VITA NOVA

TO ENCELADUS AND BEYOND

PAYLOAD CONCEPT PROPOSAL

INTERIOR & COMPOSITION FOR ENCELADUS EXPLORATION MISSION

DA VINCI TEAM 1

1.0 Introduction

Enceladus is Saturn's sixth largest moon. It was discovered by William Herschel in 1789 and is, for the most part, an icy world with a rocky core. Scientists suspect that Enceladus could be suitable for some forms of life. Along with its distinctive chemistry and water ocean between its rocky core and icy crust, Enceladus has become an auspicious lead in the search for life in space. Team Vita Nova's goal consists of creating and designing a payload, which will be housed in the UAH spacecraft, to complete a specific objective on Enceladus. The team will collaborate with UAH to successfully accomplish said goal. With enough research and evidence, Vita Nova hopes to learn if there is a possibility that life from Earth could survive on Enceladus. Other missions, such as Cassini, have discovered components that could potentially support life on this icy moon, and Vita Nova hopes to use these past discoveries to uncover new truths.

"Vita Nova" stands for "new life" in Latin. The team decided on this name because we wanted something that would go along with our scientific objective, which is monitoring life from Earth on Enceladus. Our logo includes a moon shape, which represents Enceladus, with a ring around it, which represents the rings of Saturn. The team included a vital sign as part of the rings to incorporate the life aspect of our objective.

2.0 Science Objective and Instrumentation

After analyzing all of the potential science objectives given to us by UAH, the team decided that it would be best to create our own goal and put our imagination, knowledge, and creativity to work. Vita Nova aims to expand on UAH's Interior and Composition for Enceladus Exploration mission by creating a new science objective. Vita Nova researched the **Cassini** spacecraft mission, which showed interesting magnetometer data that encouraged scientists to further investigate and take a closer look at Enceladus. This mission also discovered Enceladus' global ocean, icy jets, and the first ever indications of hydrothermal activity, including methane in its plumes. The team also researched various experiments done here on Earth dealing with bacteria that could survive under Enceladus-like conditions. During their study, scientists found out that a certain microbe called **Methanothermococcus Okinawensis**, which lives here on Earth in a hydrothermal vent off the coast of Japan, could survive under conditions that are beneath Enceladus' icy crust. Methanothermococcus Okinawensis converts molecular hydrogen and carbon dioxide into methane, all of which Cassini found in the geysers. Out of the 3 tested, only this microbe seemed to survive the changing simulated Enceladus conditions. Although this experiment is not full proof that Enceladus could sustain life from Earth, it suggests that something can live there and explains a possibility as to why there is methane in its plumes.

Team Vita Nova's science objective is to house bacteria (Methanothermococcus Okinawensis) in the payload and transport it to Enceladus to be exposed to the environment and analyze how it responds to it. The goal is to land near the South pole on the Alexandria Sulci tiger stripe. The team's created objective is called "B.A.T.T.L.E., or "**Bacterial Analysis to Test Life on Enceladus**", and serves to further investigate if this Saturnian moon could be one of the prime locations while searching for life in space. The team decided on this science objective by analyzing all of the potential missions using a decision matrix.

The science trade study was crucial when choosing the final objective. The team's potential science objectives included understanding the structure and properties of the tiger stripes and understanding structure and properties of plumes. Each prospective objective was rated by the team using different figures of merit (FOM) given to us by UAH. Based on the ratings each one received, B.A.T.T.L.E. was the winning objective.

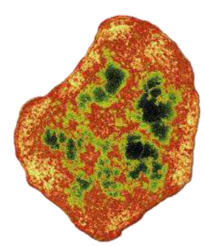

Figure 1. Methanothermococcus Okinawensis

Table 1. Science Objective Trade Study

FOMs	Weight	Plumes		Tiger Stripes		B.A.T.T.L.E.	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	3	27	1	9	9	**81**
Applicability to other science fields (broadness)	1	3	3	3	3	9	**9**
Mission Enhancement	1	3	3	9	9	3	**3**
Measurement Method (easy to obtain)	9	3	27	3	27	9	**81**
Understood by the Public	9	3	27	3	27	3	**27**
Creates excitement in the public ("wow factor")	3	3	9	1	3	9	**27**
Ramification of the answer	3	3	9	3	9	3	**9**
Justifiability (nice, neat package), (self-consistent)	1	3	3	3	3	9	**9**
TOTAL			**108**		**90**		**246**

