DA VINCI TEAM 4

EDEN

ENCELADUS DISCOVERY EXPLORATION AND NAVIGATION

Payload Concept Proposal

"Opening the gates to Enceladus"

1.0 Introduction

Enceladus is one of the 62 known moons of Saturn—one among various orbiting bodies—distinguishing itself by its bright icy surface and its hidden liquid ocean. Discovered in 1789 by William Herschel, this moon is one of the few places in the solar system that harbors liquid water and is home to mysterious geysers that eject water vapor in its South Pole. Team Enceladus Discovery Exploration and Navigation (EDEN), has embarked in the Interior & Composition for Enceladus Mission, and thus has the finality of creating a payload that will deploy and venture into the recondite confines of Enceladus. Inspiring from Biblical and Greek backgrounds, our team's identity recalls the beginning of life in the Garden of Eden, which could reproduce with this mission, as we *Open the Gates to Enceladus*. The Greek background recalls the mythical giant Enceladus' spear, depicted in the logo, as our mission involves penetration for the discovery of this moon's secrets. With the objective of conducting scientific analysis through selected instruments, our payloads will deploy from the UAH orbiter Cleopatra, and reach Baghdad Sulci, one of four linear depressions known as Tiger Stripes. These features in the surface eject liquids into outer space, being a breathe of life in what would be deemed an inhospitable world. To accomplish our mission, two payloads will be deployed, Scrat and Acorn, and will jointly provide essential information pertaining to the composition and environmental conditions of the destination. Scrat will analyze the surface environment and composition in the upper region, and Acorn will conduct a similar task but within the still unfathomable interior of the Tiger Stripe.

2.0 Science Objective and Instrumentation

Our final science objective is Tiger Stripes Composition selected due to our interest in exploring the environment in the Tiger Stripes in the south region of Enceladus. The science objective was decided through the Science Objective Trade Study provided by UAH, where we allocated values for each figure of merit. Observing the results, Tiger Stripes Composition appealed the most to our team, with a total score of 172, predominantly due to the many features we would have to research. These "Tiger Stripes" are one of the main attributes to Enceladus' uniqueness, and researching them would provide astonishing information to the world of science. Throughout the research of this essential moon, scientists have detected various factors that could indicate the possibility of life on Enceladus. The idea of humans living somewhere else other than Earth was fascinating, filling minds with curiosity and excitement. Therefore, we will investigate the surface near the Tiger Stripes and the materials being ejected from them in order to see if they contain any life-supporting elements.

Table 1. Science Objective Trade Study

Figures of Merit	Weight	Geological Activity		Surface Analysis		Tiger Stripes Composition	
		Raw Score	Weight	Raw Score	Weight	Raw Score	Weight
Interest of Team	**9**	1	9	3	27	9	81
Applicability to other science fields	**1**	3	3	1	1	9	9
Mission Enhancement	**1**	3	3	1	1	9	9
Measurement Method	**9**	3	27	9	81	1	9
Understood by the Public	**9**	9	81	3	27	1	9
Creates excitement in the public	**3**	3	9	1	3	9	27
Ramification of the answer	**3**	1	3	3	9	9	27
Justifiability	**1**	3	3	9	9	1	1
TOTAL			**138**		**158**		**172**

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instruments Selected
Geological Activity	Investigate geologic processes	Measure temperatures and record pressure	Thermocouple and Pressure Transducer
Surface Analysis	Analyze the composition the surface material	Observe molecular composition and magnetic correlations	Mass Spectrometer and Magnetometer
Tiger Stripes Composition	Study the composition and environment of Tiger Stripes	Record the environmental conditions and correlations with other processes (i.e. plumes)	Thermocouple, Pressure Transducer, Mass Spectrometer, and Magnetometer

