NASA L’Space Cryogenesis

Preliminary Design Review

Contributing Authors:

Manav Dave - Project Manager/Aerospace Engineer
Evelyn Wendt - Deputy Project Manager/Aerospace Engineer
Rosalina Ascensio - Science Team Lead/Safety Officer
Brianna Platt - Business Team Lead/Environmental Scientist
Robert Ross - Engineering Team Lead/Aerospace Engineer
Jaden Carollo - Safety and Hazard Mitigation
Julio Gutierrez - Electrical and Communications Engineer

Mission Overview

1.1: Team Introduction

The Cryogenesis team consists of seven members of various science and engineering disciplines. Each member of the team is listed below, with their respective college and relevant experience.

Last Name	**First Name**	**College/University**	**Location**	**Relevant Experience**
Ascencio	Rosalina	Lone Star Community College	Texas	Chemistry
Carollo	Jaden	Missouri University of Science and Technology	Missouri	Aerospace Engineering
Dave	Manav	University of Alabama - Huntsville	Alabama	Aerospace Engineering; propulsion
Gutierrez	Julio	Kansas State University	Kansas	Electrical Engineer
Platt	Brianna	Santa Clara University	California	Environmental Science; spatial analysis
Ross	Robert	Wichita State University	Kansas	Aerospace Engineering
Wendt	Evelyn	Texas A&M University	Texas	Aerospace Engineering

1.2: Mission Highlights

1.2.1: Mission Statement

Cryogenesis is a science-driven mission that will explore the possibility of microbial presence on Enceladus using mass spectrometry and seismometry. The lander's scientific data will offer further understanding of similarities of the organic composition on Earth and other celestial bodies. The project will also give insight into the possibilities of extraterrestrial life on other water worlds in the universe.

1.2.2: Mission Requirements

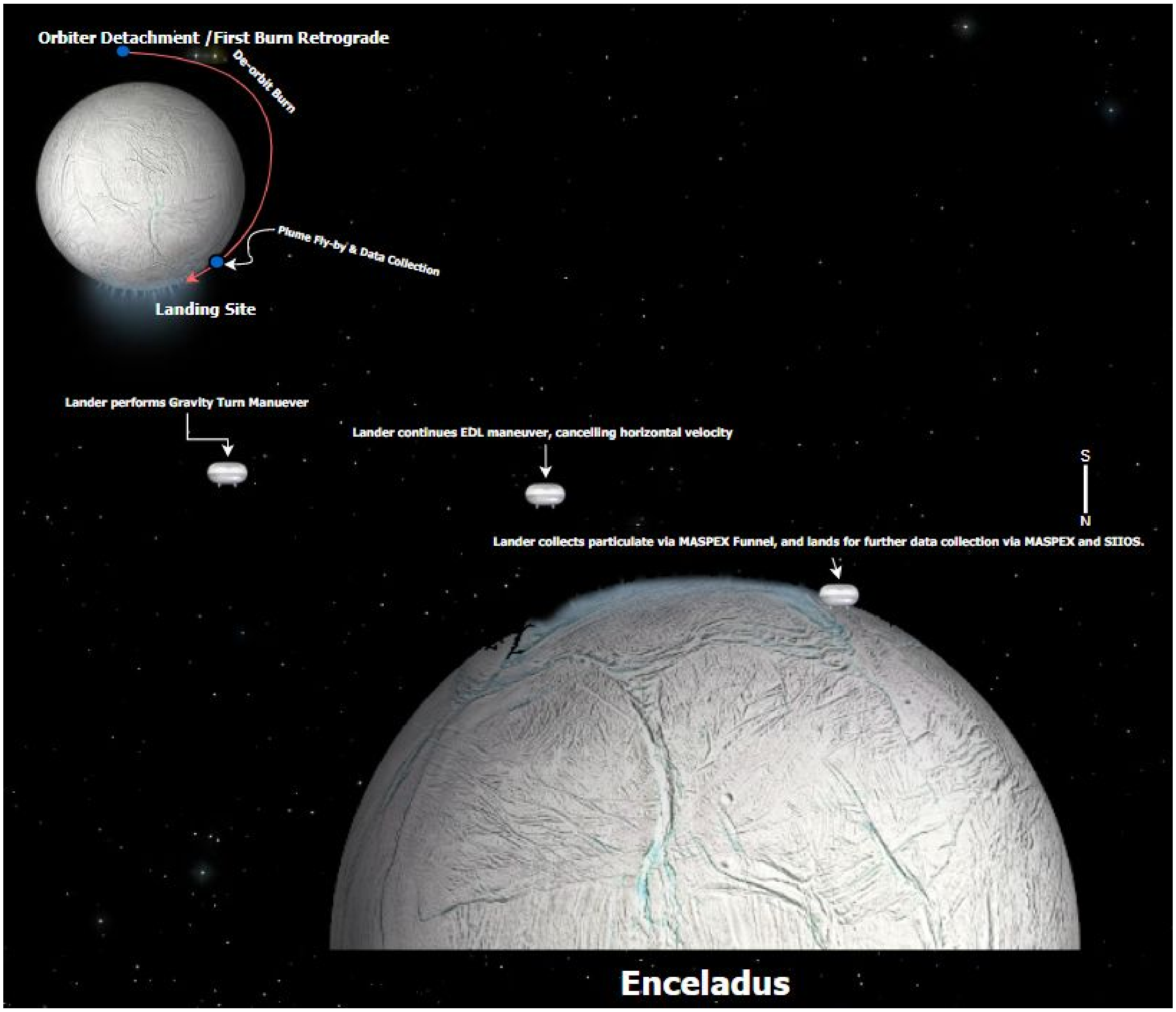
This project adheres to guidelines set by L'Space Academy, along with the team's own goals. The mission requirements are as follows:

- The total mass of the lander shall not exceed 77kg.
- The lander shall not exceed 51cm3 in a stowed configuration.
- The lander shall make use of a monopropellant engine burn to ensure landing at speeds that will not damage the lander or instrumentation.
- The lander's legs shall wholly support the shell to prevent extreme thermal conduction through the hull.
- The lander should fly-by a plume during descent to collect hydrocarbon compounds.
- The lander shall utilize a mass spectrometer and funnel system to collect and analyze Enceladus' particles.
- The lander should collect surface data using two seismometers placed within the lander.

1.2.3: Mission Success Criteria

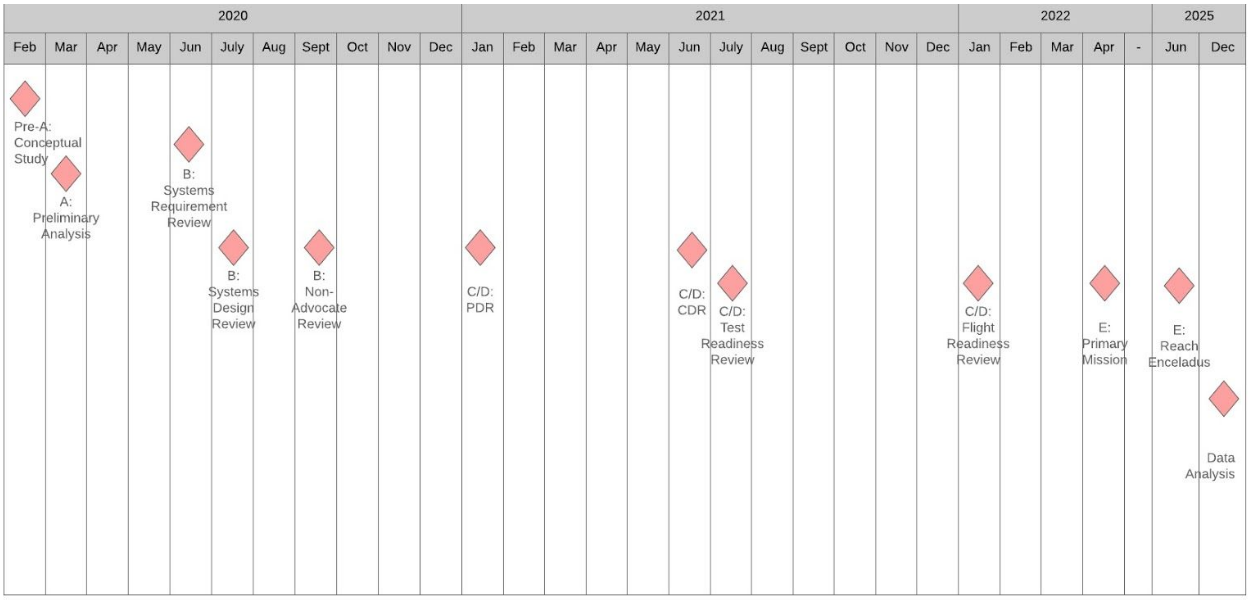
- This mission shall characterize structures regarding the depth of the ocean, ice layer, and other unknown structures on Enceladus.
- The mission shall improve the understanding of Enceladus' eccentric orbit as a source of tidal heating.
- The mission shall investigate Enceladus' plume activity and the impact of surface ice stresses using a seismometer.

1.2.4: Concept of Operations Graphics



1.2.5: Major Milestones Schedule

This is the team's milestones schedule. A more detailed description and explanation of this is provided in Section 6.2 of this document.



1.3: Descent Maneuver and Lander Summary

The EDL Maneuver will consist of a Hohmann transfer to lower the lander's periapsis to just above the target landing site, then a gravity turn descent from orbit to the surface. A gravity turn when landing is performed by burning retrograde to cancel out the spacecraft's horizontal and vertical velocity, such that the velocity of the spacecraft reaches zero a few meters above the surface, and then slowly hovers down the rest of the way to the surface. This maneuver is very similar to a gravity turn for launching a rocket into orbit, and is the most efficient method of landing, because the thrust vector is in the retrograde direction for the duration of the burn, and none of the impulse is wasted maintaining an angle of attack.

The trajectory for the EDL maneuver will be plotted using a program called GMAT (General Mission Analysis Tool). The gravity turn maneuver can be described by the differential equations and other equations shown below.

$$m\frac{dv}{dt} = F - mgk$$

$$v = g(n - cos\beta)$$

$$v\beta = gsin\beta$$

The lander has a tare mass of 47.2 pounds, a wet mass of 97.8 pounds, and a volume of 473in3.

1.4: Payload and Science Instrumentation Summary

The project shall include MAss SPectrometer for Planetary EXploration (MASPEX) and 2 seismometers. Neither instrument deploys.

MASPEX shall determine biosignatures in Enceladus' plumes through measuring and characterizing the composition of volatile organic compounds and particles. The instrument will be located on the main cargo component of the lander with a small funnel included to collect samples. MASPEX will also work in conjunction with a gas chromatograph, cryotrap, and funnel.

Two SIIOS seismometers shall be utilized to measure ice shell thickness, ice structure, and monitor ice stresses and movement. Seismometers should be located in the bottom cargo hold of the lander near the legs, the most stable portion of the lander.

Section 2 - Evolution of the Project

2.1: Evolution of Descent Maneuver and Lander

The lander changed throughout the PDR's lifespan in a few ways. The team was initially unsure of the precise shape and structure the lander would be. It was researched that an ellipsoidal shape, as shown in earlier figures and the Cassini-Huygens lander, was a sound choice. The team stuck with this design choice throughout, but slight adjustments were made.

The first major change was the material for the lander. Initially, the materials team decided to use Aluminum-6061, (AL-6061), for the shell of the lander. In this instance, the shell would be a ½ inch thick wall around the body, otherwise known as a hull or casing. The landing legs were also decided to be made of AL-6061 at the early stages. However, the team decided upon Aluminum 2024-T4, (AL-2024-T4), later on. This design choice was due to AL-2024-T4's low material embrittlement factor at extreme temperatures, and its overall common use in the aerospace industry.

The landing legs were also changed. After the team calculated heat flow for the lander, conduction through the landing legs was found to be extreme. While radiative heat transfer was somewhat minimized using MLI, MLI did not cover the legs. The team decided to change the legs to a different material: Inconel 600. This customized superalloy was specifically designed for aeronautical and aerospace applications and selected due to its low thermal conductivity, over 30% less than the team's previous material choice.

The legs saw further change after Inconel was implemented. The original design choice was to have the legs solidly welding and attached to the bottom of the lander shell, but brazeability of Inconel and AL-2024-T4 was found to be difficult. Thus, a new design was created that situated the leg attachments within the lander hull partially. This did not sacrifice structural integrity, and allowed for much simpler machinability; in fact, this new design was able to be manufactured in-house.

Another simple change was the internal grille of the lander. Initially a large slab of AL-2024, this was changed to be a grid-like circular grille. This did not sacrifice the safety of the materials and instrumentation resting atop it and saved mass for the lander.

Section 2.2: Evolution of Payload and Science Instrumentation

Science instrumentation and payload decisions change very much throughout the mission planning process. The Science sub-team was initially unsure of instrumentation due to lack of planetary instrumentation knowledge, however was able to develop a preliminary plan seen in section 4.

Originally, the team had looked into including MASPEX First Generation as the main instrumentation and the Neutral Mass Spectrometer utilized on the Cassini mission as the redundancy. However, due to the Engineering team's specifications and recommendations, this combination was no longer a logical choice due to weight and size constraints. The team then pivoted to only including MASPEX. The Science sub-team lead was unsure of some of MASPEX's functional details so the Principal Investigator for MASPEX at Southwest Research Institute, Hunter Waite, was contacted. Through this interaction, new information and insight was gathered including that of use of a gas chromatograph. The team then decided to use a scaled down version of a gas chromatograph as the refinement system for MASPEX and redundancy system if MASPEX were to fail.

For the seismometers, it was originally difficult to find an accurate model that was not overly heavy and large for the size and weight constraints of the Cryogenesis mission. The Science sub-team lead originally pointed to the seismometer used on the Curiosity rover. However, this seismometer is focused on earth movements and not for water world use. This seismometer, however powerful, was not the right one for the mission. The team then found that a department at Arizona State University had developed SIIOS, a small seismometer designed to be used explicitly for water worlds. The team decided on using two SIIOS instruments located in the most stable place inside the lander storage compartment.

The team also had to take into account how to refine the 'possibly dense snow' fallout from the plume into compounds small enough to be analyzed by the gas chromatograph and the MASPEX. The email interaction with Principal Investigator for MASPEX at Southwest Research Institute, Hunter Waite, also revealed that the use of a cryotrap was necessary in order to refine and prepare the compounds for analysis. Without this information, the team would not have included an instrument such as this which could have led to mission failure.

An extra portion of the mission design the science team had considered was the design on the funnel. However, due to lack of science team members, this task was not reached in time for the final PDR presentation and proposal. This is an aim for the team in the CDR process as well as possible inclusion as a proposal for the NPWEE program led by Arizona State University's L'SPACE Workforce Preparation Program.

Section 2.3: Evolution of Mission Experiment Plan

Firstly, the science team had wanted to drop a probe directly into the plume cracks in order to possibly obtain water samples. However, this was not feasible due to the battery power constraints. The team then decided to fulfill the mission goal of sampling and analyzing liquid via the plume fallout instead. This was a much easier process and could be done with a stationary lander.

Secondly, the team had planned to thermally image the moon for a more detailed render using another instrument from Europa's lineup– E-THEMIS. However, this was deemed unnecessary since the main mission goal was to sample for possible biosignatures. It was then an all team consensus to not include the imaging mission goal as it was not feasible for the lander mission.

Thirdly, the team had also wanted to incorporate an imaging system on the lander itself. However, due to design and temperature concerns, this goal was not realized and a camera of any sort was not included on the lander. For the future, a camera would be ideal to include on this mission if size and weight constraints were slightly larger.

Overall, the science team went from a very rudimentary vision of the mission goals and what was truly viable to creating goals that were within reach through the instruments chosen.

Cryogenesis - Section 3

3.1: Design, Verification, and Selection

3.1.1: System Overview

Summary

The Cryogenesis project features a lander that will detach from an orbiter orbiting Enceladus. The lander contains a monopropellant hydrazine engine that allows it to perform a deorbit burn and subsequent gravity turn; this is the lander's method of descent to the surface. The lander also has small landing legs that allow for a margin of error when landing, and it carries a small array of scientific instrumentation to reach certain goals as described in Section 1 of this document. The project evolved throughout, with major changes to its lander hull design, materials, method of descent, and scientific instrumentation and data acquisition process.

