Payload Concept Proposal

Frostbound

"Falling Into Lower Orbit"

Da Vinci School for Science and the Arts

Team 2

Spring 2019

Interior

&

Composition

for

Enceladus

Exploration

1.0 Introduction

Enceladus, the most reflective celestial object in our solar system has shined gleaming light into the dark depths of space for billions of years. It is Saturn's sixth largest moon and covered in a vast, smooth, and icy landscape with interesting features that include cryovolcanoes (ice geyser). Fascinatingly, these geysers burst out material from the moons core that may contain life-sustaining elements. Previous planetary exploring operations such as Voyager's mission had only captured hints of noteworthy material that could be studied. It was not until scientists sent Cassini into the Saturn system and did a flyby around Enceladus that they discovered an entire ocean of water was concealed below the surface. Such findings have prompted scientists to take a closer look at this icy moon and for this reason our team, Frostbound, has collaborated with the University of Alabama in Huntsville (UAH) to design our Charmion and Apollodorus payloads that will assist in a scientific mission by researching the debris that is ejecting from Enceladus' plumes. The payloads will travel to the moon aboard the UAH orbiter, Cleopatra, and will deploy individually as directed; Charmion will fall into a lower orbit to conduct research over the plumes, and the two Apollodorus payloads will plummet towards the plumes collecting data from debris before impact, all in efforts to better examine the compositions of Enceladus' plumes.

- The team's name "Frostbound" was collectively chosen by the team and signifies how the payloads will be inbound to one of the frostiest moons in our system.
- "Falling Into Lower Orbit" describes our mission operations of taking a lower descent from Cleopatra to conduct our studies on compositions of the plumes.

2.0 Science Objective and Instrumentation

After majority vote, the team had first determined the mission's celestial destination which would be Enceladus rather than Saturn. When choosing a science objective Frostbound selected three objectives to evaluate: Atmospheric Measurement, Tiger Stripes, and Exploration of Organic Molecules. The Exploration of Organic Molecules was originally a UAH provided mission called "Composition of Plumes" but because of the mission's research requirements, the idea to change the name was to elucidate the research that would be gathered. It was after consolidating the team and others from the public that scores were finalized for each objective and that the data concluded the team would conduct an *Exploration of Organic Molecules.* NASA has been on the verge to discover where life could possibly exist, and research collected from this mission will assist scientists on further answering questions about environments for celestial life. Specifically, Frostbound will be searching for the base elements needed in order to sustain life; Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Sulfur (CHONPS). Investigations for these elements will be targeted samples from plume compositions that will be collected by the Charmion and Apollodorus payloads.

Assessments of these analysis will reveal more to the team and researchers about materials in the subsurface ocean and whether these life-supporting elements can potentially host life on Enceladus. The most important selected instruments being used to execute these studies during operations include the Mass Spectrometer for measuring atomic mass, and the Scintillation Counter and Langmuir probe to narrow down origins of our samples. Other Primary instruments will ensure false data is not being collected and support equipment will be utilized to receive, process, send all data; and power the payload.

The following charts show the scoring process of the science objectives with figures of merit (FOM) and weights provided by UAH and further information over the instruments that will be used during the scientific operations.

Table 1. Science Objective Trade Study

FOM	Weight	Atmospheric Measurement		Tiger Stripes		Exploration of Organic Molecules	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	3	27	3	27	9	81
Applicability to other science fields (broadness)	1	3	3	1	3	9	9
Mission Enhancement	1	3	3	9	9	9	9
Measurement Method (easy to obtain)	9	3	27	9	81	3	27
Understood by the Public	9	9	81	3	27	9	81
Creates excitement in the public ("wow factor")	3	1	3	9	27	3	9
Ramification of the answer	3	1	3	9	27	3	9
Justifiability (nice, neat package), (self-consistent)	1	3	3	9	9	9	9
TOTAL			150		210		234

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Analyzing Plume Composition for CHONPS	Atomic Mass	Examine composition of the plumes to find elements such as CHONPS that support biotic material	Mass Spectrometer
	Temperature		Thermocouples
	Ionizing Radiation		Scintillation Counter
	Temperature and Density		Langmuir Probe
Discover Origin of Plume Composition	Radiation	Analyze collected samples from the plumes to trace the source of the material	Scintillation Counter
	Orientation		IMU
	Pressure		Pressure Transducer