Table 3. Instrument Requirements

Payload 1 Scrat							
Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (days)	Frequency (hr)	Duration (s)
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	40	1	40
Magnetometer	0.05	1.5	0.0008	2.1 x 1.9 x 0.8	40	1	40
Pressure Transducer	0.131	0.04	1.0	2.2 dia x 8.6 length	40	1	40
Thermocouple	0.020 /meter	N/A	1.0 x 10^{-4}	100 length	40	Constant	Constant
IMU	0.013	0.22	0.160	2.2 x 2.4 x 0.3	40	1	40
Payload 2 Acorn							
Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (hr)	Frequency (min)	Duration (s)
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	80	5	40
Magnetometer	0.05	1.5	0.0008	2.1 x 1.9 x 0.8	80	5	40
Pressure Transducer	0.131	0.04	1.0	2.2 dia x 8.6 length	80	5	40
Thermocouple	0.020 /meter	N/A	1.0 x 10^{-4}	100 length	80	Constant	Constant

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
On-Board Computer	0.094	0.4	2 x 2 GB onboard storage	96 x 90 x 12.4 mm ISIS On Board Computer 400 MHz, ARM9 processor
Transceiver	0.085	1.7	Up to 9600 bps downlink; up to 1200 bps uplink	96 x 90 x 15 mm
Antenna	0.100	0.02	(see above)	98 x 98 x 7 mm
Batteries	0.444*	N/A	N/A	*Combined weight for both payloads; Scrat (0.226), Acorn (0.218)

3.0 Payload Design Requirements

There are several requirements that are considered when determining the success of our payload mission. UAH project requirements include that our payload must fit within a *44 cm x 24 cm x 28 cm* space, weigh under *10 kg*, and possess the necessary structure for enduring the harsh and mostly unknown environment of Enceladus' surface. UAH functional requirements include that our payload must successfully deploy from the UAH spacecraft, independently take measurements, collect/transmit data and power itself. The environmental restrictions of Enceladus include temperatures ranging between *80* and *85 Kelvin*, the existence of certain chemicals (i.e. hydrogen, carbon dioxide, methane), and a relatively sparse atmosphere. According to research, it is possible that an additional source of heat can be found inside of Enceladus. This can be found in the south polar region of Enceladus in an "arc-shaped swathe" that is *500 km* long and *25 km* wide and is located north of the Tiger Stripes. Meaning the ice layers are minimally thinned down and temperatures are warmer near the Tiger Stripes.

4.0 Payload Alternatives

Figure 1.

Figure 2.

Team A designed the first payload concept for achieving the mission, naming it the Enceladus Valiant Explorer, or EVE (Figure 1). The name was given due to the intent of sending the payload solely into a Tiger Stripe, an ambitious yet dangerous mission, a challenge only the bravest could achieve. This concept aims to investigate the internal environment of the Tiger Stripe, employing mass spectrometers, thermocouples and pressure transducers; all efficiently housed in a thermally protected aluminum shell. It will also search for magnetic anomalies in the unknown lower region of the Tiger Stripe through magnetometers. Team B designed the concept "Siegfried & Roy" (Figure 2). This payload will remain stationed at the orbiter until its deployment. After deploying, the bigger payload would penetrate the surface near the Tiger Stripes and upon landing, the smaller payload will deploy from the orbiter and will penetrate into the Tiger Stripes. This concept will employ IMU's, mass spectrometers, pressure transducers and thermocouples, housed in a carbon fiber shell. Both payloads will conduct research of the ground composition and collect data, for eventually comparing and contrasting the two.

5.0 Concept Selection Trade Study

Table 5. Payload Concept Selection Trade Study

FOM	Weight	Enceladus Valiant Explorer		Siegfried & Roy	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	9	81
Complying Project Requirement	9	9	81	9	81
Science Mass Ratio	9	3	27	3	27
Design Complexity	3	1	3	9	27
ConOps Complexity	3	1	3	9	27
Likelihood Mission Success	9	3	27	9	81
Manufacturability	9	9	81	3	27
Instrument Capacity	3	9	27	3	9
Data Retrieved	3	3	9	9	27
Efficient Housing	3	9	27	3	9
TOTAL			**366**		**396**