Lander Design Considerations

For the lander hull, a ½ inch thick ellipsoid shell of Aluminum-2024 alloy (AL-2024) was chosen. This unique shape allows for the lander to have two divided subsections in its body. One section contains scientific instrumentation, communications systems, and power supply system, while the other is dedicated to the mono-propellant engine. The top section, (Section A), will house three seismometers, a mass spectrometer, (MASPEX), and its supplemental particle capture apparatus. Section A also holds a C/TT-510 Electra-Lite Transceiver, the project's communication system. Furthermore, Section A houses a VES180 power supply that outputs 180W of power to the lander.

The lander also has its bottom section, denoted Section B.

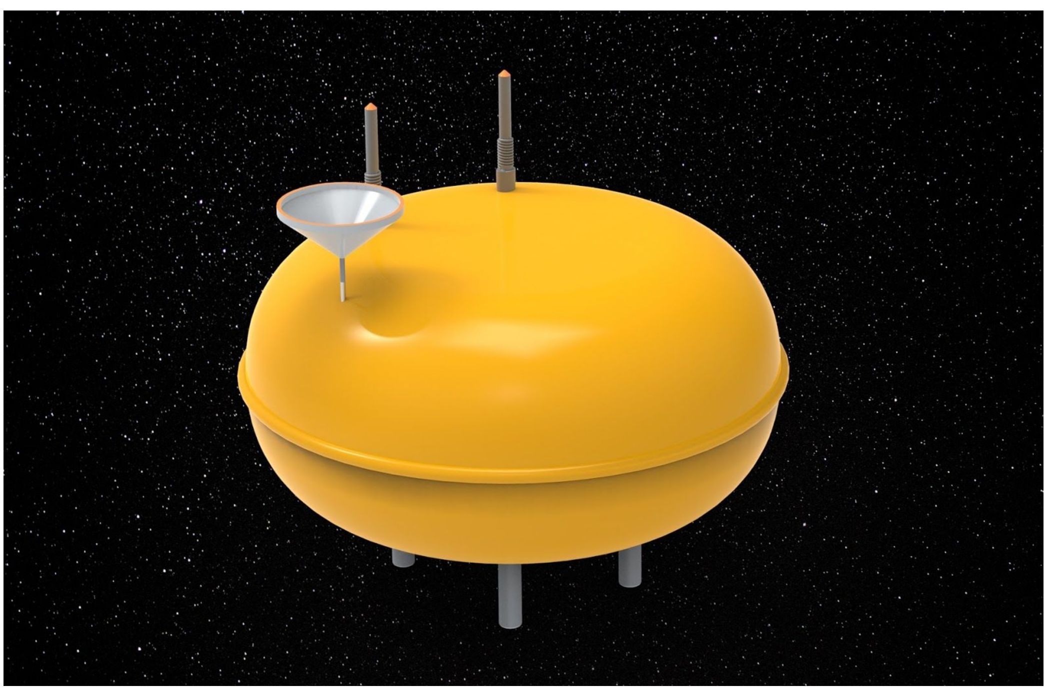
The ellipsoid shape of the lander also allows for a low ballistic coefficient, (BC). An object's BC dictates its effectiveness at resisting drag; thus, an object with a significantly high drag coefficient should also have a low BC. As seen in Fig. XX, the lander has a nearly flat bottom side, similar to a basic circular plate. An estimated ballistic coefficient was calculated at 0.015 using Eq. 1. This low BC shows the lander will also be aided in slowing down during its descent simply by its shape.

$$BC_{lander} = \frac{\rho * L}{C_d} \qquad \textbf{Eq. 1}$$

As aforementioned, the shell and internal grille are constructed out of AL-2024. AL-2024 is a commonly used material in similar aerospace projects; it has excellent tensile and yield strengths, thus allowing the lander to remain structurally intact during descent. AL-2024 also has a somewhat low coefficient of thermal expansion. This low value allows the lander to withstand the extreme temperatures of Enceladus and deep space, thus protecting the lander from embrittlement. However, while AL-2024 does have a lower rate of thermal conductivity than typical aluminum alloys, it is still significant at 121 W/m-k.

The lander also has four landing legs embedded into the main structure. Thus, the legs do not need to deploy, saving power, mass, and engineering complexity. Inconel was chosen as the material for the landing legs; this custom alloy allows the legs to be structurally sound during both the descent and landing maneuver. Furthermore, Inconel has been engineered to have a very low thermal conductivity, only about 16% of AL-2024's. This low thermal conductivity rate ensures that the lander legs will not be detrimental to the overall temperature of the lander body. This is covered more in-depth in Section 3.1.2 of this document.

EDL Graphics goes here. (almost done, awaiting few things)



Cryogenesis Lander as seen in space

3.1.2: Subsystem Overview

Gravity turn maneuver

The lander will use a gravity turn maneuver for descent and landing as it is the most efficient way to land on a planet or moon without a substantial atmosphere. The gravity turn is also the most efficient way to launch a rocket into orbit, and it works essentially the same for landing as it does for launch. The key difference is that instead of accelerating into orbit, the lander will be burning the engine retrograde to arrest the horizontal and vertical motion. The gravity turn descent to landing begins with a Hohmann transfer to lower the periapsis of the orbit to just above the surface at the landing site. The lander will then coast to periapsis and perform a retrograde burn, this burn will continue until the lander is just above the surface when all of the horizontal velocity will have been arrested, at which point the lander will slowly hover down to the surface. This is a very similar maneuver to what the Lunar Landers used during the Apollo program. The gravity turn is the most efficient maneuver for landing, due to all of the impulse of the engine being pointed directly parallel along the retrograde vector, and none of the impulses are lost to maintaining an angle of attack.

$$m\frac{d\vec{v}}{dt} = \vec{F} - mg\hat{k} \, .$$

$$\dot{v} = g(n - \cos\beta) \, ,$$
$$v\dot{\beta} = g\sin\beta \, .$$

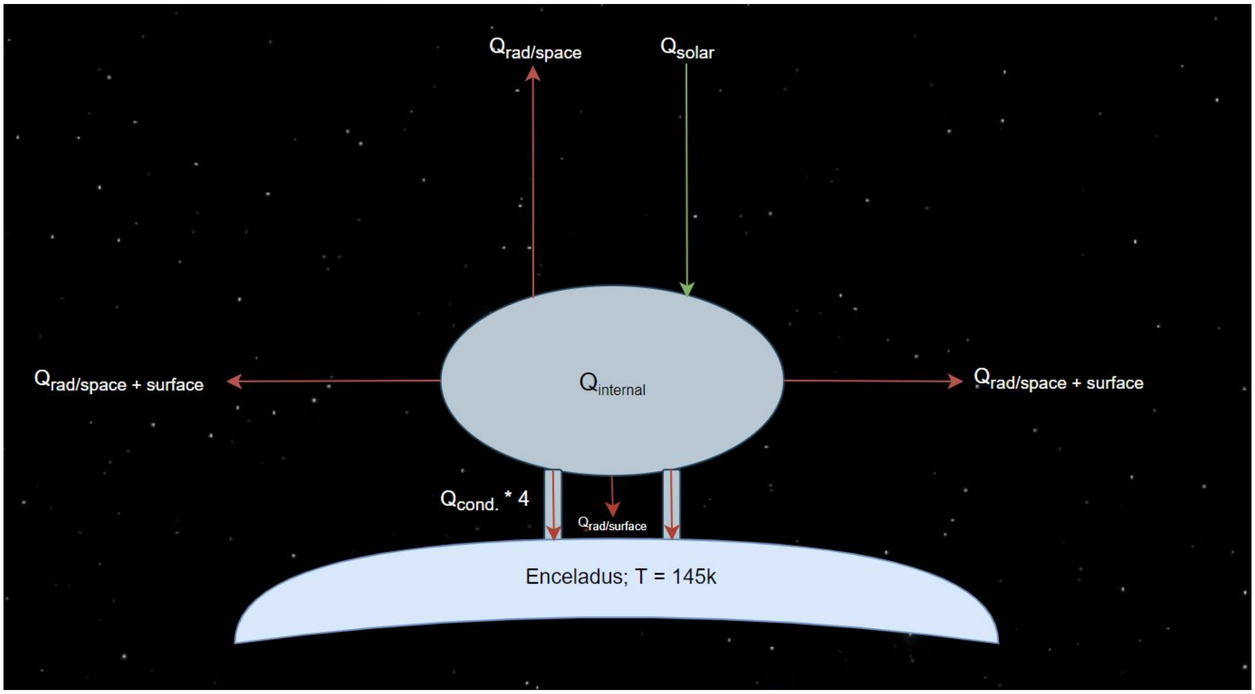
Power System

The lander will use the VES180 power supply from Saft that outputs 180W of power to the systems. This was chosen based on the cost, weight, size, power output, and data from current use in spacecraft. The cost calculated is $ 2,395,487.35 and the weight is 1.11 kg. This battery also has a high specific energy, with 165 Wh/kg being proven in spaceflight applications. Additionally, the VES180 includes a long life-cycle — a necessity for a long duration mission such as the Cryogenesis project. VES180 also provides moderate heat to the lander in the form of directly translated power to the lander's electronics and instrumentation. This battery is also a Lithium-Ion battery, most commonly used in satellites, rovers, and other space vehicles. This has been researched thoroughly by NASA scientists and other companies. Since the power system is the main source of a lot of different spacecraft and all yield positive results with strong reliability, the Lithium-Ion battery was the best choice.

Thermal Regulation

Due to the extreme conditions of Enceladus, the Cryogenesis project needs a thermal regulation subsystem to ensure fragile instrumentation and electronics do not surpass minimum operating temperatures. Given that Enceladus' temperature can reach as low as -201°C, and the minimum operating temperature for many of the project's electronics are as high as -40°C, it is clear that some sort of thermal regulation is needed for the lander.

The first consideration for this subsystem was to identify the amount of thermal management needed. A steady-state heat flow model of the lander was created to avoid complex transient conditions. A steady-state model allowed the team to avoid complex transient heat transfer calculations, yet ascertain a nominal estimate of heat lost vs. heat gained. Using the high-level equations 2,3, and 4, a heat flow map was created as seen in Figure XX.



Cryogenesis Heat Flow Map

$$\Sigma Q_{in} = \Sigma Q_{out} \quad \textbf{Eq. 1}$$

$$\Sigma Q_{in} = Q_{solar} + Q_{internal} \quad \textbf{Eq. 2}$$

$$\Sigma Q_{out} = Q_{radiative-space} + Q_{radiative-space/surface} + Q_{radiative-surface} + Q_{conductive} \quad \textbf{Eq. 3}$$

It was calculated that during cold-side operations, there would be a discrepancy of almost 40W between internally generated heat and heat lost to conduction and radiation. Cold side operations were defined here as periods when Enceladus was at its coldest temperature and the operating power of instrumentation was either completely off or in a low-power/standby mode. It was determined that a suitable thermal control system was needed after these calculations. The first considerations were active vs. passive heating systems. Active thermal regulation allows for greater precision and control of the system but commands greater engineering complexity and attention to detail. Passive systems allow for simpler management but typically will not perform as well as active systems. It was decided to use a passive system for a project of this scale.

Since a passive system was needed, two main modifications could be made to the lander. The first option considered was to increase the absorptivity of the lander. This option was ruled out due to the very low solar flux coming into the lander regardless of high or low absorptivity. The second option is to lower the emissivity of the lander. Lowering the overall emissivity effectively lowers the heat lost to radiation. Either coating the lander with surface coatings/paint or wrapping it in a Multi-Layer Insulation (MLI) blanket will assist with this. It was decided to utilize a system of MLI for this project.

MLI drastically reduced emissivity for the lander. While the lander’s hull material, AL-2024, already has a relatively low emissivity constant, (assumed about 0.3 for calculations), an advanced 3-layer MLI setup can achieve as low as 0.05. Using a similar setup, the lander’s emissivity would drop by almost 17%.

3.1.3: Dimensioned CAD Drawing

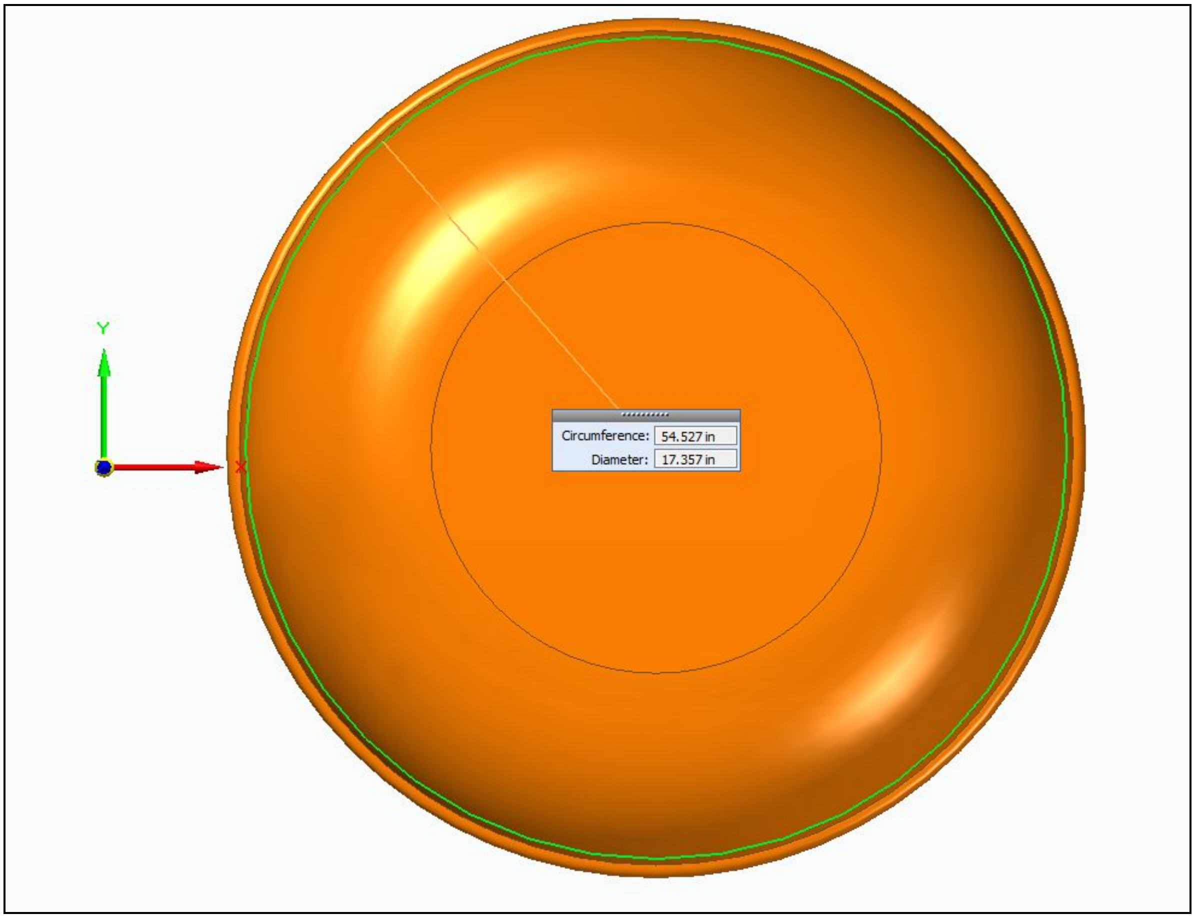
This section goes through the CAD model of the lander.

