocated towards cost from the payment of team members, to manufacturing cost.

The largest portion of the budget will be dedicated to the category of manufacturing the lander which is a total of $200 million. This portion will then be distributed in equal parts to engineering and materials and to the purchase of science instruments. Although the engineering and materials will receive a budget of $100 million and the purchase of science instruments will also receive a budget of $100 million, if more resources need to be acquired then a reallocation of funds to necessary resources will originate from the manufacturing portion of the budget.

It is estimated that facilities and administrative costs will be $40 million. The F&A costs will mainly be allocated towards the rental of a facility that will be used to construct the lander itself along with any other costs that may be associated with it.
Additionally, a small percentage of that budget will go towards the business team which should not take much resources as the main cost will come from outreach.

Another $40 million is expected to be allocated towards employee related expenses such as each team member’s salary, as well as each team member’s transportation costs and personal spending. Additionally, these costs will have to cover insurance, retirement, and investment contributions etc. Each team member will receive a salary of $80,000 with those on the science and engineering teams also receiving Employee Related Expenses of 28%. With having three members on the science team, six members on the engineering team, and one member on the administrative team, the following table outlines the cumulative personnel costs and all project costs for six years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Personnel Costs</th>
<th>Manufacturing/Instrument Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>$720,000</td>
<td>$750,000</td>
</tr>
<tr>
<td>Year 2</td>
<td>$720,000</td>
<td>$500,000</td>
</tr>
<tr>
<td>Year 3</td>
<td>$720,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>Year 4</td>
<td>$720,000</td>
<td>$20,000</td>
</tr>
<tr>
<td>Year 5</td>
<td>$720,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>Year 6</td>
<td>$720,000</td>
<td>$630,000</td>
</tr>
<tr>
<td>Cumulative Total</td>
<td>$4,707,088</td>
<td>$1,400,000</td>
</tr>
</tbody>
</table>
Lastly there is a $120 million that is reserved for flexibility. The reserved funds will allow the team to have extra funds on hand in the event that more equipment, instruments, testings, or other costs are required for the mission. A portion of the reserved funds will most likely be designated to the all other sections in various amounts.

### 6.2 Schedule

The following figure is the gantt chart the team developed for goals to be met in the development of EGGO.

![Figure 31: Team Gantt Chart](image-url)
Phase A is about creating an initial concept design for the mission concept. This is where the scope of the mission really gets defined along with science goals and listing all primary system interfaces. It is estimated to take approximately about a three-quarters of a year to research and establish the optimum design for the mission requirements this is also when key trade studies will be established to determine the suitable technologies necessary for mission requirements and using technique such as cost benefit analysis to determine the most optimal equipment best suited for carrying out the mission requirements.

Phase B is estimated to take approximately one and a half years for design maturation for a prototype lander. Such plans include manufacturing plans and system integration plans. This is also where the preliminary design review comes in and creates a clear communication of the concept in written form. Designing a model of the lander will all the determined systems is estimated to take approximately a year to complete a final design for the lander and will most likely go through many iterations to evolving the lander design. Technology development such as lander leg deployment and other technology maturation will take place during this phase.

Phases C & D (Design and Development): During this phase, the design and development for EGGO are negotiated. This phase will initiate building and creating systems that will operate EGGO as it is launched onto Enceladus’s service to explore its oceanic chemistry and organic compounds within the ice geysers. Phases C & D will occur simultaneously with the writing of the PDR as the PDR also documents the design and development plan progress of EGGO. Since the PDR will be completed by November 29, 2020, the design of EGGO will also be completed by November 29, 2020. Though the preliminary design will essentially be complete, the development phase is still underway. In collaboration with the administrative team, the engineering team will study the budget allocated for the development of EGGO which includes the necessary materials and instruments. The team anticipates that the development phase will take at least three years before completion and is ready to launch.