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (hr)	Frequency (sec)	Duration (sec)
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	4,380	6	3
					.051	N/A	183.9
Thermocouple	0.020 / meter	N/A	1.0×10^{-4}	Wire (length TBD)	4,380	6	3
					.051	N/A	183.9
Pressure Transducer	0.131	0.04	1.0	2.2 diameter x 8.6 length	4,380	6	3
					.051	N/A	183.9
IMU	0.013	0.22	0.160	2.2 x 2.4 x 0.3	4,380	6	3
					.051	N/A	183.9
Langmuir Charge	0.5	0.5	0.08	4 antenna ,each 0.05 diameter x 2.5 length	4,380	6	3
					.051	N/A	183.9
Scintillation Counter	0.027	7.5	1.5	3 diameter x 14.3 length	4,380	6	3
					.051	N/A	183.9

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
On-Board Computer (processor with board)	0.094	0.4	2 x 2 GB onboard storage	96 x 90 x 12.4 mm
Transmitter/ Receiver (Transceiver)	0.085	1.7	Up to 9600 bps down-link; up to 1200bps uplink	96 x 90 x 15 mm
Antenna	0.100	0.02	Reference antenna data rate	98 mm
Batteries	400 Whr/kg	N/A	N/A	Dependent on lifetime (TBD)

3.0 Payload Design Requirements

NASA has launched roughly 196 missions and continue to travel amongst the stars, but with every mission comes basic preparations. To enable our operations and enhance the likelihood of mission success we had to meet the functional, project, and environmental payload requirements given by UAH.

To satisfy project requirements the payloads may not exceed a combined mass of 10kg and must be within a 44cm x 24cm x 28cm volume. Furthermore, constraints the payloads must meet for functional operations require deploying from the Cleopatra orbiter, taking autonomous measurements, analyzing and transmitting data, providing sufficient power, and protect itself from the exterior environment.

Lastly, payloads sent to Enceladus must deploy from the space craft without causing any damage to the main vehicle and should be able to endure the harsh environment. Chosen destinations for this mission include the Alexandria (most active) and Baghdad (least active) at which are the points the two Apollodorus payloads will drop through icy debris during their descent. Meanwhile, the Charmion orbiter will follow its trajected course around the thin atmosphere of Enceladus, which we must assume to be non-existent.

4.0 Payload Alternatives

Payload designs have to be well thought of and orchestrated to conduct a mission objective and enhance mission success. Each of the following payloads were specifically designed to accomplish our science objective through different means. As engineers, the team wanted to consider the different options of how to collect the data most effectively. In order to generate diverse ideas, the team was split into two groups, one lead by the Chief Engineer and the other by the Design Leader. Once each team had their final preliminary designs, the payloads were presented amongst the whole team to then compare their functional features. The differences between each payload were then evaluated by all members to judge all reasonings behind each aspect of the design.

Below follow the three payload concepts created by the two groups.

Concept 1: Scout

Figure 1. Scout

The Scout payload was assigned its name in relation to its tasks of scouting within the plumes for their compositions. Designed by group one, Scout's intentions were to penetrate Enceladus' plumes. Collecting data from the plumes physical surface composition was its targeted sampling task in order to gather accurate information. The spikes at its nose would allow it to crater itself into the plumes and acquire direct material. The two payloads would deploy from Cleopatra downwards and fall into the Alexandria and Baghdad geysers and begin studies after impact and continue until power loss. Scout would have a longer lifetime to analyze data over a period of time.

Concept 2: Apollodorus

Figure 2. Apollodorus

Cleopatra had many servants, and Apollodorus was one of her known recon specialists similar to how this payload will perform closer investigations for the Cleopatra orbiter. Designed by group 2, the two Apollodorus payloads will be leaving orbit and descending into the surface of Enceladus. The unique feature of these payloads is their vents inspired by the aerodynamic vents in sports cars to create downforce. However, the vents on the payloads are meant to allow plume material to flow through the payload, enabling the instruments to read the samples, without exposing them to the environment. The payloads will descend rapidly, taking only one continuous reading, focusing on analyzing the composition and origin of the plume material at different altitudes. Finally, the payloads will transmit all their data before crashing into the surface, not surviving impact.

Concept 3: Charmion

Figure 3. Charmion

Charmion's were known servants to Cleopatra and because this payload design is to conduct studies from orbit as well, the connection between our mini-orbiter serving the UAH orbiter Cleopatra was made. This specific payload was designed by both groups and not included into the Concept Selection Trade Study because it was our only orbital payload and it was communally agreed upon to make this one of the final designs. Charmion would deploy from Cleopatra into a lower orbit and collect samples of debris over the plumes after every cycle passing over the southern pole. It would also receive relayed data from either the Scouts or Apollodoruses findings and compare it to its own.