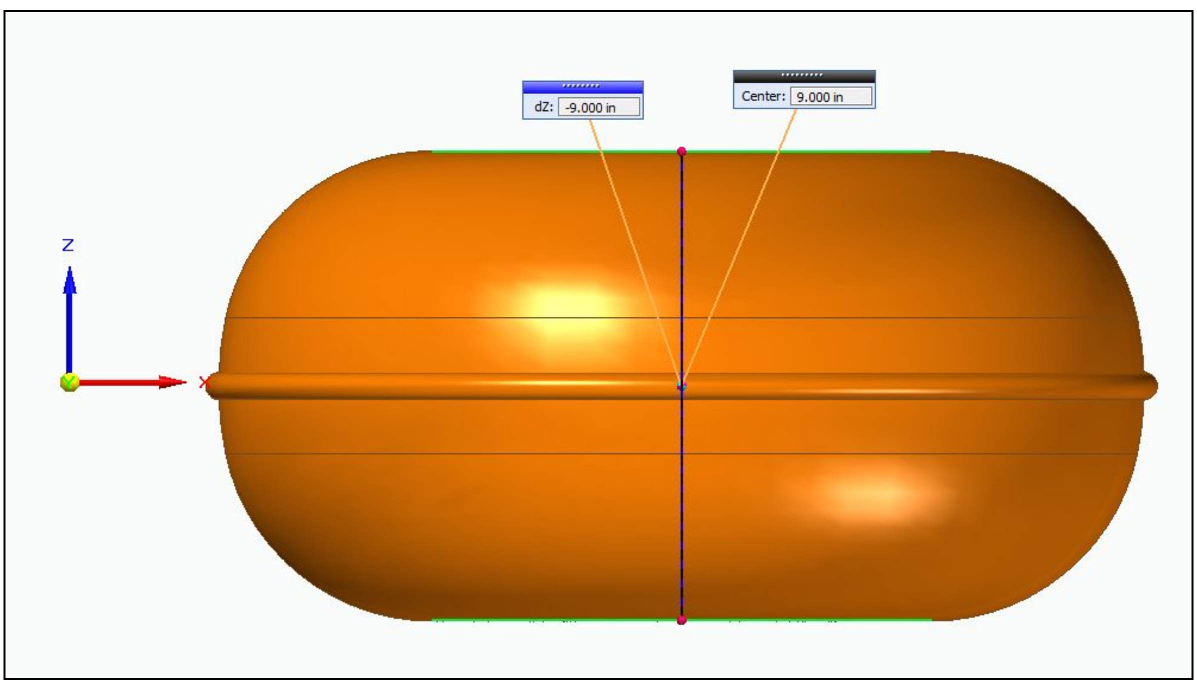
- Software - Siemens Solid Edge 2020
- Tare Mass - 47.2 lb.
- Dry Mass - 78.87 lb.
- Wet Mass - 97.8 lb.
- Volume - 473 in.3
- Shell Material - AL-2024-T4 (ρ = .100 lb/in.3), Leg Material - Inconel 600

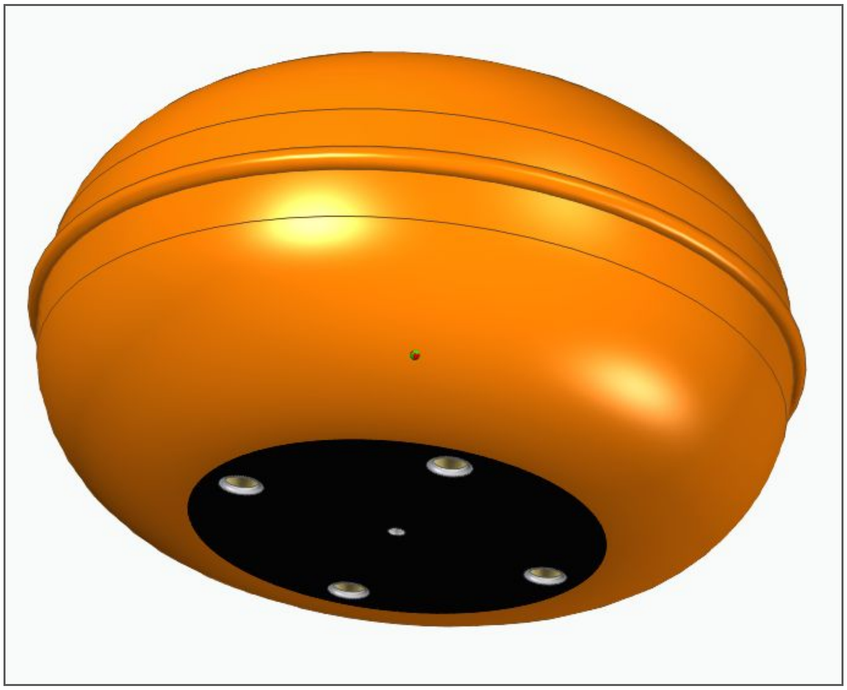
Shown below is the CAD model designed for the Cryogenesis project's lander. It was modeled in Solid Edge 2020, where Finite Element Analysis was also performed to ensure structural integrity during operations. The lander's shell material is AL-2024-T4, a tested and proven reliable material for aerospace applications.

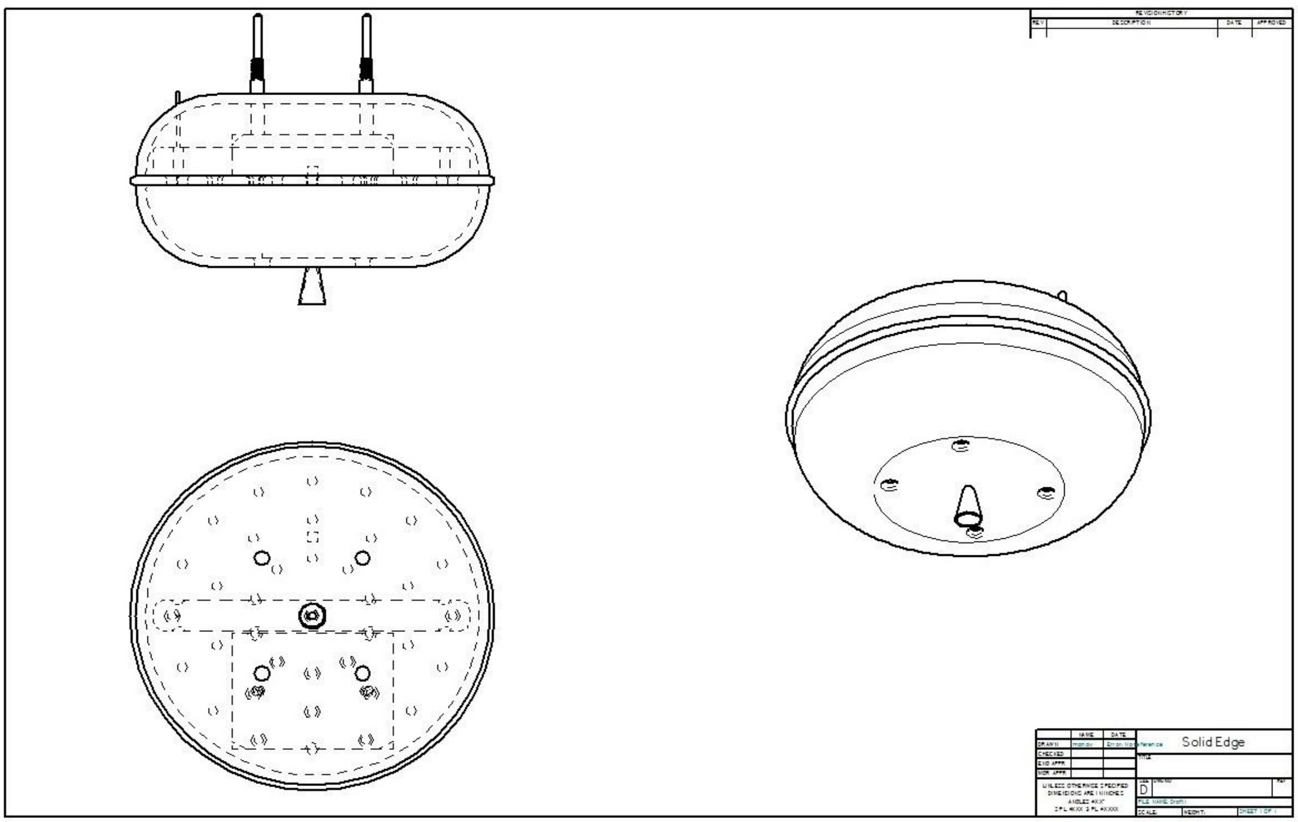
This first image shows some basic dimensions of the lander; the first image is also the working diameter of the lander; in other words, this is the measurement that the team had to work with for instrumentation, power, and everything else regarding diameter. The image below the first shows the height of the lander; however, recall that two distinct sections split up the lander.

The third image shows the lander stripped of all of its peripherals, such as communication instruments, science instruments, the engine, landing gear, and more. The final image is a drawing of the assembly, which contains everything that the lander carries, including the engine and MASPEX funnel.


Y
X
Circumference: 54.527 in
Diameter: 17.357 in


dZ: -9.000 in
Center: 9.000 in
Z
X





REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
NAME
DATE
DRAWN
CHECKED
ENG APPR
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
Solid Edge
TITLE
D
FILE NAME: Draft1
SCALE:
WEIGHT:
SHEET 1 OF 1

3.1.4: Manufacturing and Integration Plans

The team plans to acquire its engineering materials at multiple locations. Firstly, sheets of AL-2024 for the hull will be purchased and delivered from Midwest Steel and Aluminum. Inconel 600, a special metal alloy used for the lander's landing legs, will be acquired from California Metal. The lander will also utilize an MR-106L monopropellant hydrazine engine for its gravity turn maneuver. This engine will be outsourced from Aerojet Rocketdyne, and it is a proven flight-ready and Commercial-Off-The-Shelf (COTS) engine. The propellant will be stored in a scaled-down ethylene propylene diene monomer (EPDM) bladder tank, which will be stored in Section B of the lander. This tank will hold approximately forty pounds of propellant.

The team plans to outsource heavy machinery work to a manufacturing shop. Firstly, the lander hull and internal section separator will need to be created and welded together. The landing legs will be attached to the bottom of the lander, near the outer rim of the bottom plate. These legs will not be welded on, and instead, be bolted to the main hull. The landing leg attachment will be done in-house, but the manufacturing of the landing legs will be outsourced to a machining shop. The manufacturing process for the hull, separator, and legs duration will be from January 1st to January 18th. The team will also be doing additional in-house assembly. First, COTS items will be acquired for various goals; the MR-106L engine, EPDM propellant bladder tank, a VES180 battery pack, a UHF transceiver, and a computer/DAQ system used for Field Testing and operations. The team will then commit work to the engine and plumbing connections; members of the project have experience with this, allowing for precise work while saving budget. The team will also wire the lander's power systems, and secure its payload and instrumentation. Measurements were calculated beforehand on CAD software to ensure proper integration and fittings.

The testing procedure will start with a general test of the system itself, starting with the power supply, basic operations, and any movement of the lander. Once verified, testing of the MASPEX and seismometer will be performed to ensure that the scientific equipment is reading data and working properly. The communication between the scientific equipment, transceiver, and endpoints will be tested last to demonstrate the strong, clear transmission of data.

3.1.5: V&V Plans

In preparation for verification, the verification plan and requirements will be collected, reviewed, and confirmed. The product in question will be obtained with all enabling products, such as support resources and interfacing products or equipment that are needed for verification. The verification methods and activities are finalized and approved. The requirements are that the lander will operate by itself, the lander will move, MASPEX will collect organic molecules, the seismometer will start reading the ground environment, and that the communication system C/TT-10 Electra-Lite Transceiver will transmit data from the MASPEX and seismometer.

The Cryogenesis spacecraft will go through a demonstration verification testing procedure. This will show that the use of the product achieves the specified requirements. This procedure is used at the end of the development stage before launch to verify the product will perform necessary duties. This involves running at least one “test” without special testing equipment or instrumentation to collect sets of data that will be analyzed to prove the system and product meets a requirement. There will be a physical model of the spacecraft to be tested.

The product verification report is recorded with the product and system testing. Proof that the product did or did not satisfy the specified requirements will be documented. The report will include: verification results, version of requirements, version of product verified, version of equipment and tools used, results of each verification including pass or fail, and discrepancies.

Validation is performed for each piece of the system from the lowest end to the top end product, the complete system. This will confirm that the end lander functionality fulfills the intended use when operated in the intended environment. Validation will provide evidence of the system structure meeting the capability and expectations of the operator and team. This allows for problems discovered to be resolved before launch and that integration with other products can happen.

The Cryogenesis spacecraft will go through the testing method of validation. This will help determine the lander’s behavior and will be done on the final product. The testing method will validate the equipment, materials, and tools to provide proof that it meets the design specifications. The validation plan will include those expectations, validating the product works within the environment, and that the lander is evaluated for adequacy, completeness, and readiness.

A validated product is established with confirmation that the appropriate results were collected and evaluated to show completion of the validation objectives stated below. Determination is made that the validated product is appropriately integrated with the validation environment. The lander and equipment will be tested in harsh environments that are very cold with rough terrain to validate the durability of the product. The equipment and communication systems will also be tested in the same rough environment to ensure they are accurately collecting, measuring, and transmitting data and information.

Testing validation results will include lander anomalies, deficiencies, variations, and/or issues are identified. This assures that appropriate replanning, design, and/or redefinition of requirements will be made based on results. Validation reports will include the recorded validation and results, version and form of the product validated, version of equipment and tools used, the outcomes of each validation including pass/fail, and any discrepancies between expected and actual results.

3.1.6: FMEA and Risk Mitigation

Process Step/Input	Potential Failure Mode	Potential Failure Effects	Severity (1-10)	Potential Causes	Occurrence (1-10)	Current Controls	Detection (1-10)	RPN	Action Recommended
What is the process step or feature under investigation?	In what ways could the step or feature go wrong?	What is the impact if this failure is not prevented or corrected?		What causes the step or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?
To provide the lander with a safe and stable landing trajectory from its orbit to the landing site	Engine does not deliver thrust as expected	Lander does not reach intended landing sight, or breaks orbital trajectory	10	Engine Manufacturing error	1	Engine testing to ensure nominal thrust; known reliable company	2	20	N/A
				Engine/propellant plumbing and wiring error	3	Continuation of engine testing to ensure nominal performance	2	60	Plumbing and wiring inpsection after test firings
				Battery malfunction	2	Include voltage regulator/temperature sensors in order to avoid any battery malperformance	2	40	Consistency in electrical testing of various batteries. Include redundant batteries.
				Engine overheating	1	Pulse firings of the engine to test heating conditions	2	20	N/A
	Computer/Navigation Failure	Improper flight guidance calculations, resulting in landing off target	4	STK/GMAT Software Bug	2	Professional software; bug testing	1	8	Professional bug sweep
				STK/GMAT User Planning Error	7	Reviewing team member's code	4	112	Professional code analysis
				Communication Error	3	Extra monople backup antenna	2	24	Rigorous physical/hardware tests for both antennas
		Improper flight guidance calculations, resulting in lander impact	10	STK/GMAT Software Bug	2	Professional software; bug testing	1	8	Professional bug sweep
				STK/GMAT User Planning Error	7	Reviewing team member's code	4	112	Professional code analysis
				Communication Error	3	Extra monople backup antenna	2	24	Rigorous physical/hardware tests for both antennas
To ensure structural integrity of lander during and after operations	Embrittlement of landing legs before touchdown	Lander loses symmetry; lander tips over, damaging mission critical equipment	10	Large space debris impacting landing legs	3	Specific material chosen for mission; landing site avoids plumes, low chance of debris impact	1	30	N/A
				Extreme landing angle/velocity	4	GMAT simulations, precise gravity turn manuever	4	160	Professional code analysis; ensuring proper manuever parameters
	Unplanned disassembly of lander hull	Lander and instrumentation freeze	9	Manufacturing error	1	Outsourcing manufacturing to professionals; rigorous integration testing	1	9	N/A
				Large space debris impact	1	Specific material chosen for mission; landing site avoids plumes, low chance of debris impact	4	36	N/A
				Acoustics/vibrations from launch	5	Vibration and resonance testings	1	45	Modify landing lander accoring to testing results
	Lander temperature drops below minimum operating temperature of instrumentation and electronics	Lander and instrumentation freeze	8	MLI blanket rupture	1	Specific landing site chosen to avoid space debris	4	32	N/A
				Thermal transient not in equilibrium	1	Heat flow map + TCS created to ensure equilibrium	1	8	N/A

3.1.7: Performance Specifications and Predictions

Engine Data

The lander will utilize an MR-106L resistojet rocket engine built by Aerojet Rocketdyne, which will burn hydrazine as a monopropellant. The engine has a specific impulse ranging from 228 to 235 seconds and can produce between 10 N and 34 N of thrust. The engine requires a max propellant flow rate of 14 g/s and a maximum electrical power input of 36.16 W for the valve, valve heater, and catalyst bed heater. It is also flight-proven in extreme temperature conditions that meet the requirements for this mission. The engine will be situated in the aforementioned Section B of the lander, with its propellant tank being placed right above it. Finally, this engine is the best choice for the lander because it matches the thrust requirements and is a flight-proven engine, developed by Aerojet Rocketdyne, a well-renowned rocket engine company.

Environmental Predictions and Mitigations

One major hazard plaguing this project is the cold temperatures that are present on Enceladus. Enceladus has an average temperature of about -200°C, and with that comes a myriad of issues for the lander. The first issue is simply the extreme cold of the surface, which is mitigated by the lander’s thermal control system/MLI apparatus. However, recent scans and mapping of Enceladus show it to have superfine ice crystals and particles dominating the landscape. The massive plumes also slowly deposit fine snow particles on the landscape; however, this deposition is minimal, with an estimate of about 100 meters taking tens of millions of years. Additionally, due to the low gravity of Enceladus, only 0.113 m/s^2, slippage on the icy surface of Enceladus would be nearly impossible. The team understands these issues and has adapted the lander legs to fit the extreme conditions of Enceladus.