5.1 Compromise

Figure 3. Scrat

Figure 4. Acorn

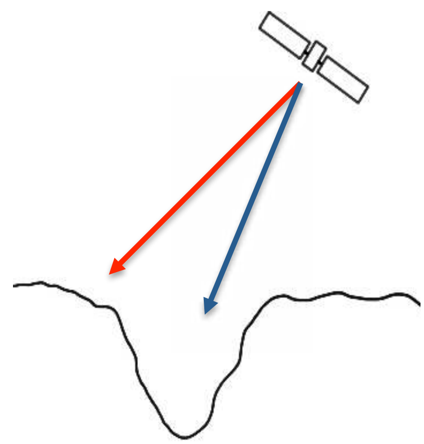
After carefully reviewing the two models including our own figures of merit, the team reached the consensus that Siegfried and Roy was the superior concept. However, certain features from E.V.E. were incorporated (given the close scores), for drawing upon its best elements, such as the enhanced instrument capacity, versatility, efficient usage of space and the resistant shell of aluminum Additionally, the payload was divided into two fully separate pieces. The improved concept was baptized as Scrat & Acorn, inspiring from the character of the same name in the colloquial film Ice Age, renowned for his adventures pursuing his Acorn to great depths in an icy environment.

6.0 Payload Concept of Operations

Our mission will include two concepts of operations. The difference in both ConOps is very noticeable due to the fact that one payload is designed for specific penetration depth while the other is intended for an elongated time of flight.

Scrat (red) along with Acorn (blue) will be both stationed on the UAH orbiter, housed in their individual barrels composed of PVC pipes. Both payloads will be deployed downward using helium pressure. Scrat will experience a pressure of *518.61 psi* and Acorn a pressure of *0.17 psi*. These pressures will ensure our payload mission runs smoothly. Once deployed Scrat will penetrate *0.20 m* into the surface of Enceladus. Once Scrat is stable at the edge of the Tiger Stripe Baghdad Sulci it will conduct research at 1 hour intervals. Acorn, however, will be conducting research while in flight at 5 minutes intervals, before its equipment is harmed on impact with the bottom of the Tiger Stripe Baghdad Sulci. Both sets of data will be transmitted to the UAH orbiter, which will then be transmitted back to Earth to be analyzed.

Figure 5.



7.0 Engineering Analysis

7.1 Structural Mass Analysis

With the objective of deploying two different payloads, into mostly unknown grounds, structural integrity is a fundamental element. For enduring the inhospitable environment, both payloads are protected by a cover of *1 cm* thick Aluminum Beryllium alloy (AlBeMet AM162). To sustain the temperatures an aerogel insulation is included, of *0.5* and *0.4 cm* for Scrat and Acorn respectively. In the case of Scrat, a segment is composed of the penetrating cone, a critical part of the payload that requires further reinforcement, thereby a series of nine stilts are included for better absorbing the impact, illustrated in Figures 6 & 7. Adding up to such structure, there is also an internal structure for allocating instruments within the payload. Unlike Scrat, Acorn does not require rigorous reinforcement due to its mission, only an internal structure for placing the instruments, similar to that of Scrat will suffice. Overall, given the mass of Al Be alloy as $2.16\ g/cm^3$, the structural mass for Scrat and Acorn, notwithstanding the instruments, reaches *3.802* and *0.962 kg* respectively.

7.2 Deployment, Scrat

After acquiring our orbital velocity, our mission required us to de-orbit and penetrate into Enceladus' surface. In order to deploy downwards and penetrate exactly *20 cm*, it was crucial for the deployment and trajectory to accommodate the depth of penetration so our payload can successfully transmit data back to the orbiter. Therefore, our mission will result in high velocities. Our assumed deployment velocity is *105.67 m/s*. To find the pressure to achieve this velocity we modified the formula given to us by UAH, resulting in a pressure of *518.61 psi* (*3575661.33 Pascals*). In result to the fact that Scrat would be deployed abruptly at a high velocity, Scrat would experience a g-load of *2115.8 G's* and an acceleration of *21473.4* m/s^2 inside its barrel aboard the orbiter. Our angle of deployment, derived by using the equation tan-1, is *36.62°*.