5.0 Concept Selection Trade Study

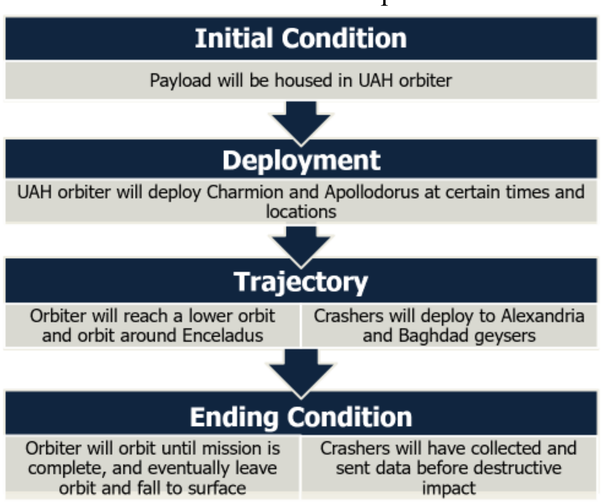
With completed concepts at hand, it was time to score and evaluate the Scout penetrator and Apollodorus crasher designs. Using the chart below on Table 5, Frostbound was able to critique the payload developments based on criteria that considered mission enhancement and/or success. The weights and first seven figures of merit (FOM) and were provided by UAH, but the team included the last three FOM's, research capabilities, durability, and battery capacity to identify key aspects that could augment a mission significantly. After totaling points, the data concluded *Apollodorus* was the more suitable concept for Frostbound's science objective. During their plummet, Apollodorus' ventilation system allows for the collection of accurate samples coming from the core of Enceladus' cryovolcanoes. They also increase the likelihood of mission success because data can be recorded and sent before having to touch the surface, and enhance the accuracy of samples collected as the particles come straight from beneath the surface of the plumes.

Table 5. Concept Selection Trade Study

FOM	Weight	Scout		Apollodorus	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	9	81
Likelihood Project Requirement	3	3	9	9	27
Science Mass Ratio	1	9	9	9	9
Design Complexity	3	3	9	9	27
ConOps Complexity	3	1	3	9	27
Likelihood Mission Success	9	3	27	9	81
Manufacturability	1	9	9	9	9
Research Capabilities	9	9	81	9	81
Durability	3	9	27	3	9
Battery Capacity	9	9	81	9	81
TOTAL			**336**		**432**

6.0 Payload Concept of Operations

Table 6. Con-Ops



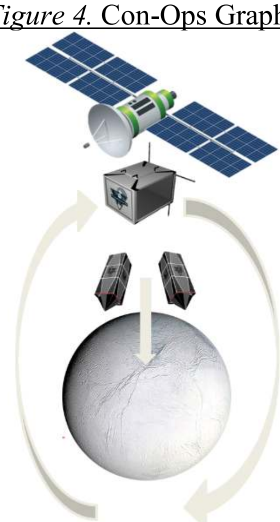


Figure 4. Con-Ops Graphic

Establishing a set mission for the payloads to follow is a key component of space exploration. Since the team will be having two types of payloads, and three payloads in total, the concept of operations were divided into two sections. The first section pertains to Charmion (***a.***), the orbiting payload, and the second section is for Apollodorus 1 and 2(***b.***), the crashing payloads.

Initial Condition- The first phase of the mission both Charmion and the Apollodorus' will begin aboard the UAH orbiter, Cleopatra. The payloads will be housed in their designated locations, awaiting to deploy towards their intended locations.

Deployment- ***a***. Charmion will deploy from Cleopatra, when its orbit is several minutes from passing above the south pole. Charmion will use the provided pressured helium to reach its intended deployment velocity and reach a lower orbit. ***b***. Apollodorus 1 will deploy as the orbiter hovers over the Baghdad geyser, and Apollodorus 2 will deploy to the Alexandria geyser. The two payloads will also deploy through a deployment barrel using the provided pressurized helium.

Trajectory- ***a***. Once Charmion has successfully deployed, it will gain velocity and descend towards a 70-km orbital altitude. When Charmion establishes a stable orbit, it will open its wing, and expose the instruments required to analyze the plume material. Then it will orbit for 6 months collecting and sending back data. ***b***. Apollodorus will begin its descent to the geysers. When descending the plume material will pass through the vents and allow for the instruments inside the payload to begin analyzing and measuring the material, while also transmitting back data.