The lander has four legs made out of Inconel, a custom made nickel and chromium superalloy. Inconel minimizes internal heat lost to the surface of the moon through conduction, thus allowing a longer operational life. Additionally, the lander has adopted a flat plate style on each leg, allowing for maximum hold without slippage and ensuring a smooth final landing.

Another concern for the lander was the unusual landscape patterns of Enceladus. Due to the small scale of the Cryogenesis lander, small perturbations near the landing site, such as a small crag jutting out, could prove fatal to the final descent maneuver, and thus, the project. The team utilized a program known as the Java Mission-planning and Analysis for Remote Sensing system, or JMARS. JMARS assisted the team in identifying a precise landing zone that would meet both the project’s scientific goals and avoid any unnecessary hazards.

3.1.8: Confidence and Maturity of Design

Cryogenesis is a science-driven mission that will explore the possibility of microbial presence on Enceladus using MASPEX and seismometry. The lander's scientific data will offer further understanding of similarities of the organic composition on Earth and other celestial bodies. MASPEX will collect the large organic molecules ejected from jets with its improved sensitivity we hope to decrease the ambiguity of Hydrocarbons up to C8, Nitriles, O-bearing hydrocarbons, NO-bearing hydrocarbons, H2S, PH3, Ar, C3H5Cl that were observed from Cassini spacecraft to identify biological activity and enable the search for life. The seismometer will also provide more insight into the ice shell response to the environmental stresses compared to the rocky core. The seismometer will also give more information on the interior structure of Enceladus to assist the team in understanding the tidal heating process and how it is divided between the core, ocean, and ice shell. The MASPEX and seismometer will both be supported by the lander's power source and communications system. The design evolved by deciding what the main mission criteria and tasks were. The plumes and possible organic material drove the team to use the MASPEX and seismometer to gather information about the surface and plume material. The lander will be sent to the East Antarctic Plateau to test if this can withstand the coldest, uneven Earth environment. The MASPEX, seismometer, and entire lander systems will test with the ice, snow, and harsh conditions.

One key aspect of the lander that changed over time was the materials used for the hull and the legs. The hull's original proposition was 6061 Aluminum; this material was chosen due to its resistance to extreme temperatures and machinability. The team decided on AL-2024 as its hull material soon afterward due to its greater resilience to thermal deformation, and its greater resistance to imparted forces during landing. It also exhibits similar workability to AL-6061. The legs for the lander were also originally chosen to be AL-6061; this was scrapped soon afterward since AL-6061 has a relatively high coefficient of thermal expansion. Inconel 600 was chosen as its replacement. Inconel has a 75% lower coefficient of thermal expansion compared to AL-6061, meaning thermal conduction through the lander would be significantly lower. Additionally, the internal grille was originally a solid plate of AL-6061. To cut down weight, the solid plate was replaced with a grille consisting of multiple circular holes. This gave the lander an approximate 6% decrease in weight without a decrease in its factor of safety.

The lander will undergo a variety of integration testing before launch. The initial testing would consist of burp testing the engine and lander to ensure proper plumbing and wiring. The lander will also undergo drop testing to account for unforeseen events during vertical descent and to account for any potential side loading on impact. Resonance and acoustics data will also be collected during engine firings to plan for mitigation of any hazards that arise. The lander shall also undergo rigorous physical testing of its internal components, such as its power supply, communication system, and wiring harness.

The Electra-Lite UHF Transceiver casing was reduced by ½” in height allowing for a good fit into the lander. Originally with dimensions 6.35” W x 8” D x 4.11” H and now with the redesign of its casing giving the final size of 6.35” W x 8” D x 3.61” H.

3.2: Recovery and Redundancy System

The Cryogenesis spacecraft includes 40 layers of Multi-Layer Insulation that will prevent damage from cosmic rays to the onboard equipment, electronics, and will provide thermal regulation. Another purpose of the thermal control system is to help avoid ‘Single Event Latchup’ which can short out chips on the circuit boards to ground. To avoid any sort of high latch-up onboard, the team included a voltage regulator. The software onboard will power cycle the UHF transceiver to continue the efficient running of the communication and testing equipment on board.[1] The software onboard will also initiate the experiments autonomously with the completion of multiple stages in order to commence the testing.

Another key component onboard the lander is the monopole antenna or what is known as a whip antenna. The use of their low directionality will be of great use in the case of the malfunctioning of the UHF antenna. Even though this UHF antenna has been through rigorous tests in case of its failure, the monopole antenna has the capability to communicate through robust scenarios, such as tumbling of the lander, in which case, the lander can communicate in almost any sort of orientation due to it being low gain.[2] One great drawback would be the uplink times as it provides a lower transmission rate of data.

Lastly the lithium ion VES 180 batteries which are built by Saft have shown promising results especially for space vehicles. A VES 180 battery will be surrounded by interstitial materials that will help “absorb and distribute energy so that it is not localized to a single neighbor, which may help to prevent the thermal runaway.”[3] Apart from this a PPTC (Polymeric Positive Temperature Coefficient) device will be incorporated in the circuit design in case of overheating of the battery.[4] This will help detach the battery cell as soon as possible from the components avoiding further overheating of that specific cell which could have caused thermal runaway creating even bigger issues with other close by components. The PPTC device will create a resistance with three orders of magnitude by causing the crystallites it is composed of to change whenever an abrupt current or temperature spike is detected.

---

[1] https://mars.nasa.gov/MPF/rovercom/radio.html#:~:text=The%20Microrover%20radio%20is%20located,the%20wall%20of%20the%20WEB.
[2] https://www.nasa.gov/smallsat-institute/sst-soa/communications
[3] https://www.nasa.gov/offices/nesc/articles/li-ion-batteries
[4] https://www.mpoweruk.com/protection.htm

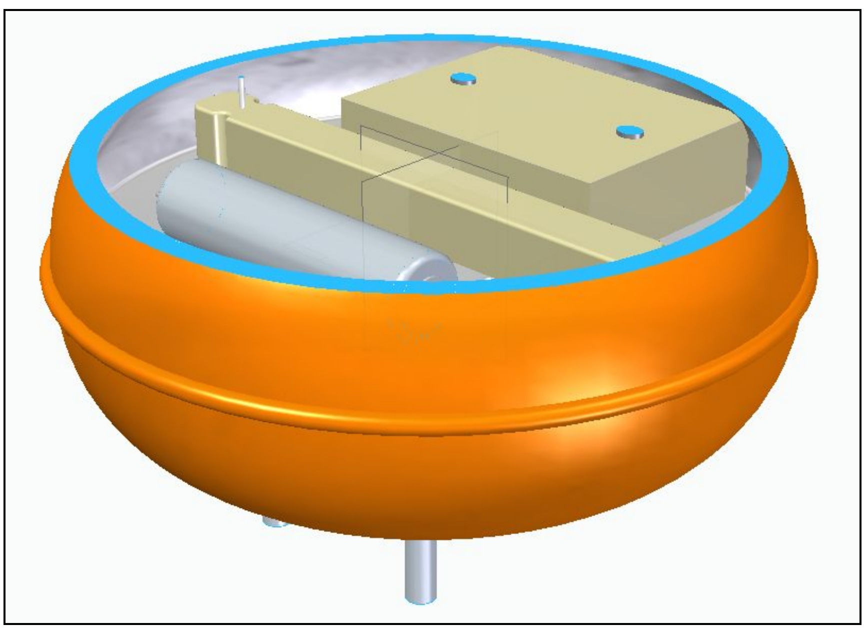
3.3: Payload Integration

The Cryogenesis project has one main instrument, and two other, smaller instruments. Of main importance is the MASPEX. Section A, or the top half, of the lander will house the MASPEX. The MASPEX will be seated on the internal grille, as mentioned in Section 3. The MASPEX is a COTS item that will ship with bolt holes in the instrument; a drill press will be used to properly bolt and affix the MASPEX into the grille. The MASPEX will also contain a large funnel used to collect particles that stabs through the hull.

The lander also will carry 2 seismometers, which will be situated in Section B, or the bottom, of the lander. They will be affixed to the landing legs, diagonal from each other They will be tied down to the lander using steel ties in a cross beam style. Each tie will also be securely bolted to the lander to ensure that the seismometers experience minimal turbulence.

Finally, the lander will contain a gas chromatograph. This will be placed right alongside the MASPEX. In fact, the intake of the GC is valved off to the MASPEX intake to avoid dual funnels. This instrument is also located on Section A.

The image below shows the instrumentation, such as the UHF transceiver box, the MASPEX, and the VES180 power supply.



Cutaway CAD Model showing UHF Transceiver, VES 180, and MASPEX

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1. System Overview

The main systems used to maintain the instruments on the surface will be the battery pack, which will supply the power, and the thermal control system, which ensures the instruments do not get too cold. The lander will utilize MLI (Multi Layer Insulation) similar to what was used on Cassini to hold in the heat generated by the electronics of the lander and to protect the lander from radiation. The benefit of using MLI is that it does not require any power. Power for the lander will be provided by a 180W lithium battery, and the systems that will be using power are the computer, the communication system, the engine, MASPEX and the seismometer. The engine will use a maximum of 49W during the descent, and after landing will shut down and not consume any more power.

The payload consists of three scientific instruments, MASPEX, a gas chromatograph and a seismometer. MASPEX will be used to to study large organic molecules ejected by Enceladus' plumes that fall out back onto the surface, and the gas chromatograph will be used to study trace gasses at the surface. The seismometers will measure the seismic activity of the surface at the landing site, and will also pick up seismic activity from the ocean floor, which will hopefully provide information about the core of the moon.

4.1.2. Subsystem Overview

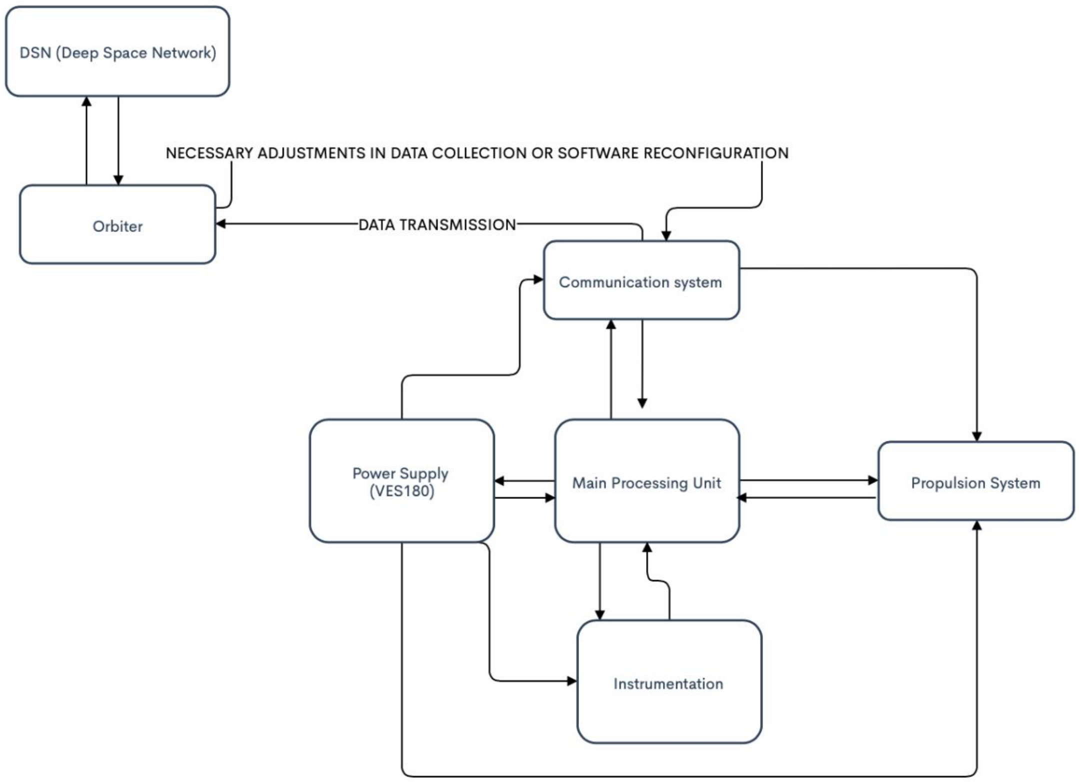
The subsystem that supports the MASPEX system includes the use of a cryotrap and gas chromatograph refinement subsystem. A vacuum system is needed to ensure the mass spectrometer is brought down to the low pressures needed and fast introduction of sample materials into the MASPEX system.

The lander will utilize the Electra-Lite UHF Transceiver for data acquisition and communications. The data packets from the lander will be sent through the team's UHF antenna and also could be sent through the monopole antenna in case of an emergency. The main method of communication will be through the UHF monopole antenna that will have a return frequency (from lander to orbiter) at around 402 MH.[5] This will allow engineering telemetry information to be sent to the orbiter for communication with Earth. The orbiter will work as an amplifier to give clearer information on tests and data being collected on Enceladus. The digital board will allow communication between the analog board and the computer. The digital board

---

[5] https://descanso.jpl.nasa.gov/DPSummary/MER_article_cmp20051028.pdf

will receive and command information allowing the UHF antenna to know when it is time to listen or send out information.[JG2] During the sending stage of information from the lander, the UHF transceiver will power on to send out radio waves which are then taken and formatted by the digital board. This information will then be sent through the UHF antenna that will be received by the nearby orbiter when it is in view for the lander and will act as a repeater for this incoming information. This will then be sent to the Mission Control Center which will use the DSN to collect any incoming information.



4.1.3. Manufacturing Plan

MASPEX will be produced and manufactured at it's parent company Southwest Research Institute. The gas chromatograph will be partly off the shelf and designed as there are minor modifications needed to be made to the oven system and the premade coils to ensure the proper functioning of the system as a whole. The seismometers will be off the shelf produced by parent institute Arizona State University. As suggested by Principal Investigator Hunter Waite via communications, a cryotrap will be designed and developed to accommodate the size constraints of the lander. The cryotrap will be based on an off the shelf version sold by Xtractor Depot.

4.1.4. Verification and Validation Plan

The payload will consist of MASPEX, seismometer (SIIOS) , gas chromatograph, and cryotrap refinement subsystem. The spacecraft will go through rigorous structural testing in order to ensure the payload will survive both launch and landing. Once verification methods and activities are finalized this will help in proceeding with development of the mission. Requirements for the scientific instruments include ability to collect samples of the Enceladus plumes through the cryotrap, trace gasses at the surface with the gas chromatograph, and analyze organic molecules. Along with the harsh temperature testing that the payload will be put through, there will be additional acoustic testing that will simulate the vibrations of the lander as it descends through and to the Enceladus surface. This verification test will show structural integrity of the lander as a whole and will ensure science instruments will be able to function accurately.

The complete spacecraft will be tested in Alaska to validate that the payload will be able to operate and collect data in a harsh environment similar to the surface of Enceladus. This test will verify that the MLI will be able to maintain the internal temperature of the spacecraft for a long period of time, and will also provide a chance to test the data collection abilities of the payload in a known environment. The advantage of testing the payload this way is that it will be able to cross check the data collected by the scientific instruments, to ensure that they are working properly. To more accurately simulate the surface temperatures on Enceladus, the spacecraft will also be submerged in liquid nitrogen, to fully validate the ability of the MLI to maintain the internal temperature of the spacecraft.

Verification testing of the MASPEX, cryotrap, and gas chromatograph will be completed through testing various samples of atmosphere collections of organic molecules. Accurately recognition of known molecules in the similar simulated environments like that of Alaska will verify that collection and analyzing is successful, showing instruments are functioning as intended to.

The instrument verification of the seismometer (SIIOS) will show that there are appropriate readings of movements of the area it will be set on. This will be tested through comparison of other similar seismometers in the same environment showing accuracy and reliability to record the correct data once upon the Enceladus surface.

4.1.5. FMEA and Risk Mitigation

Seismometer (SIIOS) needs to be in a well protected vault to avoid wind detection from environment since it will be mounted on lander, usually seismometers are deployed in small array depending on the frequency we are interested in but outside conditions do not permit that deploying at the stiffest joint will provide reliable data, we are deploying two seismometers probably of the same instrument type because of the difficulty to space qualify instruments, due to irregular terrain in order to ensure recording of seismic motion along the 3 separate components we are using a broadband seismometer and using silicon audio to meet criteria, we will observe and take into account the self noise produced by instrument.