7.3 Trajectory, Scrat

Taking into account the acceleration due to gravity, Scrat deploying downwards means our velocity on the y-axis increases very little, due to the "exosphere" of Enceladus. By reverse calculating and solving for our final velocity using the formulas UAH provided to find the depth of penetration, we reconfigured the equation to solve for the final velocity, having as a result *106.93 m/s*. Next, we were required to utilize vectors, our y-vector being our final velocity *106.93 m/s* and our x-vector being our orbital velocity, *143.03 m/s*. We applied these vectors using Pythagorean theorem and obtained a vector velocity of *178.58 m/s*.

7.4 Ending Conditions, Scrat

We desired our payload to penetrate *20 cm*. This depth ensured our payload would be able to transmit the data accumulated back to the UAH orbiter. Therefore, our pressure, accelerations and velocity directly accommodated the depth of penetration. Our final velocity was calculated to be *106.93 m/s* with the assumption of constant gravity and no drag. From this we were able to derive our deceleration and our g-load impact. Scrat will experience a deceleration of *-28,585.1* m/s^2 and a g-load of *2913.87 G's*.

7.5 Deployment, Acorn

An extra *500 m* of distance was added to the equations of Acorn with respect to the depth of the Tiger Stripe it will be descending. Our second payload would be conducting research and acquiring information while in its flight, therefore, it was imperative for our team to calculate as much flight time as possible. First, we determined our initial velocity to be *1%* of our orbital velocity, our orbital velocity being *143.03 m/s* totaling *1.43 m/s*, the minimum velocity allowed. Once we had determined our initial velocity, we solved for the pressure and acceleration that would allow us to reach our initial velocity, along with the g-load our payload would experience within the barrel. Acorn would be deployed with a pressure of *0.17 psi* (*1202.15 pascals*), experiencing an acceleration of *6.82* m/s^2, and an initial g-load of *0.7 G's*.

7.6 Trajectory, Acorn

Our final velocity was calculated to be *150.72 m/s* with the assumption of constant gravity and no drag. Due to the fact that Acorn will be deploying into a Tiger Stripe, we assume our payload will not survive the environment within the Tiger Stripe or its impact.

7.7 Time

Once we completed our engineering analysis and the ending conditions of our payloads were determined we continued onto other specifics necessary to our mission such as our time of flight. Scrat's time of flight reaches a total of *1115.62 sec (18 min, 36 sec)* with the assumption that gravity is neglected on Enceladus. Acorn's time of flight added to *1321.15 sec* (*22 min, 1 sec*) with the assumption of no drag during its descend down the Tiger Stripe.

7.8 Battery Mass Analysis

In order to accomplish our objective, we need the power to fulfill it, thereby batteries play a fundamental role. The necessary battery mass was calculated based on the designated lifetime, frequency, and duration for both payloads. For Scrat, its instruments will have a lifetime of *40 days,* a frequency of *1 hour* and a duration of *40 seconds*. In the case of Acorn, its instruments will have a lifetime of *79.95 hours (~3 days*), a frequency of *5 minutes* and a duration of *40 seconds*, for making the most out of the living descent time. The total operational time for both payloads reached *10.66 hours*. Afterwards we solved for the weight by multiplying the operational time according to the total energy requirements for each payload. The battery mass for Scrat is *0.226 kg*, and for Acorn *0.218 kg*, giving a total of *0.444 kg*.

8.0 Final Design

Based upon the necessities of our mission and the decision made through the Payload Decision Analysis, a final agreement was reached by the team for the final design. Team EDEN's final design is an optimized version of Scrat and Acorn, with enhanced aerodynamics and ultimate efficiency in housing the instruments.

Our main penetrating payload, Scrat, has a diameter of *20 cm and* is *25 cm* tall, with a cone segment dedicated for achieving penetration, and a "drum" for housing the instruments. Scrat will be deployed from the UAH orbiter Cleopatra, with a trajectory aiming towards the brim of the Tiger Stripe Baghdad Sulci, close to the precise South Pole of Enceladus. An aerogel insulation of *0.5 cm* in thickness enables the payload to endure the harsh environmental conditions, protecting the vital instruments. The Aluminum Beryllium alloy stilts in the cone section will ensure the survival of the payload upon impact to the surface (seen in Figure 6). Once stable, the instruments will continue with the readings of the surface for the anticipated duration of the mission, *40 days*. The data gathered will explain the environment and ground composition on the upper level of the Tiger Stripe.