Ending Conditions- Charmion and Apollodorus were both designed to not survive impact with the surface of Enceladus. ***a***. Charmion will exit its orbit and begin falling towards the surface. Since it has completed its mission its survival is not required. ***b***. Apollodorus will complete its mission as it descends through the plumes debris, and therefore its survival after impact is not necessary.

7.0 Engineering Analysis

7.1 Structural Mass Analysis

The designs of the payloads began by identifying the geometric and weight constraints given to the team by UAH. Since the mission required three payloads, the team had to split the constraint dimensions between all three of the payloads. Charmion would have a volume of **18x20x24 cm**, meanwhile each Apollodorus payload would have the dimensions of **12x12x20 cm**. Payload material for would be an Aluminum-Beryllium Alloy shell that is 1 cm thick, and Apollodorus would have an Aluminum 8090 Alloy shell that is 0.5 cm. Charmion has a total mas of **5.897 kg**, and Apollodorus has a total mass of **3.647 kg**, adding up to a total mass of **9.544 kg**; falling under the weight requirement.

7.2 Battery Mass

To fulfill Frostbound's mission, knowing the amount of battery required to power the payloads was key in the engineering analysis. The first step was to identify the instruments each payload would use, and their power in Watts (*W*). ***a.*** Charmion's instruments were put in two categories; the instruments that would take readings and the ones that send back data. The power usage of Charmion was separated into cycles, one cycle is one orbit, to make the calculations easier. Each cycle would take 100 readings that would last 3 seconds every 6 seconds and send back data 2 times every 150 seconds for 30 seconds. The engineering team then multiplied the total operational time by the power and found that Charmion would use **0.85 W-hr per cycle**. Since the mission would be 972 cycles, the team solved that the mission would need **831.13 W-hr**. The next step was to divide the total power 400 W-hr/kg and found that Charmion would require **2.08 kg** of battery. ***b.*** Apollodorus 1 and 2 would have similar instruments with exception of a magnetometer and Langmuir probe. The Apollodorus payloads will have a continuous reading that last 16 minutes, meaning that once the instruments' power is divided by their operation time, the payloads would use a total power of **3.44 W-hr**. The team then divided that by 400 W-hr/kg and found that each payload would need **8.59 grams** of battery.

7.3 Initial Conditions

The team concluded that beginning the mission aboard the UAH orbiter would best complement the science objective. The first step of the Frostbound mission would be to know the orbital velocity of the housing vehicle. To solve for the orbital velocity the engineering team multiplied the universal gravitational constant ($6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$), by the mass of Enceladus ($1.08 \times 10^{20} kg$). Then divide that by orbital altitude (352,000 m), and finally square root all numbers, to get an orbital velocity of **143.05 m/s**.

7.4 Deployment

All three payloads would deploy from Cleopatra, using the provided pressurized helium. ***a.*** Charmion would deploy forward to be able to achieve a lower orbit. The engineering team began by assuming that Charmion would reach a 70 km orbit, meaning the orbital velocity needed to increase. The required orbital velocity to have a 70 km orbit was 149.59 m/s (refer to *7.5 Trajectory*). To get the deployment velocity, the team simply subtract the orbital velocity of Cleopatra by the desired orbital velocity, resulting in **6.52 m/s**. Therefore, to get the acceleration we used $a = (v_f^2 - v_i^2)/2d$, which the team found the payload would accelerate from the barrel at **48.25** $\mathbf{m/s^2}$. This means that for the payload to deploy at the desired velocity it will need **79.05 Pascal or .01 Psi**. ***b.*** Apollodorus 1 and 2 would deploy downwards from Cleopatra at **50 m/s**. This velocity was chosen to keep the G load the payloads would experience at a low level. The next step was to solve for the rate the payloads would accelerate from the barrel. Using the same formula and process as with Charmion, the team found that the Apollodorus 1 and 2 would have an acceleration of **550** $\mathbf{m/s^2}$. Consequently, using the formula $P = (am)/A$, the payload would require **3,572.83 Pascal or .53 Psi** to deploy.