In order for Vita Nova to complete the created science objective, we will need the assistance of various instruments provided to us by UAH that are crucial for success. The instruments that the team chose include all of the ones included in the 'Plumes' science objective provided by UAH, assuming that the bacteria needed to be exposed to the plumes and would require the same measures. The most important instruments the team will need include the thermocouples, which serve to measure the temperature at which the bacteria is being exposed, and the pressure transducer, which allows the team to know at what pressure the bacteria was induced during impact and deployment. The scintillation counter helps to determine Legion's ending position. The team also plans to use a microscopic camera to monitor the bacterial activity. It is also important to mention that the payload will include an airlock mechanism that will expose and seal the bacteria inside the payload to not contaminate the surface of Enceladus.

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instruments Selected
B.A.T.T.L.E. (Bacterial Analysis to Test Life on Enceladus)	To measure and analyze how life from Earth reacts to life on Enceladus. Measure the masses and temperature within a sample.	One probe ejected from the lander, which will house our bacteria and expose it to the environment to complete the science objective.	Mass Spectrometer
			Thermocouples
			Pressure Transducers
			IMU
			Magnetometer
			Electrical Charge (Langmuir Probe)
			Scintillation Counter
			Microscopic Camera

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (mos.)	Frequency (hrs.)	Duration (mins.)
Mass Spectrometer	0.230	1.5	22.4	1.45 x 0.50 x 0.80	6	12	1.0
Thermocouples	0.020/meter	N/A	1.0 x 10 ^ -4	wire (length TBD)	N/A	N/A	N/A
Pressure Transducers	0.131	0.04	1.0	2.2 dia. X 8.6 length	6	12	1.0
IMU	0.013	0.22	0.160	2.2 x 2.4 x 0.3	6	12	1.0
Magnetometer	0.05	1.5	0.0008	2.1 x 1.9 x 0.8	6	12	1.0
Electrical Charge (Langmuir Probe)	0.5	0.5	0.08	4 antennas, each 0.05 dia. X 2.5 length	6	12	1.0
Scintillation Counter	0.027	7.5	1.5	3 dia. X 14.3 length	6	12	1.0
Microscopic Camera (1080 Auto Focus C-mount Microscopic Camera with HDMI+USB Mouse)	0.6	1.25	60	6.6 x 6.6 x 8	6	12	1.0

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	Dimensions: 96 x 90 x 12.4 mm
Transmitter/Receiver (Transceiver)	0.085	1.7	Up to 9600 bps downlink; up to 1200 bps uplink	Dimensions: 96 x 90 x 15 mm
Antenna	0.100	0.02	Up to 9600 bps downlink; up to 1200 bps uplink	Dimensions: 98 mm
Batteries	400 Whr/kg	N/A	N/A	Size Varies

3.0 Payload Design Requirements

As part of the payload design requirements, there are some guidelines that the team must follow in order to successfully complete the mission. To begin with, the design cannot harm the UAH vehicle, needs an internal temperature of 294 K, needs access to the data delivery system, and must have continuous power. As far as the functional requirements, the team must make sure that the payload deploys from the spacecraft. The payload must also take accurate measurements, collect data, provide sufficient power, send data, and house our payload. The team must make sure that the payload is able to be contained within a space of 44cm x 24cm x 28 cm and must not exceed a total mass of 10 kg. The team must also keep in mind that the temperature on Enceladus is -201° C (-330° F) and that the gravitational pull is 0.113 m/s². The payload must be able to withstand these environmental features on Enceladus.

4.0 Payload Alternatives

Team Vita Nova has a total of three potential concepts. All payloads were designed for the purpose of testing Enceladus' ability to sustain the life of Methanothermococcus Okinawensis. The concepts were similar to each other in most ways except in that of their shape. To create each concept, the team split into 2: the project manager's group and the chief engineer's group.

4.1 Concept 1: Pompeiia

The chief engineer's group created concept 1, Pompeiia. The team decided on the name Pompeiia because it alludes to Julius Caesar's second wife. The team found this to be a good name since it relates to Caesar (Roman general and politician), which is the UAH lander's name. Concept 1, Pompeiia, will be ejected from the lander and penetrate the surface. As one can see in figure 2, Pompeiia will have a cylindrical body with a cone-shaped tip. It will be able to provide power and collect and send data after its impact, showing bacterial response to the Enceladus environment. Pompeiia will also contain an airlock mechanism that will prevent the bacteria from contaminating the surface, since this can have serious consequences, such as providing false readings of alien life in the future.