Figure 6. Scrat Cross Section

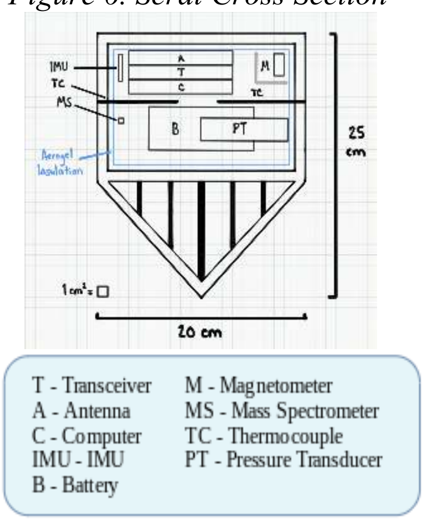
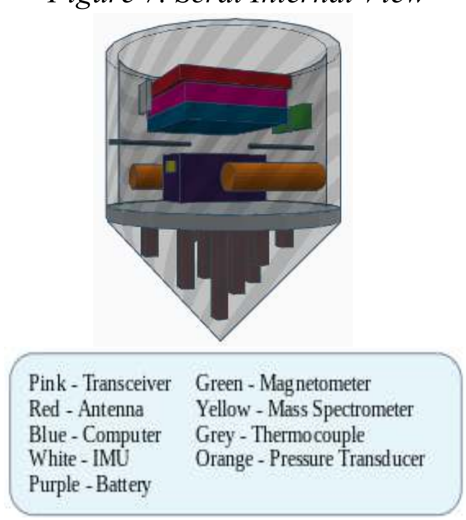
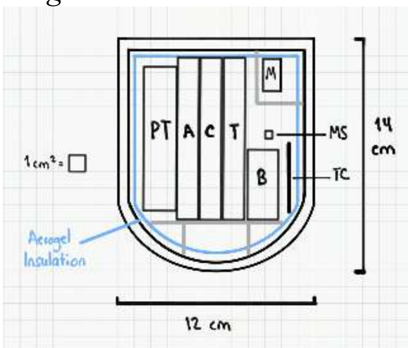


Figure 7. Scrat Internal View



Our secondary payload, Acorn, has a diameter of *12 cm* and is *14 cm* tall. There are two notable segments, a hemispherical head designed for the intent of skipping when reaching the surface, and a main "drum" dedicated for allocating the instruments. Similarly, it will deploy from the orbiter and upon this phase, all the instruments shall commence operations. Acorn will travel into Baghdad Sulci, conducting the readings and measurements of the Tiger Stripe as long as permitted during the mission. Its main focus will be to record the environmental conditions at the lower levels of the Tiger Stripe and analyzing the ground composition from a distance, intending to later associate the results with other process, such as geyser activity in Baghdad Sulci. Figures 8 & 9 depict the internal structure and instruments.

Figure 8. Acorn Cross Section



T - Transceiver
A - Antenna
C - Computer
IMU - IMU
B - Battery
M - Magnetometer
MS - Mass Spectrometer
TC - Thermocouple
PT - Pressure Transducer

Figure 9. Acorn Internal View

Pink - Transceiver
Red - Antenna
Blue - Computer
White - IMU
Purple - Battery
Green - Magnetometer
Yellow - Mass Spectrometer
Grey - Thermocouple
Orange - Pressure Transducer

Figure 10. Scrat

In full, the two payloads have the combined objective of better understanding the nature of the Tiger Stripes, and discerning between the environmental conditions in the two destinations (upper & lower sections of Baghdad Sulci). The contrast between the results in terms of temperature, pressure, magnetic anomalies and composition will deliver a bonanza of information. Figures 10 and 11 depict the final external rendering on the payloads for team EDEN. Figure 12 illustrates a recapitulation of EDEN's mission.