7.5 Trajectory

Charmion and the Apollodorus payloads will have different trajectories, as Charmion will be orbiting and The Apollodorus payloads will descend to the surface. ***a.*** Charmion will be orbiting 70 km from the surface, however for the orbital velocity formula required the team to convert the orbital altitude to meters (70,000 m) and add it to the plant radius (252,000 m), resulting in 322,000 m. Next the team multiplied "G" ($6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$) by M ($1.08 \times 10^{20} kg$) and divided it by the new radius, and placed everything to the square root, and got the new orbital velocity of **149.59 m/s**. Then the engineering team solved for the time it would take to complete one orbit by solving for the circumference of the planet (2.02×10^6), and the new orbital velocity, and found that each orbit would last **3.76 hours**. ***b.*** The Apollodorus payloads will be affected by gravity as they fall, meaning their velocity will increase. To get the final *y-velocity* the team used the formula $v_f^2 = v_i^2 + 2ad$, where "a" was gravity ($.113\ \mathrm{m}/s^2$) and "d" was Cleopatra's altitude (100,000 m), and got **158.43 m/s.** Then to get the Vector velocity of the payloads, the *x-velocity* and the *y-velocity* were plugged into the Pythagorean Theorem and got **213.45 m/s.** Finally, to solve for the flight time, the final *y velocity* was subtracted by the initial *y-velocity* and divided by gravity ($.113\ m/s^2$), which resulted in **959.55 seconds.**

7.6 Ending Conditions

As stated in the concept of operations, the survival of Charmion and Apollodorus 1 and 2 is unneeded. Since the mission will be complete before impact, the engineering team did not calculate ending conditions.

8.0 Final Design

Cleopatra will be orbiting around Enceladus at an altitude of 100km's when our payloads, Charmion and Apollodorus, will deploy using a helium initiated thrust. Special design functions for each payload will allow them to strategically expose instruments for research; Charmion's hatch will open once it has reached its trajected lower altitude, and the Apollodorus ventilation system will allow for debris to flow through the payload structure without harming the instruments, but still permitting to collect data. Once reaching these stages of operations, the Apollodorus payloads will transfer information to Charmion until their destructive impact. When allocating housing materials to these payloads, a stronger metal was chosen for Charmion, Aluminum Beryllium Alloy with a one-centimeter thickness. In contrast to Charmion, a lighter and thinner structure was given to Apollodorus of Aluminum 8090 Alloy with a .5-centimeter thickness. These chosen metals used to house each payload were determined by the duration and importance of each payload's mission.

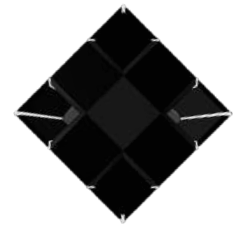
Figure 5. Frostbound's Mission

Dimensions:
18x24x20 cm
Weight: 5.9 kg
Surface Area:
TSA= 2,400 cm^2

Dimensions:
12x12x20 cm
Weight: 1.82 kg each
Surface Area:
Nose= 28 cm^2
Body= 960 cm^2
TSA= 988 cm^2

Bottom View

Top View



The following chart expresses how instruments were allocated to the different phases of Frostbound's con ops and includes the instrument mass to show that we did meet our payload mass requirement.

Table 7. Final Design Mass Table

Function	Components	Mass (kg)
Deploy	N/A	N/A
Measure	Mass Spectrometer, Thermocouple, Pressure Transducer, IMU, Magnetometer, Langmuir Charge, Scintillation Counter	2.586
Collect Data	On-Board Computer	0.282
Provide Power	Space Batteries	2.095
Send Data	Transceiver, Antenna	0.555
House/Contain Payload	Aluminum Beryllium Alloy, Aluminum 8090 Alloy	4.026
Total		9.544

Without meeting project constraints, Frostbound's mission would not be possible. The chart below displays how the requirements set by UAH have been abided by in order to conduct Frostbound's mission.

Table 8. Requirements Compliance Table

Requirement	Verification	Compliance
44cm x 24cm x 28cm	Charmion: 18x24x20 cm Apollodorus: 12x12x20 cm	✓
10kg Constraint	Charmion: 5.897 kg Apollodorus 1 & 2: 3.647 kg Total Weight: 9.544 kg	✓
Deploy from UAH Orbiter without harm to Spacecraft	Propelled ejection using helium	✓
Acquire Proper Measurements	Mass Spectrometer, Thermocouple, Pressure Transducer, IMU, Langmuir Charge, Scintillation Counter	✓
Collect Data	On-Board Computer	✓
Provide Sufficient Power	Space Batteries	✓
Send Data	Transceiver, Antenna	✓
House Payload	Aluminum Beryllium Alloy, Aluminum 8090 Alloy	✓