GC/MS will include a cryotrap sampling system which provides over three orders of sensitivity enhancement, it will be in a vacuum to provide a radiation-hardened vault, a low leak rate high conductance valve isolates the instrument from the external environment. We were advised that mass spectrometry on its own relies on the purity of the sample and there is the possibility of two different molecular fragments sharing a similar ionization pattern, while GC on its own typically cannot differentiate between multiple molecules that have the same retention time and therefore elute at the same time.

Table 1. FMEA Characterization.

Severity	Classification	Equipment/ Maintenance cost	Production	Environmental	Risk1 Remote	Risk 2 Extremely Unlikely	Risk 3 Very Unlikely	Risk 4 Unlikely	Risk 5 Likely
5	Disastrous	Extensive damage >$8M	Major Loss, not recoverable. More than 3 days lost production.	Major pollution with sustained environmental consequences external to the site	5	10	15	20	25
4	Catastrophic	Major damage $6-$8M	Major loss. Up to 50% not recoverable Up to 3 days lost	Major pollution external to the site. Evacuation of persons	4	8	12	16	20

			production.						
3	Major	Localized damage $2M-$6M	Medium loss, not wholly recoverable through normal production <24 hours lost production	Moderate pollution, within site limits. Product liability	3	6	9	12	15
2	Serious	Minor Damage $200K-$2M	Minor loss recoverable through normal production 2 to 8 hours lost production.	Spill or release of pollutant without environmental consequences	2	4	6	8	10
1	Moderate	Slight Damage <$200K	Little to no effect. Production easily recovered. <2 hour lost production	Minor spill or release of pollutant.	1	2	3	4	5

4.1.6. Performance Characteristics

Enceladus reflects most of the sunlight away from itself creating a cold environment of about minus 330 degrees Fahrenheit (minus 201 degrees Celsius). Its icy surface is remarkably smooth in some places littered with house-sized ice boulders and regions carved by tectonic patterns unique to this region of the moon. Icy water particles and gas gush from the moon's surface at approximately 800 miles per hour (400 meters per second). Enceladus will be in the Southern Autumnal Equinox and transitioning to winter. A wide range of volatile organic compounds were successfully separated at temperatures below 120 °C. Vacuum packaging reduces the steady-state power requirements to less than 100 mW. Under vacuum conditions, 600 mW is needed for a temperature-programming rate of 40 °C/min. The TCR (2300 ppm/°C) of the temperature sensors and the sensitivity (50 fF/kPa) of the pressure sensors satisfy the requirements to achieve reproducible separation in a µGC system. While no perfect terrestrial analog for Europa exists, Gulkana is used as an analog site because it is accessible, well-studied, and has thick ice with passive sources that mimic those on icy worlds. The testing of SIIOS was performed at Gulkana Glacier in September where temperature ranges from low of -35°C to a high of 16°C. Testing is also conducted at different locations in Greenland in similar conditions.

4.2. Science Value

4.2.1. Science Payload Objectives

The original mission science goals mentioned in section 1.2.3. state:

> “MASPEX will collect the large organic molecules ejected from Enceladus’ plumes. With its improved sensitivity, we hope to decrease the ambiguity of hydrocarbons up to C8, nitriles, O-bearing hydrocarbons up to C8, NO-bearing hydrocarbons, H2S, Argon, and C2H5Cl that were observed from Cassini spacecraft to identify biological activity and enable the search for life on the ocean moon.”

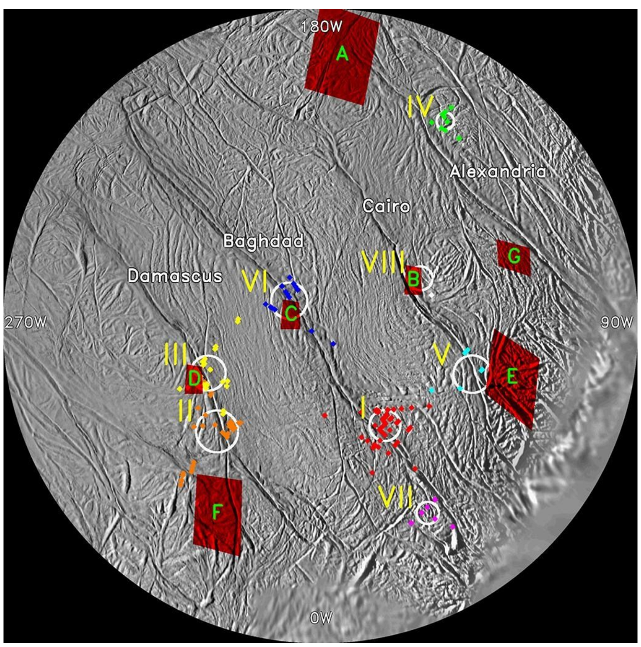
The Cryogenesis team has decided on this main objective for MASPEX’s function in response to the outcome of Cassini’s data collection. As mentioned in the seminar ‘Enceladus: The best characterized ocean world beyond Earth’ seminar by Johns Hopkins Applied Physics Laboratory planetary scientist Shannon MacKenzie, Cassini was able to characterize physiochemical conditions for life via the identification of biosignatures. However, the Cassini mission was not able to pinpoint the exact composition of those biosignatures due to increased ambiguity of the ion and neutral mass spectrometer. In order to further investigate the precedent Cassini has set, MASPEX is the instrument of choice as it has enhanced mass range for heavy organic molecules, improved mass resolution which provides insight into critical isotopes found in compounds, and improved sensitivity overall. MASPEX is also highly diverse in its mission applications making it in the run to be included in Europa Jupiter System Mission (EJSM), Europa Clipper mission, Jupiter Icy Moons Explorer Missions (JUICE), and other ocean worlds such as Enceladus.

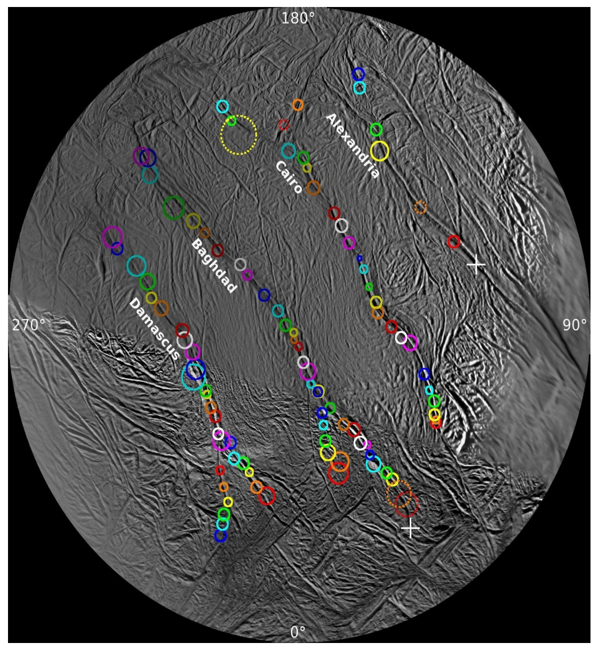
In order to obtain the desired level of specificity needed to mission success, MASPEX will work in conjunction with gas chromatography and a cryotrap system. This system provides data on the identification of chiral compounds and biosignatures to confirm and establish the claim of life present in the oceans underneath Enceladus’ icy shell, and possible origins of that life via plume sampling. The cryotrap retains the sample of gas and keeps the sample static as new material from the plumes is collected. Gas chromatograph will analyze compounds before traveling into the cryotrap and then the MASEPX instrument. Such data will be obtained via cryotrap, gas chromatography, and mass spectrometry analysis processes. MASPEX will also be able to further detect the pH and oxidation states of the plume fallout it collects. Overall, MASPEX will identify amino acid patterns, clusters of membrane-building molecules, and compositional trends. For improved clarity, generation 3 of MASPEX is the instrument being discussed.

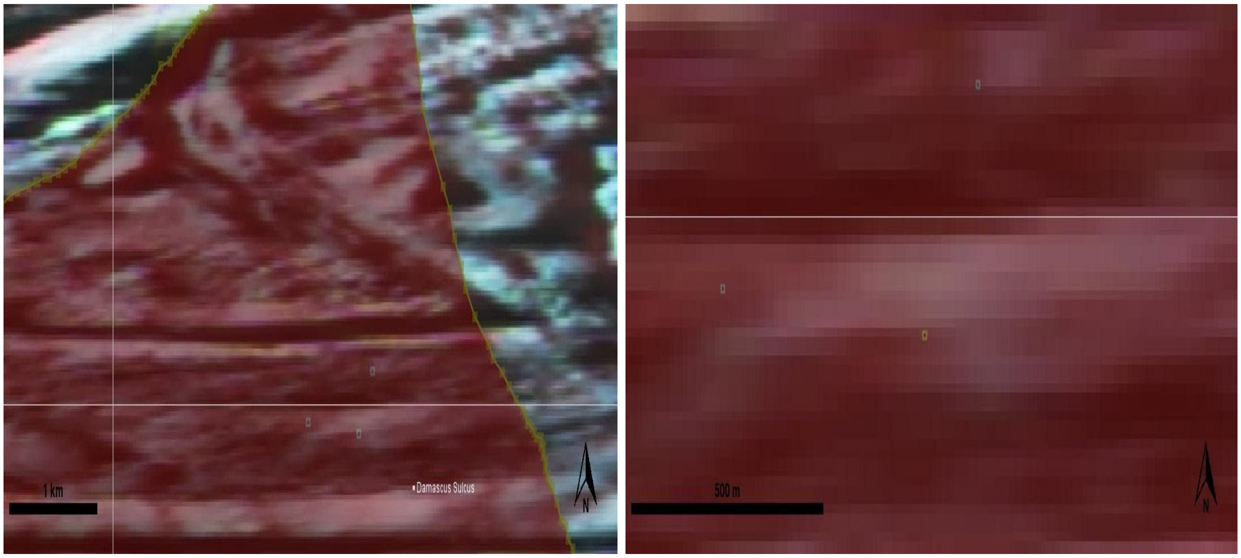
The seismometer will also provide heightened insight on the active geologic activity as well as the ice shell response to environmental stresses compared to the rocky core. It will also help gain more information on the interior structure of Enceladus to understand the tidal heating process and how it is divided between the core, ocean, and ice shell. The seismometer was chosen to more accurately determine the depth of the global ocean as well as the presence of lakes nestled in the ice. Enceladus' tiger stripes region is constantly shifting, possibly due to the higher heat areas at the southern pole. The seismometer will investigate the movements and stretching of the ice crust at the southern pole, possible moonquakes, and ice shell thickness as well as subsurface ocean depth. Overall, the array of seismometers has a goal of pinpointing sources of seismic activity.

4.2.2. Creativity/Originality and Significance

The project's mission will be collecting larger organic molecules ejected from the plume to improve humanity's understanding over Enceladus' inner workings to identify biological activity and enable the search of life. While also collecting data to provide information on how environmental stresses impact this icy moon to detail the tidal heating process and how it divides the process in order to create the material that makes up the jets. Site of landing was chosen based on the team's science needs and referenced from Enceladus Jet Sources as well as Surveyor's Map of Enceladus' Geyser Basin provided by NASA's Cassini spacecraft. The spacecraft will be landing near the Damascus sulcus coordinates -80.121°N, 72.684°E due to the level of activity, proximity to a jet source, warmer temperature, line-of-sight intersections, and moderate level of uncertainty on the location.







Enceladus Landing Site via JMARS program.

4.2.3. Payload Success Criteria

The MASPEX shall analyze organic molecules, pH, and oxidation states of the fall out plume . Full success of MASPEX will be if there are no ambiguous results of C8, nitriles, O-bearing hydrocarbons up to C8, NO-bearing hydrocarbons, H2S, Argon, and C2H5Cl. The gas chromatography and a cryotrap system shall record data on chiral compounds collected from the atmosphere containing heavy plume material. Biosignatures may not be recorded due to lack of knowledge of the Enceladus beginnings. Confirming biosignatures will be of great success and will help further knowledge of bio organism beginnings. The gas chromatograph shall analyze samples of traveling gases while cryotrap collects samples of gases from the atmosphere and retains them. The seismometer shall take measurements of the movements and stretching of the ice crust around the southern pole. If movements minimally relating to those seen in field testing are not recorded this will demonstrate failure to collect appropriate data due to knowledge of basic rhythmic movement of water retaining surfaces. Ability to appropriately record shifts of the ice surface will further understand the behavior of Enceladus and its subsuperficial flowing waters. This may help show correlations between the locations of the tiger stripes and how the body of water under the surface behaves.

4.2.4. Experimental Logic, Approach, and Method of Investigation

Once we land on the surface of enceladus we have chosen a landing site that is close to a jet source, with warmer temperature, many line-of-sight intersections, and moderate level of uncertainty on the location. The location provides an area where activity as well as plume sources were observed and calculated by the Cassini spacecraft to help collect samples through the MASPEX funnelling system that did not reach escape velocity. Collecting larger and denser particles that fall back onto the surface as snow as well as vapor in order to investigate planetary biosignatures.

The funnel will reach its first microelectromechanical systems (MEMS) technology in order to heat the sample and feed it into the vacuum pump that will pass the molecules into the injector system in order to begin the separation technique performed by the Gas Chromatography (GC). In the GC system, a sample is vaporized and injected into the head of the separation column packed with a finely divided solid or coated with a film of a liquid. When a sample passes the column by the flow of an inert gas employed as the mobile phase, its components are separated due to differences in their interactions with the stationary phase. Upon extracting one material from another by washing with a solvent, the separated compounds pass over a detector that generates a signal corresponding to the concentration of the compound.

Following a linear pattern the Ion source will be separating the GC from MASPEX which determines the mass of some chemical components in the atmosphere and how the chemicals are affected with Saturn and Diones gravitational pulls to build up a record of not only what kind of ion molecules but also how many. Also adding to development by looking for biosignatures. The multi-bounce lenses, mirrors and drift tube make measurements of amino acids and hydrocarbon gases possible.

Lastly, a seismometer to investigate Ice and Ocean structure (SIIOS) will be used to measure the movement of Ice and the depths of the ice and water. Assessing the habitability by detecting the ocean and constraining the crustal thickness to identify how close sources of liquid water are to the surface and also characterizing surface properties to support future explorations. Also providing information pertaining to the tiger stripes dilation and contraction and active plumes compared to the influence of the tides. Identifying Seismic velocities will constrain the structure to connect local properties and begin to quantify how geologically active Enceladus is. The team will need to evaluate self noise to identify the events that will be detectable by the seismometers as a function of frequency.

4.2.5. Testing and Calibration Measurements

To ensure the proper functioning of Cryogenesis' instrumentation systems and subsystems, rigorous testing cycles will be performed in testing facilities on Earth and on the surface of Enceladus. The instrumentation being tested includes one MASPEX instrument, two gas chromatographs, one cryotrap, and two SIIOS seismometers. To test on Enceladus, baseline values and comparative control measurements will be done in the laboratory and in the field.

MASPEX will undergo a series of testing in the laboratory. The primary testing will be performed by the manufacturer, Southwest Research Institute, and will then be testing at Glenn Research Center for in-flight simulation testing. Basic testing will ensure that MASPEX is able to operate at the level of specificity required for mission success. Laboratory procedures shall include introducing the previously mentioned target compounds into MASPEX alone, and separately in conjugation with the rest of the system– gas chromatograph and cryotrap.

Gas chromatographs will also undergo similar testing as MASPEX in terms of types of compounds introduced. There is a necessity to ensure the oven is adequately functioning to heat the coil in order for the gas chromatograph system to function properly. The testing of the integration of MEMS technology as a replacement for bulky components will also be carried out.

The cryotrap is a smaller device, but will need to be tested on its own as well as in conjunction with the other systems.

SIIOS seismometers will need to be testing in the laboratory and in the field. In order to establish stable and reliable readings for this seismometer, it will be necessary to test in a vacuum chamber. The results will be compared to the most accurate seismometer declared by the United States Geographical Service (USGS). This particular instrument is capable of detecting minute amounts of stress, so it is necessary to test at the Structural Dynamics Laboratory (SDL) in order to observe the amounts of vibrations stress it can endure, whether it will survive launch, travel, and landing, and what baseline amount of noise to factor out of data readings during these events.