Figure 11. Acorn

Figure 12. EDEN's Mission

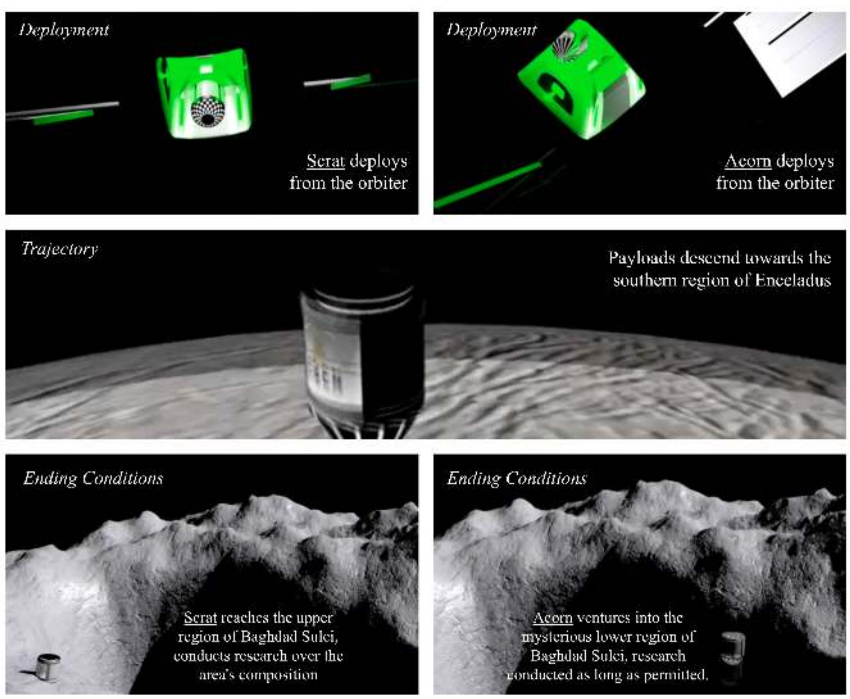


Table 7. Final Design Mass Table

Function	Components	Mass Scrat (kg)	Mass Acorn (kg)
Deploy	PVC Barrel	1.876	0.666
Measure	IMU, Magnetometer, Pressure Transducer, Thermocouple and Mass Spectrometer	0.855	0.481
Collect Data	On-Board Computer	0.094	0.094
Provide Power	Batteries	0.226	0.218
Send Data	Transceiver	0.185	0.185
House Payload	Aluminum Beryllium alloy metal	3.652	0.859
Internal Structure	Carbon fiber structuring	0.139	0.100
Insulation	Aerogel	0.011	0.003
TOTAL		**7.038**	**2.606**

Table 8. Payload Design Compliance

Requirements	Verifications	
Dimensions: 44 cm x 24 cm x 28 cm	Scrat: 20 cm dia x 25 cm Acorn: 12 cm dia x 14 cm	✓
Total mass may not exceed 10kg	The weight of Scrat adds up to 7.038 kg, and reaches 2.606 kg for Acorn; the final weight remains 0.356 kg below the limit, at 9.644 kg	✓
Must endure the environment	The payload's housing of Aluminum Beryllium metal combined with an aerogel insulation counter the harsh conditions expected during the mission	✓
Can not harm spacecraft	Payloads will be safely stationed on spacecraft, each located specifically within safe PVC barrels	✓
Must Deploy	Payloads will deploy from the deployment barrels through the use of pressurized helium	✓
Take Measurements	IMU, Magnetometer, Pressure Transducer, Thermocouple, and Mass Spectrometer will fulfill the readings and analysis of the missions	✓
Collect Data	On-Board Computer included on both payloads	✓
Provide Power	A total of 0.444 kg of batteries provide the necessary power for the proper execution of the mission	✓
Send Data	A transceiver is located on both payload for sending data	✓
House Payload	An Aluminum Beryllium alloy metal frame is used for housing the payload, containing an internal structure for withstanding impact and other forces	✓