Figure 2. Pompeiia

4.2 Concept 2: P.S.A.S.

The project manager's group created concept 2, P.S.A.S., which stands for "Payload Skipping Across Surface". P.S.A.S. will be ejected from the lander and will skip across the surface, as the name suggests. As one can see in figure 3, it is a rectangular prism-shaped payload made out of aluminum alloy that will provide power and send data. Much like Pompeiia, P.S.A.S. will collect data after impact, showing bacterial responses to the environment on Enceladus.

Figure 3. P.S.A.S.

4.3 Concept 3: Legion

After debating about the two concepts that each group created, the team decided that both designs had positive and negative aspects to them. Vita Nova created a third payload that incorporated all of the positive aspects of the other two designs. Legion, named after the men in the ancient Roman army that performed missions for the emperor (Caesar), has a rectangular prism shape and will be ejected from the lander at an angle to skip across the surface. This design, unlike P.S.A.S., includes an airlock mechanism, a feature included in Pompeiia. Much like the other designs, Legion will start to collect and send data after its impact, showing how the bacteria responds to the Enceladus environment, and will be able to provide power. The team's ideal design will not expose the bacteria to a large g-load, which can be harmful, and will not require a lot of pressure. The benefit of having this shape as a payload is that there will always be a way for the bacteria to be exposed to the environment since it will always land on its sides, which is the team's main science objective and is a crucial aspect to complete the mission.

Figure 4. Legion

5.0 Concept Selection Trade Study

To decide on a final concept, the team created a trade study to rate each design on how effectively it met the requirements for each figure of merit (FOM), which provide a representation of the key aspects. This way, Vita Nova was able to determine the best possible design for the mission. The first 7 FOMs were provided by UAH, and the last 3 FOMs were made by the team. The "Data Collected" aspect refers to the productivity of the payload in collecting information and sending it back for revision. As observed in table 5, Pompeiia, P.S.A.S, and Legion all ranked the same for this FOM since they will be utilizing the same instruments to comply with the main objective. "Longevity" refers to how long the payload and the bacteria inside it can survive within the period of time of the UAH baseline mission. As regarded in table 5, Pompeiia scored the lowest on the "longevity" FOM because of its high probability of killing the bacteria during impact. P.S.A.S. also ranked low because the team wasn't sure of the mechanism needed to monitor the bacteria and expose it to the environment since this concept wouldn't include an airlock. "Housing Safety" is how well the payload can protect the bacteria that the team is sending. For this last created FOM, Pompeiia scored the lowest because, since it would penetrate the surface, it would most likely induce the bacteria to a high amount of g-load and potentially kill it. On the other hand, the other two concepts ensure a lower amount of g-load, therefore protecting the bacteria and completing the mission successfully.

The value of the weights (1, 3, and 9) on the chart were given to us by UAH. We ranked these FOMs according to their importance in regard to the completion of the science objective. The winning concept, as seen on table 5, was Legion with a total score of **414**. Legion met the seven UAH-given FOMs and the team's three personalized FOMs.

Table 5. Payload Concept Selection Trade Study

FOM	Weight	Pompeiia		P.S.A.S.		Legion	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Completion of Science Objective	9	3	27	9	81	9	**81**
Likelihood Project Requirement	1	3	3	9	9	9	**9**
Science Mass Ratio	9	3	27	3	27	9	**81**
Design Complexity	3	9	27	9	27	9	81
ConOps Complexity	3	1	3	3	9	3	**9**
Likelihood Mission Success	9	3	27	9	81	9	**81**
Manufacturability/ Functionality	3	3	9	9	27	9	**27**
Data Collected	1	9	9	9	9	9	**9**
Longevity	3	1	3	3	9	9	**27**
Housing Safety	9	1	9	9	81	9	**81**
TOTAL			**144**		**360**		**486**

6.0 Payload Concept of Operations

To begin our mission, **Legion** will be deployed from UAH's Lander, or 'Caesar,' which is either slanted plus 12 degrees or negative 12 degrees. Using pressurized helium, our payload will be shot at an angle of **75 degrees**. Once deployed, **Legion** will travel in a parabolic shape accelerating to its peak height and then descending to impact the surface of Enceladus.

After the **Legion** has impacted, it will skip across the surface for an assumed **20 m** and suffer a final G-load of **3.23**, assuring that all of our instruments will survive in order to complete our science objective.