SIIOS will undergo field testing in Alaska in order to complete active source comparative testing. The Alaska testing will be conducted on Gulkana Glacier where it was previously tested for the Europa mission as well. The instrument will be testing directly on top of the ice and on top of a basic lingerie structure. This will allow for daily monitoring of signals due to glacier movement as well as the influence of layering of ice, water, and rock. (Marusiak). To obtain consistent signal data, a 25-lb hammer will be used to strike an aluminum plate 15 times in 3 different locations on the glacier. Compressional (P-waves) and shear (S-waves) arrival times are used to determine the P-wave velocity in terms of ice depth. A similar SIIOS experiment is to be conducted in Greenland over a subglacial lake that will be compared to possible subglacial lakes on Enceladus. The same methods will be used to calculate the P-wave velocity. The results are to be used as a comparative control.

All the aforementioned instruments will need to be tested in the Structural Dynamics Lab (SDL) in order to verify how structurally sound the components are in assemblage, also known as environmental stress screening. This screening includes sinusoidal vibration, random vibration, and shocks. The instruments will undergo modal testing where modal shakers will simulate impact and MIMO. This testing is all compared to a previously established control studied at the Glenn Research Center. This testing will work together with the Microgravity Emissions Laboratory (MEL) to simulate instrumentation function in microgravity environments. Testing will also be performed at the Structural Static Laboratory to test modes of possible failure occurrences such as leaks, strain, and ultimate failure.

Once a successful landing has been achieved on the surface of Enceldaus, the instruments will run at full capacity and properly calibrate for 10 minutes. MASPEX will run 5 collections and analysis to determine the system is functioning as well as determining the control relative to Enceladus' environment and baseline planetary ice and core movements. The initial calibration of MASPEX also requires the funnel inlet design, gas chromatograph, and cryotrap to be tested.

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

Timing will be obtained with a GPS Synchronizer with 1-2 microsecond accuracy. The flight-candidate seismometer performs comparably to the TPH at frequencies above 0.1 Hz and that instruments coupled to the mock-lander perform comparably to ground-based instrumentation in the frequency band of 0.01-10 Hz. A highpass. Filter of 90Hz will be applied to the table data to remove the effects of the table's resonance.

Optimizing GC separation requires fine-tuning of a number of variables and their interactions. Both physical (internal diameter, length, and stationary phase) and parametric (temperature and flow velocity) column variables affect the separation process. The longer the column, the more theoretical plates and the better the separation. Resolution is proportional only to the square root of the column length, that is, if the column length is doubled, the resolution increases only by the square root of two or 41%.

Extended mass range (>100 amu) for heavy organic molecules. Enhanced mass resolution(>30,000 M/dM) for critical isotopes. Enhanced dynamic range (10^9 in a 1s period) for high S/N. Improved sensitivity (better than 1ppt with cryo) for rare noble gases. High throughput (>5000 samples/s) for rapid descent probes.

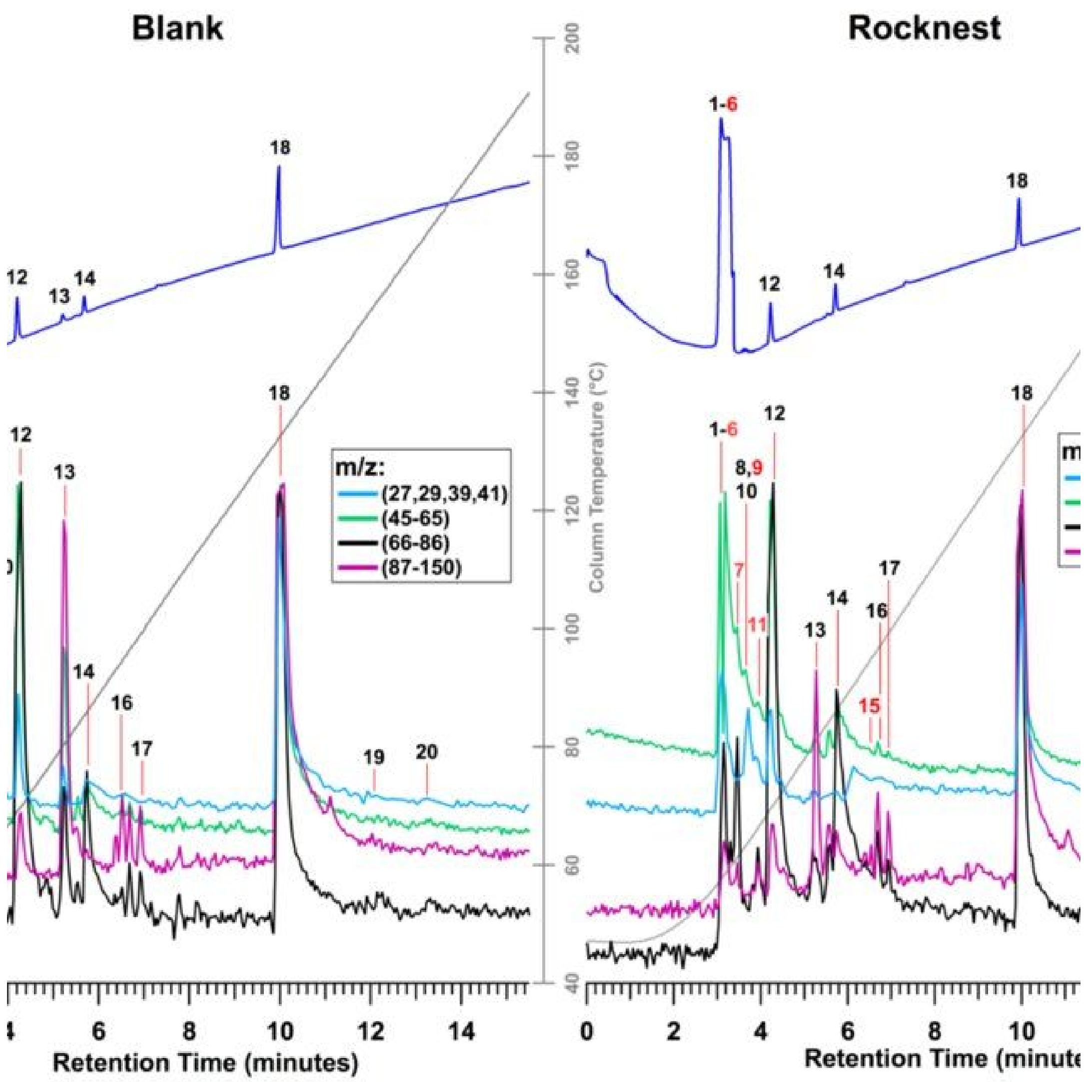
Once safely landed on Enceladus, all instrumentation systems will undergo testing to ensure functionality and determine a baseline. As mentioned in the previous section, all instruments will be calibrated for 10 minutes and run 5 times to collect baseline data. This includes the MASPEX, gas chromatograph, and cryotrap system as well as the seismometers.

The landor will deploy with two seismometers probably of the same instrument type because of the difficulty to space qualify instruments.Which allows the lander to have redundancy to identify how close sources of liquid water are to the surface and also characterizing surface properties achieving the missions success criteria . Being informed that mass spectrometry on its own relies on the purity of the sample and there is the possibility of two different molecular fragments sharing a similar ionization pattern, combining it with GC will provide separation of different components of a mixture and help the identification of a compound. Providing some kind of redundancy with the identification and sampling of plume and gas material on Enceladus.

Data packets contain the information payload. The three way handshake is used to make sure that both the sender and receiver agree to communicate before data is sent across the wire.They can also be sent through the monopole antenna in case of an emergency. The orbiter will work as an amplifier to give clearer information on tests and data being collected on Enceladus.Radio waves will be taken and formatted by the digital board. This information will then be sent through the UHF antenna that will be received by the nearby orbiter when it is in view for the lander and will act as a repeater for this incoming information.

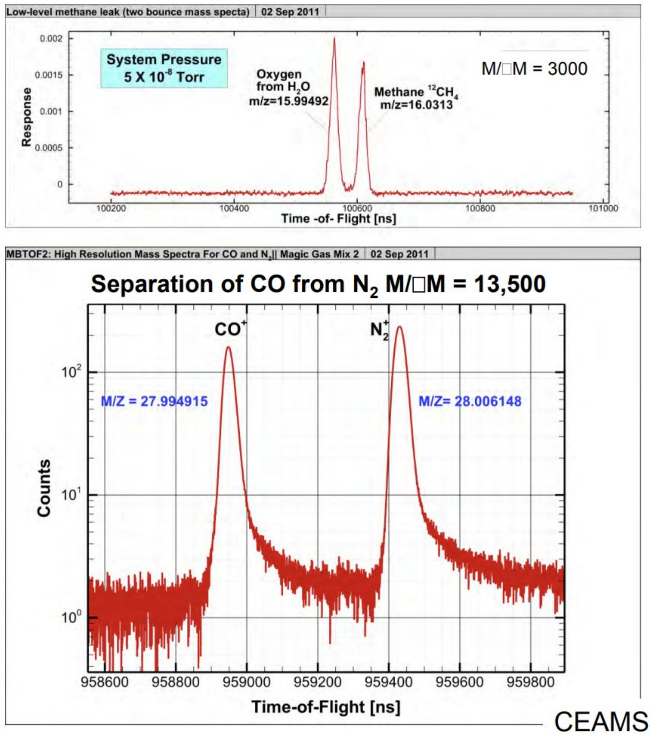
4.2.7. Expected Data & Analysis

The gas chromatograph and MASPEX have similar expected data reporting via graphs over time. Below are two examples, the first corresponds to a gas chromatograph and the second to MASPEX.



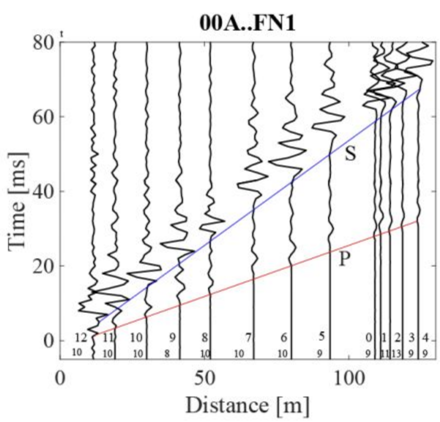
Expected Data for Gas Chromatograph. Example sourced via the *Volatile, Isotope, and Organic Analysis of Martian Fines with the Mars Curiosity Rover* research paper.

MASPEX Performance (High-Resolution Mode)

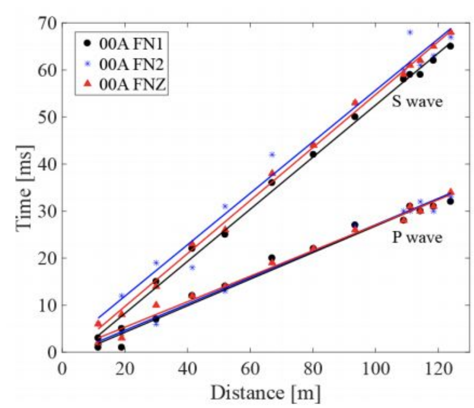


CEAMS / SwRI, H. Waite

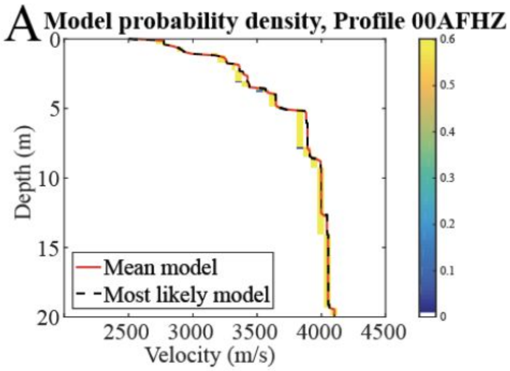
Expected Data for MASPEX. Sourced via Peter Wurz's *Mass Spectrometric Investigations of the Atmospheres of Giant Planets* presentation given at the International Planetary Probe Workshop (IPPW) 2019 at Oxford University.

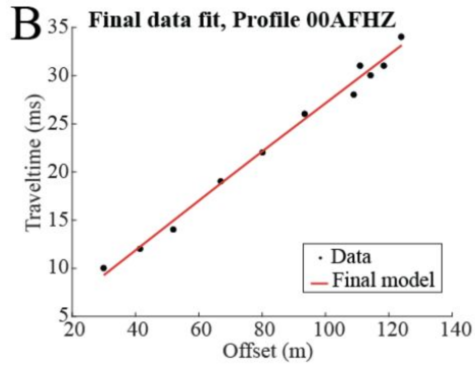


A



B





C D

Expected Data for SIIOS Seismometer. Figures A-D are sourced from *SIIOS in Alaska-Active Source Comparative Test for an Europa Lander Seismometer* research paper presented at the 49th Lunar and Planetary Science Conference.

MASPEX and chromatography data is to be interpreted based on the number and location of peaks on the provided graph. Seismometer raw data will be transformed to model probabilities for velocity as a function of depth. This information will be submitted and reviewed via peer review panels and presented on the team's website.

5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

The Cryogenesis Safety Officer is Rosalina Ascencio and Jaden Carollo. Both will take roles and responsibilities regarding the safety of the mission from beginning to end. This role is responsible for inspecting site conditions to determine if there are any hazards present and to establish procedures and policies that might be hazardous to the personnel and lander/payload during the course of the mission development, launch, and landing operations. Sources used to generate the team safety protocols for the duration of the mission are detailed at the end of paper.

5.1.2. List of Personnel Hazards

- The lander requires precision machining out of AL-2024. Aluminum is commonly extruded and weldable, but the odd shape of the lander creates a possible hazard to inexperienced personnel.
- Chemicals (hydrazine) involved with testing - potentially harmful… could lead to cancer developing later in life, poisoning, and even death.
- Personnel will be working with tools to assemble instrumentation.
- The project will produce scrap, debris, and waste that can harm personnel.
- Personnel could be lifting objects up to 25 lbs.
- Personnel will be in a high level of noise environment.
- The environment will have many wires exposed providing uneven surfaces.
- Welders need adequate ventilation in and where welding or cutting is performed.
- The environment can produce metallic or conductive dust.
- Personnel will be handling heavy instrumentation.

5.1.3. Hazard Mitigation

- Limiting the amount of personnel working on lander at one time.
- Hydrazine: (Prevention) NO open flames, NO sparks, and NO smoking. Above 40°C use a closed system, ventilation, and explosion-proof electrical equipment. complete protective clothing including self-contained breathing apparatus. Do NOT let this chemical enter the environment. Collect leaking liquid in sealable non-metallic containers. Absorb remaining liquid in sand or inert absorbent. Then store and dispose of according to local regulations. Do NOT absorb in saw-dust or other combustible absorbents. Fireproof. Separated from acids, metals, oxidants, and food and feedstuffs. Keep under inert gas. Provision to contain effluent from fire extinguishing. Store in an area without drain or sewer access.

- Tools will be provided and need prior approval before starting work.
- We will provide designated areas and trash bins to properly dispose of any scrap, debris, and waste.
- Managers will cover basic lifting protocols during orientation.
- We will be providing earplugs, gloves, safety glasses, safety helmets, N95 masks or respirator masks, hand sanitizer, Lysol wipes.
- Areas will be zoned as a preventative measure of workplace hazards.
- Ensuring that the welding zone is in close proximity to the ventilation system.
- We will provide employees with essential cleaning supplies for their area.
- Lander/orbiter assembly shall only be moved or rotated by a qualified hoist operator.
- Enforce dress code.

5.2. Lander/Payload Safety

5.2.1. Environmental Hazards

- The surface of Enceladus is still unknown in terms of terrain. This is a hazard to the lander, there is no knowledge of the surface. A few hazards are if the ice is sharp, rough, or how uneven the ground is. The surface seems to have cratered areas, smooth plains, linear cracks, ridges, fissures, and unusual crustal deformation, but there is no knowledge of the extent. This is the largest and most unknown hazard on Enceladus.
- The south polar region is a well-defined warm region reaching 85 Kelvin (-305 degrees Fahrenheit). Even so the temperature poses a hazard to not only to the lander but instrumentation as well with the potential of freezing causing malfunctions and preventing the mission to accumulate data.
- Radiation will be present due to the lack of atmosphere on the surface. Galactic Cosmic Rays (GRCs) strike both Enceladus' surface and the icy particles produced by the plumes. These rays produce ionizing radiation which includes: high-energy electrons, protons, gamma rays, neutrons, and muons. Enceladus orbits Saturn which has a magnetosphere, this is another source of ionizing radiation.
- Enceladus releases icy particles into space and most of the particles have a high enough escape velocity to be ignored, but the larger particles fall back on the moon's surface. There is no research on how large and heavy these particles are, not to mention the velocity of them coming back to the surface. This can be hazardous and damaging to the lander depending on those factors.
- Terrestrial microbes from Earth contaminating Enceladus' environment

5.2.2. Hazard Mitigation

Mitigating landing hazards:

- Slow lander descent for uneven terrain.
- Orbiter can try to map the surface to find the best landing coordinates.