Phase E: is all about the mission operations and in this case for this mission it will be surface operations on enceladus. It is planned to be three days in case of schedule run over but actually battery life is estimated to last no more that 2 hours and 45 mins during this phase the lander will deploy from the orbit and land in the designated landing zone and carry out the science goal and in the meantime will continuously transmit data back to the orbiter which will relay results to deep space network.
6.3. Outreach Summary

To increase interest in STEM for the younger generations and promote our mission, EGGO, the team will communicate with K12 schools to give informational talk relevant to the many aspects of STEM with a focus on space missions. Through various presentations, organized community events, and forms of media publication, the team hopes to pique students’ and the general public interest. To maximize our means of outreach, the team will make strong emphasis on being proactive and passionate toward the mission’s purpose; it is essential to express a genuine interest and determination within our research proposal and project as they represent our collective appreciation for STEM and space missions.

**SCHOOLS:** As students learn best when exposed to a balance of informational and active engagement, the team will create a productive learning environment by first introducing EGGO by means of presentations; then, proceed to integrate interactive experiences through creative challenges. Challenges may involve space-themed arts and crafts, building physical prototype models, creating digital 3D design, proposing mission concepts, getting involved with individual research projects, etc. Learning about STEM doesn’t have to be limited to a school environment, students can also bring parents/guardians to participate in Summer programs, i.e. science camp, and become more informed about the various current and future development of STEM; students will be open to explore many possible career paths and learn how they can contribute to the future of world.

**LOCAL COMMUNITY:** The team will further expand its outreach in form of community services. As local schools, businesses, organizations often hold general events, the team can build a strong relationship with the local community by volunteering and attending these events—the team can also use these opportunities to promote EGGO, gain recognition for the mission, and request sponsorships and recommendations. Maintaining active involvement with the community will allow the team to identify and fulfill the community needs, while also developing innovative and effective methods to further expand the general demographic interest in STEM.

**GLOBAL COMMUNITY:** The final step to our outreach endeavor is the global community. While it may prove to be difficult to interact with a global audience, we will have an active presence throughout our multimedia production—infographics,
online videos, online seminars, and collaboration projects with other STEM groups—to keep consistent updates with our mission, EGGO.

Figure 32: EGGO Poster used to spark interest in the lander’s purpose

6.4. Program Management Approach

Team 44 was organized by first analyzing each team member’s strengths and experiences. Through analyzing each person’s talents, the Program Manager and Deputy Program manager then designated each team member into science, engineering and/or business administrative teams based on experience to the
requirements of each team. Devon Taylor and Aliza Orjalo serve as the Project Manager and Deputy Project Manager due to previous leadership roles in various organizations and similar programs.

One of the challenges team 44 faced was the almost complete loss of the science team and the way that this was dealt with was when Devon decided to take on the development of the science payload. Since Devon has a scientific background in the past due to his experience with proposing and creating scientific experiments, it was fitting that Devon be designated as the new team science lead. With the loss of about half of the original team and original mentor, it proved difficult to organize team meetings and to receive feedback on completed sections of the PDR. However with the hard work and collaboration provided by the remaining team members and the assignment of a new mentor, Team 44 was able to continue progress on the PDR.

The following figure is the team organizational chart which illustrate each team member’s role in the development of EGGO.

![MCA Team 44 Organizational Chart](image-url)

Figure 33: MCA Team 44 Organizational Chart
7. Conclusion

The Enceladus Ground-based Geyser Observer (EGGO) mission aims to explore the active plumes in the tiger stripes from the Damascus Sulcus region, in the southern hemisphere of Enceladus. To ensure the success of the mission the lander payload consists of a hardware system, a thermal system, used to assure the heating, a communication system, to assure the transmission of data, and a scientific payload, to interpret and sample the environment. The scientific payload will contain an electrothermal vaporization funnel, a Flow Injection Analysis Chamber and an inductively coupled plasma mass spectrometer used to analyze the habitability on the planet. For the Critical Design Review Team 44 aims to ensure that the baseline contains detailed hardware and software specifications, ensure that the design has been successfully audited, establish planned Quality Assurance activities for the verification and screening process and verify that the final designs fulfills the specifications established in the PDR.
Sources Cited:

[1] PerkinElmer, Inc., *NexION 300 ICP-MS Preparing Your Laboratory*, 2010-2012

Appendix

Acronym-description

ICP-MS - Inductive plasma coupled Mass spectrometer, the main science payload instrument for the EGOO mission

FIAC- flow injection analysis chamber, a sample for preparation chamber

MeCAT- Metal Coded Affinity Tag is a specific species of metal that binds to biological proteins and compounds