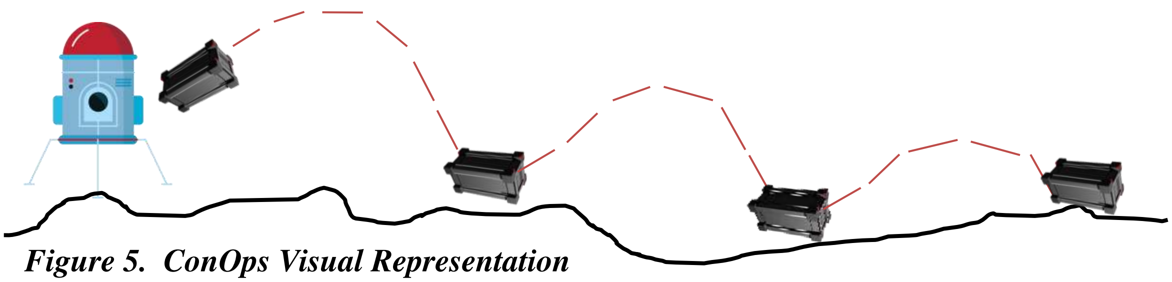

Figure 5. ConOps Visual Representation

7.0 Engineering Analysis

The engineering analysis for Vita Nova was a four-step process: initial conditions, deployment, trajectory, and ending conditions. It consists of a lander resting stable on the surface of Enceladus and ejecting a payload at an angle using the least amount of pressure (PSI) to reach a minimum distance of five thousand meters and induce our payload with a lowest possible amount of g-load. To calculate this whole process, the team created an Excel spreadsheet with all of the formulas necessary to find each one of the variables. All the units are in meters and seconds in order to maintain consistency and simplify the process.

7.1 Initial Conditions

For the first portion of the engineering analysis, the UAH lander (Caesar) is stable on the surface of Enceladus and is slanted plus or minus twelve degrees due to the uncertainty of how the terrain/surface is. This number will have to be added or subtracted from the angle of ejection that the team finds.

7.2 Deployment

For the second section of the engineering analysis, Vita Nova's payload, Legion, will be ejected from the lander at **75 degrees** (already taking into consideration the plus or minus 12 degrees) at **36.26 psi** (250,000 pascals), which was assumed, and will allow the payload to accelerate **1440** $\boldsymbol{m/s^2}$ and induce it into an initial G-load of **146.79.** This will allow the payload to achieve a vectoral velocity in the ejection of **35.6 m/s**. To solve this first portion of the problem, the team had to solve for final velocity using the formula: $vf^2 = vi^2 + 2[PA\ /\ m\ ]\ d$, the payload's cross-section area, which was **576** $\boldsymbol{cm^2}$ (calculated after multiplying the width and the length), and our mass (**10kg**). Vita Nova was able to find *a*, as well as calculate the force needed.

7.3 Trajectory

For the third portion of the analysis, the team calculated the speed that the payload will be traveling both in the y-axis and the x-axis, as well as the time of flight and the distance the payload will travel. To do so, Vita Nova had to separate the vectoral velocity of the payload when coming out from the barrel (**35.6 m/s**) into the velocity on the x-axis (constant) and the y-axis (fluctuant). The team accomplished this by following the UAH design notebook procedure, multiplying the cosine (for x) and separately, the sine (for y) of the angle the payload was being ejected with the velocity it is reaching ($Vy = \sin\theta$ and $Vx = \cos\theta$). After finding these velocities, the team had to simultaneously find the distance they would be traveling. ($vf^2 = vi^2 + 2ad$ and $v = d / t$). This gave a total distance of **5607.08 m** in the x-direction and a maximum height of **68.8 m**. Once the distances were determined, the team's next goal was to find the time of flight of the payload. Utilizing the formula:

$$vf^2 = vi^2 + 2ad$$

we were able to determine that half the time of flight (payload traveling towards the peak altitude) was **304.29 seconds** and the total time of flight was **608.58 seconds**.