Mitigation Temperature:

- Heat transfer calculations were carried out to reach a steady-state baseline of thermal regulation needed. It was found that equilibrium can be reached by mitigating heat loss to radiation during operations. Multi-layer insulation (MLI) allows extreme flexibility in engineering and lowers both the emissivity and absorptivity of the lander.

Mitigating radiation

- Radiation shielding with non-lead shielding materials.
- Radiation protection from MLI (Cassini used this)

Mitigating falling particles

- Tough top exterior to prevent any lander damage, protection from MLI.

Mitigating terrestrial microbes

- Deep clean and completely sanitize the lander to prevent contamination on Enceladus.

6. Activity Plan

6.1. Budget

The Cryogenesis mission budget has a maximum capacity of $ 400 million USD over all the projected timeline of the mission. The team will be working with a 30% total cost margin for the mission. Below is a more detailed breakdown of the mission budget costs. All costs are calculated in 2020 $USD.

The Cryogenesis mission employs five full-time employees in its personnel throughout the mission timeline. These full-time employees include the project manager, deputy project manager, and sub-team leads: Rosalina Ascencio, Manav Dave, Brianna Platt, Robert Ross, and Evelyn Wendt. Half-time employees include sub-team members. The total salary cost is $ 2,967,512.00 USD (2020). The science team personnel salary total is $ 640,000.00 USD. The engineering team personnel salary total is $ 960,000.00 USD. The business team personnel salary total is $ 720,000.00 USD. Employee Related Expenses (ERE), also known as fringe benefits, cover insurance, retirement, and investment contributions. The ERE for the Cryogenesis mission totals up to $ 647,512.00 USD over the course of the timeline period.

Travel for this mission will include travel to and from the test sites, outreach program sites, and to and from the launch site. This includes hotels, transportation, and per diem spending rates.

The science team sub-team lead, Rosalina Ascencio, will be the employee traveling to and from the testing sites for each scientific instrument. MASPEX will be tested at Southwest Research Institute in Colorado. Ascencio will reside at the Holiday Inn Express & Suites during her two-week stay and testing period for MASPEX. The seismometers used for this mission will be tested in an Arctic environment near Fairbanks, Alaska at Gulkana Glacier. Here Ascensio will reside in the Best Western Plus Chena River Lodge near the University of Alaska-Fairbanks for two weeks testing period. Car rental at $ 351.47 USD will be needed in order to travel to and from the test site and hotel. These travel costs result in a total of $ 5,967.57 USD.

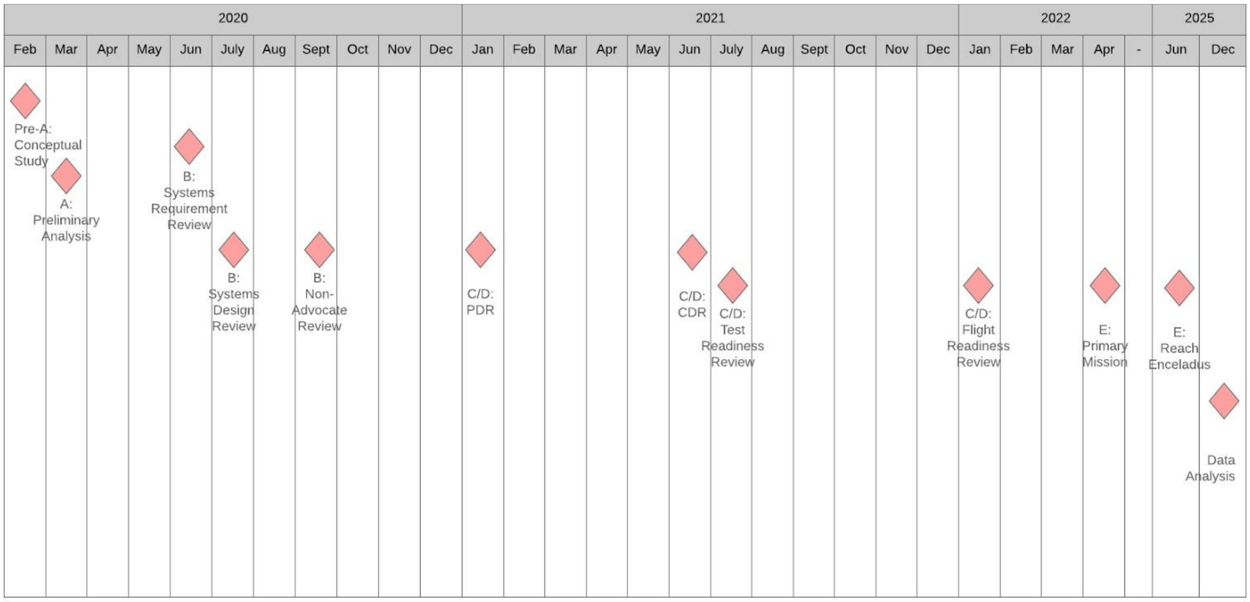
The travel to the launch site totals to $ 42,010.00 USD. All members of the Cryogenesis team will be traveling to the launch site. Departures will depend on the member's town of residence. Manav Dave will be traveling out of the Huntsville International Airport. Rosalina Ascencio, Brianna Platt, and Evelyn Wendt will be departing out of George Bush Intercontinental Airport. Jaden Carollo and Julio Gutierrez will be departing out of the Kansas City International Airport. Robert Ross will be departing out of Wichita Eisenhower National. The flights to and from the launch site range between $ 107.00-159.00 USD. Transportation to and from the Orlando Melbourne International Airport to Port Canaveral will be via 321 Transit bus lines and will cost $ 20.00 per person. The team will stay in individual rooms for a month leading up to the mission launch at Cape Canaveral. The hotel of choice is the Country Inn & Suites by Radisson in Port Canaveral, FL for $ 93 per night. Per diem rates, based on 2020 rates, are $ 71.00 USD on a normal day, and $ 53.25 USD on the first and last day of travel. Transportation for this trip will be using Uber with an allotment of $ 18 USD per person. A carpooling method from the hotel to the Cape. There is a margin if there is a need for emergency travel costs. If need be, gas or Uber reimbursements will be provided depending on the situation. Per person, the total of travel will be $ 6,001.50 USD. Total travel for the group to the launch site $ 42,010.50 USD.

Other direct costs include science instrumentation, COTS components, materials and supplies, and manufacturing and facility costs. Science instrumentation costs include MASPEX, two seismometers, mini gas chromatograph, cryotrap and VES180. Costs for each instrument include Management, Systems Engineering, Product Assurance, and Integration and Testing costs. The total cost of the instruments together is $ 23,966,665.79. Shipping costs, manufacturing and facility costs, and materials and supplies have not been included in this estimate. An additional direct cost is a pack of Golden Oreo Party Size Sandwich cookies for the team celebration after launch that will total $ 5.19 USD from Target store establishments.

Facilities and Administrative (F&A) costs are an estimated $ 80,000 USD per year. This is broken up into the main facility housing development rental cost as well as all of the materials necessary for administrative use. Office supplies will include desks, pens & paper, printers, computers, chairs, lighting, complimentary beverages (water dispenser), and whiteboards. This will also include any prototyping materials that the team will need in the facility. Desks, chairs, and lighting will be sourced from National Business Furniture or Ikea. Pens and paper, including official NASA-branded materials, will be sourced from wholesale office markets such as Quill or Bulk Office Supply. There will be approximately 2 printers located in the facility. Printers will vary from Epson T-Series Color Inkjet printer to a large format printer– taking into account the need for CAD model plan printing as well. If requested, 3-D printing will be available. However, cost estimates for the printer and related materials must be filed and presented ahead of time. Whiteboards will be located in two meeting rooms in order for presentations and planning to occur.

6.2. Schedule

The Cryogenesis mission will take place over a course of roughly 2 and a half years not including the time of the craft traveling to Enceladus. Below is an overview of the mission schedule and will go further in-depth to address more milestones that must be achieved other than the main preliminary design review schedule featured in Section 1.2.5.



Major Milestones Schedule.

Pre-Phase A: Conceptual Study will include the brainstorming of mission ideas in accordance with the main scientific goals of NASA's most recent Decadal regarding water worlds. It will be during this time where preliminary research will be conducted as well as further delving into the possibility of this project budget-wise. This is where a proposed budget will be created, and is up for discussion and debated until the beginning of Phase A.

Phase A: Preliminary Analysis will overview how viable the concept study is. This phase will include an operational feasibility study in which requirements and their proposed solutions shall be reached. Phase A will also include an economic feasibility section in which cost-benefit analysis is conducted to determine the monetary gain from the science conducted via the Cryogenesis mission. This phase will also include research into instrument design and production as well as brainstorming whether development costs will need to be taken into account.

Phase B: Systems Requirement Review will describe the features and operations of the systems planning on being used and developed on the Cryogenesis mission. This stage will also account for the basic level of risk management.

Phase B: Systems Design Review: This review will go over Cryogenesis's system requirements once more and ensure a critical baseline is established in all designs and elements.

Phase B: Non-Advocate Review (NAR) will bring in a panel of non-affiliated scientists from different specialties to review the mission concept so far. These professionals will provide feedback on the science goals and feasibility of the mission. This review shall help in the further development and highlighting certain aspects of the mission the Cryogenesis scientists had never considered before. The goal of a Non-Advocate Review is to maximize the return of an already approved program or project. (NASA Ames Research Center). After this review, the mission will be altered and reviewed based on feedback and proceeding to the next phase.

Phase C/D: Preliminary Design Review (PDR): The PDR shall show the projects meets all system and project requirements, accounts for risk and subsequent mitigation, budget, and engineering constraints. It will also show that there is a sufficient level of development and maturity in the project to ensure a smooth transition to the CDR and TRR stages. In Cryogenesis's case, it should show a clear understanding of safety and its supporting risks and hazards/mitigation, a baseline EDL maneuver, supporting engineering documentation, and scientific instrumentation/objectives.

Phase C/D: Critical Design Review (CDR): The CDR reviews the work done in the PDR, updates it accordingly, and ensures the design is ready to proceed with manufacturing, integration testing, etc. The CDR also ensures the schedule/major milestones are on track.

In terms of hardware, the CDR will go much more in-depth, showing detailed specifications and performance calculations to ensure a more defined baseline. It will also include manufacturing, integration, assembly, verification, and other plans. The CDR shall also ensure that the project still meets project requirements as set in the PDR.

Phase C/D: Test Readiness Review: The TRR draws information from the CDR/previous reviews, and ensures the project is ready for full-scale testing. It is extremely important to account for all forms of hazards, especially personnel, in this review.

Phase C/D: Flight Readiness Review: The FRR demonstrates that the system is fully ready for a safe launch, with risks and hazards accounted for/mitigated. For Cryogenesis, the FRR should ensure that all systems and hardware are properly manufactured and tested and that all personnel are sure what their launch tasks are.

Phase E: Operations Phase → primary mission + extended mission + outreach while it is traveling to Enceladus

The last phase is meant for Data Analysis. There shall be 2-3 full-time data analysts working with the data from the Cryogenesis mission sent back from Enceladus.

6.3. Outreach Summary

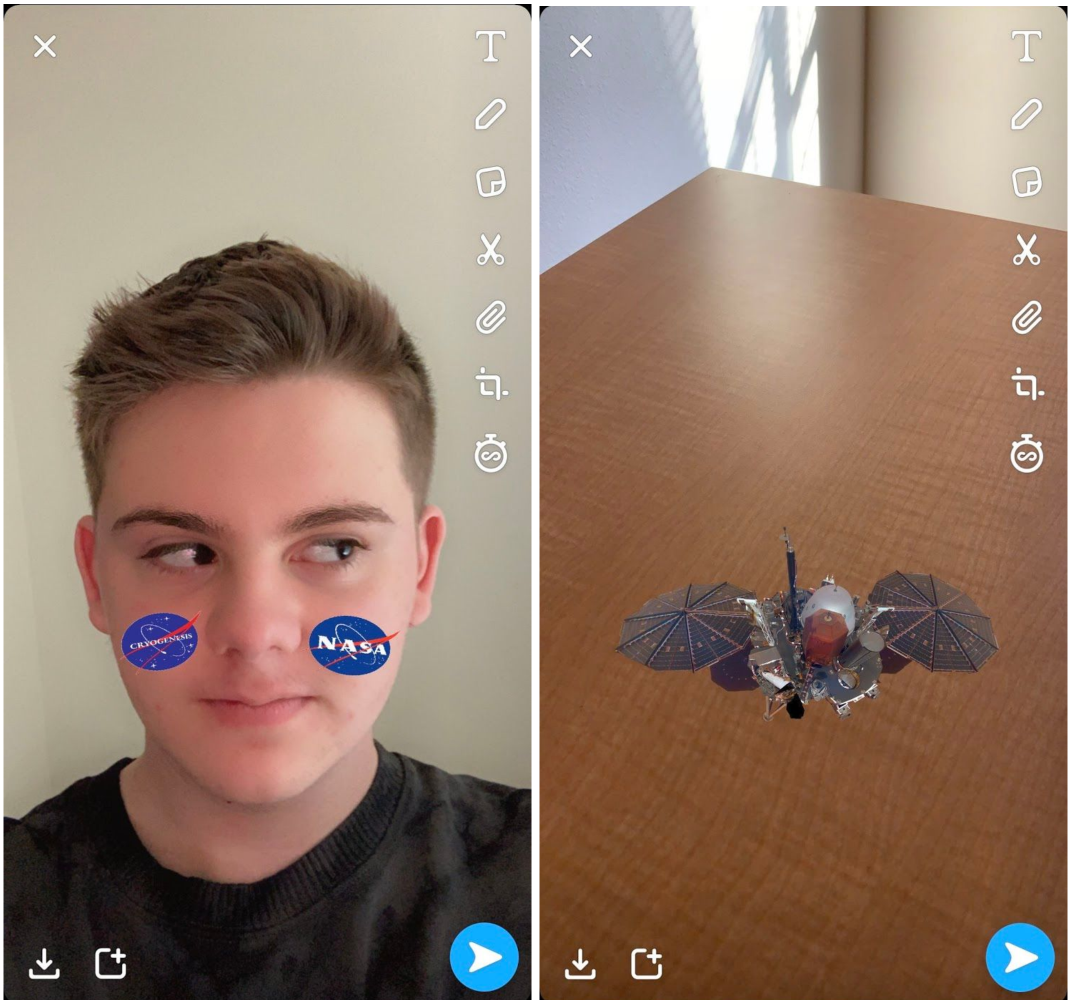
A main component of the Cryogenesis mission is increasing public awareness about the mission and interest in STEM in the general public. The target age is kindergarten through twelfth grade (K-12) low-income school districts located in high-density areas. This public outreach will be accomplished through interactive seminars and social media outreach. After COVID-19, there is hope for in-person outreach and there will be a virtual option for every event via Zoom. This will make Cryogenesis mission events more accessible for everyone interested.

Members of the Cryogenesis team will host three separate seminars. These seminars will be located in Kansas, Texas, and Alabama, respectively. Seminars will be centered around the topic of water worlds and the Cryogenesis mission to Enceladus as a whole, this will also include scientific research overviews and a Q&A at the end. Those whose questions are chosen to be asked will be awarded a 3-inch 3D-printed NASA logo which will be delivered in person or via the United States Postal Service depending on the attendee in-person or virtual situation.

The Kansas seminar will be led by team members Julio Gutierrez and Robert Ross at Kansas City, Kansas School District 500 in Wyandotte County, Kansas. The Texas seminar will be led by team members Mia Ogolo, Brianna Platt, and Evelyn Wendt at San Antonio Independent School District 907 in Bexar County, Texas. The Alabama seminar will be led by team member Manav Dave at Huntsville City School District 159 in Madison County, Alabama. All members of the school district will be able to attend these seminars through STEM program advertising within each school in the district. It will be up to the school district to decide what venue they will provide for the seminars.

In accordance with COVID-19 rules and regulations, the in-person seminars will be socially distanced. Chairs will be set up with a six-feet radius. Masks are required even if the school district decides to hold the event outside. Before entering the venue, each participant will be required to take a survey regarding personal health and COVID-19 contacts as well as a temperature check. If a COVID-19 case were to arise, county health officials will be conducting contact tracing protocols for all who attended the event. In this case, participants, including Cryogenesis team members, will be required to quarantine for 14 days. For further information on COVID-19 guidelines, visit CDC.gov/coronavirus/.

In addition to the seminars, the Cryogenesis outreach program will also host a Snaplense that will be implemented through the social media platform Snapchat. The Snaplense itself will be created using the Lens Studio 3.1 software. The lens will include the NASA and Cryogenesis mission logos on the bottom corners of the screen. When the lens is switched to landscape mode, a Cryogenesis lander model will appear on the screen complete with spewing plumes and icy surface. This lens will be hosted in the counties in which the seminars are being held. Examples are included below.



A B

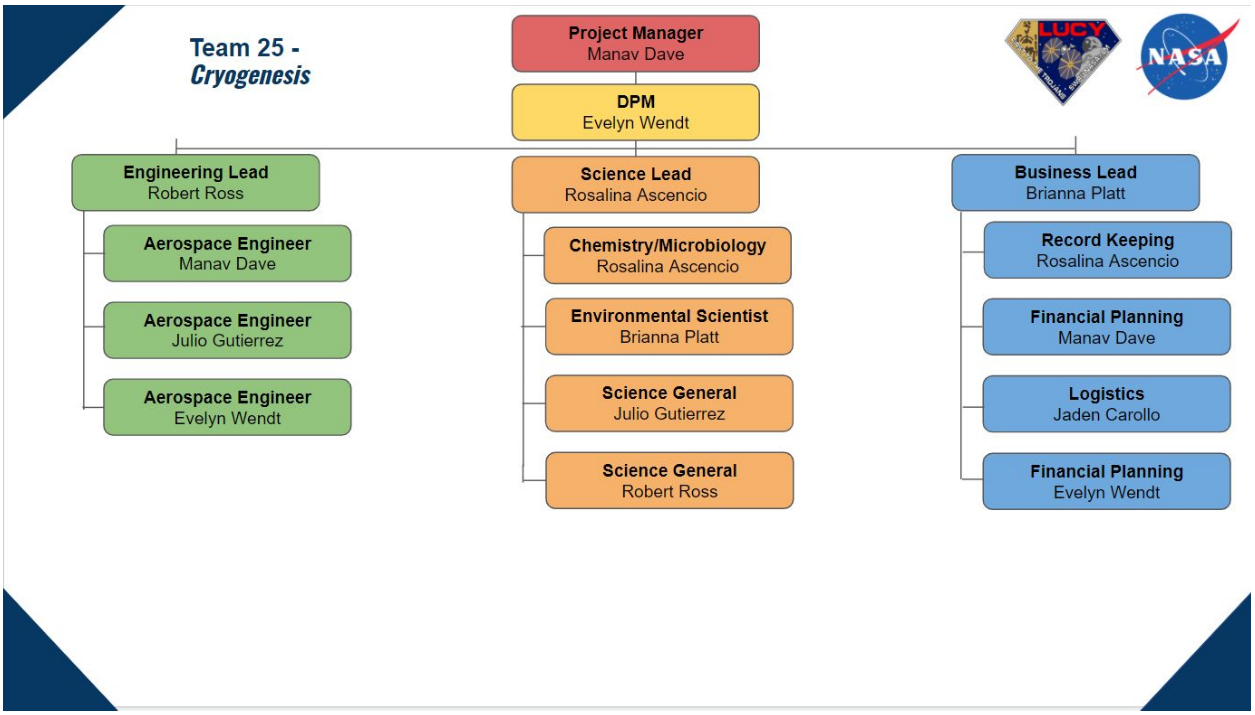
Cryogenesis Snaplens Preview.

Figure A is the front-facing camera's view and lens filter associated with it. Figure B is the rear-facing camera's view and the lens filter associated with it.

Outreach opportunities will be publicly marketed via an Instagram social media account as well as the official Cryogenesis mission website. Through social media, the team will be hosting various "Instagram Lives" and "Instagram Polls" to engage the younger demographic. Topics of these polls will be informational covering topics about Enceladus. Those who engage via social media will have the choice to be entered into the raffle to win two tickets to the Cryogenesis launch or the nearest space center. These tickets may not be resold. Official merchandise for commercial sale for the Cryogenesis mission will not be available. However, there will be posters and graphics available on the official Cryogenesis mission website available for personal use.

6.4. Program Management Approach

The Cryogenesis Team is led by an interdisciplinary team of NASA science, engineering, and business professionals hailing from different areas of the United States. Refer below for an overview of roles and responsibilities.



Cryogenesis Mission Organizational Chart.

The team is led and overviewed by the Project Manager Manav Dave and Deputy Project Manager Evelyn Wendt. The team is divided into three research sub-teams– Engineering, Science, and Business. The Engineering Sub-team is led by Robert Ross. The Science Sub-team is led by Rosalina Ascencio. The Business Sub-team is led by Brianna Platt. All members of the respective sub-teams are included in the organizational chart provided above.

These sub-teams were decided during a weekly reporting meeting. All members chose their desired sub-team and what area of expertise they could bring to the team. The Engineering and Business Sub-team leads were positions that were voted upon. This voting process took place via a Google Form in which members were prompted to select the team leads of their choosing. This Google Form was created and distributed by the project manager and roles were decided upon the next day in consideration of mission time constraints.

Team members will meet with sub-teams weekly, or at designated intervals to overview research findings, present propositions, and decide on crucial mission requirements critical to moving forward. Sub-team leads delegate work topics for the upcoming week. Team members are then required to do individual work in order to come prepared for future sub-team meetings. All team members are required to attend a weekly meeting where the project manager, deputy project manager, and sub-team leads will present their team's accomplishments for the week, reflect on next week's goals to be accomplished before sub-team meetings, and the problems that have arisen for the team. Team members are held accountable through the verbal and written delegation of tasks reported on the weekly meeting slides as well as the mission Gantt chart. All team meetings will be conducted via Zoom.us software, and recordings and minutes of these meetings will be taken by Zoom host and the Business Administration Sub-team lead, respectively.

Team members are expected to attend every meeting and participate in their subteam(s). There have been a few issues with more inactive members not participating. In order to tackle this issue, the Project Manager created attendance sheets for each meeting. This will help hold the team manageable for their own actions and allow others to check in on members. Normally, there are 10-12 team members on each team. However, the size of the team has drastically decreased due to inactive people who were onboarded but then left. There have been two people dropped from the original team roster due to commitments and two others who have not shown up to meetings or communicated with the team. This has impacted the team as a whole, specifically impacting the Science subteam who now have three active members. The team has reached out to the two inactive members to establish some sort of contact via Discord and email, but that has been mostly unsuccessful as of 10/18/2020. Another issue is the instrument choosing process, as the science subteam only has two members, this has been a huge task for both of them.

Once contact had been made with one of the inactive members, Mohamad Al-Bitar, the member clarified there had been some personal issues as well as being located in a time zone that was not conducive to a synchronous work environment. The member's time zone was eight hours ahead of Central Time United States meaning all team meetings at 7:00 PM GMT -6 took place at 3:00 AM GMT +3 for the member. This was an oversight in the team planning sector. Zoom recordings and meeting minutes were taken for Mohamad Al-Bitar. The project manager has attempted to schedule personal meetings to fit both time zones, but the member has missed these meetings and not contributed to the project in any way.

7. Conclusion

Cryogenesis is a science-driven mission that will explore the possibility of microbial presence on Enceladus using mass spectrometry and seismometry. The lander's scientific data will offer further understanding of similarities of the organic composition on Earth and other celestial bodies. The project will also give insight into the possibilities of extraterrestrial life on other water worlds in the universe.

The Cryogenesis spacecraft is a lander, which will separate from the main orbiting spacecraft and perform a deorbit burn followed by a gravity turn maneuver to land on Enceladus. The lander design featured a hydrazine fueled resistojet for maneuvering, landing legs to stabilize the lander on the surface, and an oblate spheroid shaped hull, containing the science instruments, batteries, and propellant. The hull will be covered by MLI (Multi Layer Insulation) to maintain internal temperature and also to shield the spacecraft from radiation.

The instruments chosen are the MASPEX, Seismometer, Cryotrap, and gas chromatograph. The payload will consist of these instruments that will function as a whole in order to further understand the composition of Enceladus. The instruments will collect, observe, and analyze the material that will further research the characteristics of this celestial body.

Future milestones are to design the funnel on the lander to take in amounts of “snow” from the plumes for further research. Further research of integration testing for the chosen instruments would be the team's next step. For the Critical Design Review, the team will practice with all members to solidify presentation skills. There will be editing and reviewing with our mentor to confirm that the team has completed the CDR to the best of their ability.

8. References

8.1: Engineering Team References

Ballistic Coefficient, www.chuckhawks.com/bc.htm.

Battery Protection Methods, mpoweruk.com/protection.htm.

"Enceladus." *NASA*, NASA, 8 Oct. 2020, solarsystem.nasa.gov/moons/saturn-moons/enceladus/in-depth/.

Enceladus Weather, astronomy.com/news/2011/10/enceladus-weather---snow-flurries-and-perfect-powder-for-skiing.

Gabrian, www.gabrian.com/wp-content/uploads/2018/10/2024-Aluminum-Alloy-Properties.pdf.

Hoffpauir, D. (2016, May 26). Li-Ion Batteries: Managing Risk to Secure Reward. Retrieved December 06, 2020, from https://www.nasa.gov/offices/nesc/articles/li-ion-batteries

Shea, Garrett. "5.3 Product Verification." *NASA*, NASA, 3 Sept. 2019, www.nasa.gov/seh/5-3-product-verification.

"State of the Art of Small Spacecraft Technology." *NASA*, NASA, www.nasa.gov/smallsat-institute/sst-soa/communications/.

"Thermal Conductivity of Metals, Metallic Elements and Alloys." *Engineering ToolBox*, www.engineeringtoolbox.com/thermal-conductivity-metals-d_858.html.

8.2: Science Team References

Beauchamp. (2016). Mass Spectrometers for Ocean Worlds [Slides]. Jet Propulsion Lab (JPL). https://trs.jpl.nasa.gov/bitstream/handle/2014/47158/CL%2316-4840.pdf?sequence=1&isAllowed=y

Bhushan, A., Yemane, D., Trudell, D., Overton, E. B., & Goettert, J. (2006, June 20). Fabrication of micro-gas chromatograph columns for fast chromatography. Microsystem Technologies. https://link.springer.com/article/10.1007/s00542-006-0210-3?error=cookies_not_supported&code=dda679ab-dcaf-4e27-b20e-beb3c6a9007f

CRYOTRAP - Stainless Cold Trap. (n.d.). Xtractor Depot. https://xtractordepot.com/products/stainless-steel-cold-trap

Eyes on Europa. (n.d.). Southwest Research Institute. https://www.swri.org/node/2600921

Home | Seismometer to Investigate Ice and Ocean Structure (SIIOS). (2020). ASU. https://www.lpl.arizona.edu/SIIOS/home#:%7E:text=What%20is%20The%20SIIOS%20Project,of%20different%20planets%20and%20moons

Howell, S. M., & Pappalardo, R. T. (2020). NASA's Europa Clipper—a mission to a potentially habitable ocean world. *Nature Communications*, *11*(1), 1. https://doi.org/10.1038/s41467-020-15160-9

Marusiak, A. G., Schmerr, N. C., DellaGiustina, D. N., Pettit, E. C., Dahl, P. H., Avenson, B., Bailey, S. H., Bray, V. J., Wagner, N., Carr, C. G., & Weber, R. C. (2020). The Deployment of the Seismometer to Investigate Ice and Ocean Structure (SIIOS) on Gulkana Glacier, Alaska. Seismological Research Letters, 91(3), 1901–1914. https://doi.org/10.1785/0220190328

NASA Glenn Research Center. (2019, October 31). Structural Dynamics Laboratory. Glenn

Research Center | NASA. https://www1.grc.nasa.gov/facilities/sdl/

NASA - NSSDCA - Experiment - Details. (n.d.). NASA NSSDCA. https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=EUROPA-CL-08

Phillips, M., Cataneo, R. N., Chaturvedi, A., Kaplan, P. D., Libardoni, M., Mundada, M., Patel, U., & Zhang, X. (2013). Detection of an Extended Human Volatome with Comprehensive Two-Dimensional Gas Chromatography Time-of-Flight Mass Spectrometry. *PLoS ONE*, *8*(9), e75274. https://doi.org/10.1371/journal.pone.0075274

Sephton, M. A., Waite, J. H., & Brockwell, T. G. (2018). How to Detect Life on Icy Moons. *Astrobiology*, *18*(7), 843–855. https://doi.org/10.1089/ast.2017.1656

The MAss Spectrometer for Planetary EXploration (MASPEX). (2013). [Slides]. SlidesShare. https://slideplayer.com/slide/5662707/

The Seismometer to Investigate Ice and Ocean Structure (SIIOS) in Greenland: Testing Instrument Performance on an Icy World Analog. (2018). NASA/ADS. https://ui.adsabs.harvard.edu/abs/2018AGUFM.P42B..03M/abstract

VCAM GC-MS. (n.d.). Jet Propulsion Lab. https://microdevices.jpl.nasa.gov/capabilities/in-situ-instruments-mass-spectrometry/vcam-gc-ms/

Waite, J. H. (2015). *MAss SPectrometer for Planetary EXploration, OPAG @ JHU/APL* [Slides]. USRA. https://www.lpi.usra.edu/opag/meetings/aug2015/presentations/day-1/

Waite, J. H., Bolton, S., Miller, K., Glein, C., & Miller, G. (2019). *THE IMPORTANCE OF MASS SPECTROMETRY IN THE 2061 PROGRAM* [Slides]. Horizon 2061 Conferences. https://h2061-tlse.sciencesconf.org/data/pages/4.6_Waite_H2061

Waite, J. H., Block, B. P., Lewis, W. S., Kasprzak, W. T., Anchich, V. G., Cravens, T. E., Fletcher, G. G., Luhmann, J. G., McNutt, R. L., Niemann, H. B., Parejko, J. K., Richards, J. E., Thorpe, R. L., Walter, E. M., & Yelle, R. V. (2004, February). *THE CASSINI ION AND NEUTRAL MASS SPECTROMETER (INMS) INVESTIGATION*. Kluwer Academic Publishers. http://lasp.colorado.edu/~horanyi/graduate_seminar/Ion_Neutral_Mass_Spec.pdf

Wurtz, P. (2019). *Mass Spectrometric Investigations of the Atmospheres of Giant Planets* [Slides]. IPPW Oxford. https://ippw2019.uk/wp-content/uploads/2019/07/IPPW-2019_wurz

8.3: Business Team References

“2018 Unified School Districts and County Abbreviations.” (2018) Kansas State Department of Education.

Business Furniture: Desks, Chairs & More w/Lifetime Guarantee - NBF. https://www.nationalbusinessfurniture.com/.

Buy in Bulk & Save! Bulk Office Supply Products. Buy in Bulk & Save! Bulk Office Supply Products | Quill.com. https://www.quill.com/buy-in-bulk/cbx/228.html.

Coronavirus Disease 2019 (COVID-19). www.cdc.gov/coronavirus/2019-ncov/index.html.

Enceladus, moon of Saturn - The Solar System on Sea and Sky. (n.d.). Sea Sky.

http://www.seasky.org/solar-system/saturn-enceladus.html

"Estimates of Poverty for 2017, Kansas School Districts, by County." (2017) Kansas University. PDF.

Fares And Payment Options. Fares And Payment Options – Space Coast Area Transit. https://321transit.com/transit/fares/.

Hertz - Rent A Car. Hertz. https://www.hertz.com/rentacar/reservation/.

Kovo, Y. (2015, October 21). *Non-Advocate Review Support*. NASA. https://www.nasa.gov/ames/ocs/nar.

Lens Studio. lensstudio.snapchat.com/.

Protecting electronics from the effects of radiation - Nuclear Engineering International. (n.d.). Nei Magazine. https://www.neimagazine.com/features/featureprotecting-electronics-from-the-effects-of-radiation-5890599/

Staff, U. S. I. C. (2020, October 13). US Inflation Calculator. https://www.usinflationcalculator.com/.

The Enceladus Ionizing Radiation Environment: Implications for Biomolecules. (n.d.). NASA/ADS. https://ui.adsabs.harvard.edu/abs/2016AGUFM.P32A..10T/abstract#:%7E:text=Enceladus'%20subsurface%20ocean%20is%20a,is%20inaccessible%20with%20current%20technology.&text=Galactic%20Cosmic%20Rays%20(GCRs)%20that,gamma%20rays%2C%20neutrons%20and%20muons

Video Conferencing, Web Conferencing, Webinars, Screen Sharing. zoom.us/.