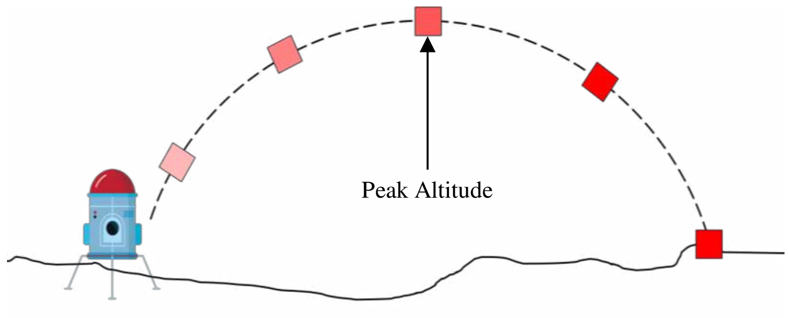

Figure 6. Payload Trajectory

7.2 Ending Conditions

The final portion consisted on figuring out how the payload performed after impact with the surface. Knowing that it will hit the surface of the moon at a vectoral velocity of **35.6 m/s**, the team assumed that the payload will skip across the surface for **20 m**. Using these numbers, Vita Nova calculated the near-exact conditions the payload would undergo. The team concluded that the deceleration would be **-31.68** $\boldsymbol{m/s^2}$ at initial impact, with a G-load of **3.23**. This now proves that the payload and instruments will survive impact and complete the science objective.

8.0 Final Design

Team Vita Nova's final design was the Legion payload. These designs were chosen based off of the results presented in the decision matrix. Legion measures 44 cm x 24 cm x 24 cm units in size. Once the lander is stationary on the surface, it will be ejected from the lander and efficiently skip across the surface of Enceladus. Upon coming to a halt on the surface, a special airlock system unique to this payload will put the bacteria (Methanothermococcus Okinawensis) to the test. The airlock system is composed of four different hatches, two outer hatches will open first, then close; the inner hatches will then open exposing the bacteria to the environment without contaminating the surface.

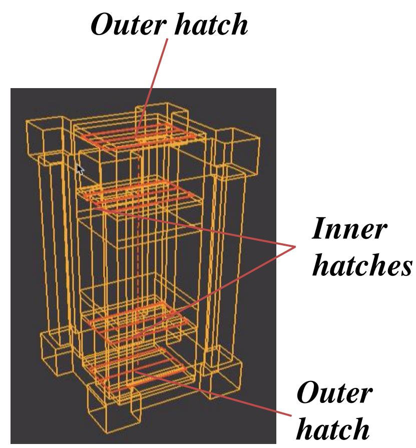

Figure 7. Payload Hatches

Figure 8. Vita Nova's Mission

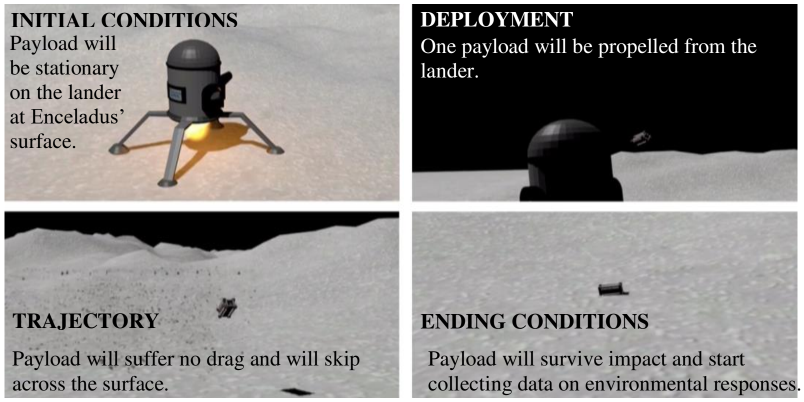

Table 6. Final Design Mass Table

Function	Components	Mass (Total)
Deploy	IMU	0.013
Measure	Magnetometer, Thermocouple, Camera, Pressure Transducer, Langmuir Probe, Scintillation Counter	0.67
Collect Data	Mass Spectrometer, On board Computer	0.982
Provide Power	Batteries	0.212
Send Data	Transceiver Antenna	0.185
House/Contain Payload	Aluminum alloy	7.938
Total		10 kg

Table 7. Requirements Compliance Table

Requirement	Verification	Compliance
less than or equal to 10 kg	Total Payload: 10 kg	✓
44 cm x 24 cm x 28 cm	44 cm x 24 cm x 24 cm	✓
Take Measurements	Mass spectrometer, magnetometer, thermocouple and pressure transducer	✓
Collect Data	On-board Computer	✓
Provide Power	Space batteries	✓
Send Data	Transceiver and antenna	✓
Contain/House Payload	Body made of Aluminum Alloy	✓