Payload Concept Proposal

Team Melt

(Mission Enceladus: Launch of Tomorrow)

Charleston Charter School for Math and Science

Team #1

"Melting our way to life"

1.0 Introduction and Baseline Mission

Team MELT is comprised of scholars who attend Charleston Charter School for Math and Science (CCSMS) in Charleston, South Carolina. Our team name is an acronym which stands for Mission Enceladus: Launch of Tomorrow. Our slogan is “Melting our Way to Life.” The slogan relates to our team name and our science objective, which is to search for signs of life from cryovolcanic ejecta from an underground ocean on an icy satellite of Saturn. Our logo is a symbolic representation of the University of Alabama in Huntsville (UAH) Baseline Mission, our payload, Team MELT’s mission, and our team. The rings around the logo represent the rings of Saturn because Enceladus is one of Saturn’s moons. The ice in the pot represents the icy surface of Enceladus. The water droplets represent the liquid ocean underneath the surface on Enceladus. The pot itself represents the Signs of Life Detector (SOLID), which is our selected science instrument for our payload. The pot also represents how our school and city are a “melting pot” of different cultures. CCSMS is a charter school that brings a math and science focus to its student body and draws students from a 156-square mile region of South Carolina. Thus, our students are ethnically, geographically, and socially diverse.

Our payload is part of the Interior and Composition for Enceladus Exploration (ICEE) Baseline Mission provided by InSPIRESS at the University of Alabama in Huntsville. The UAH Baseline Mission will deploy an orbiter around Saturn with a circular orbit of 179,032 kilometers for a lifetime of 2 Earth years. The UAH orbiter will then move to Enceladus and have a circular polar orbit of 100 kilometers for a lifetime of 2 Earth years. UAH will also have a lander on the south pole of Enceladus for 90 Earth days. Team MELT’s vehicle will be the Enceladus lander. Our team decided to name our payload “Egghead” because our payload is ovoid-shaped, similar to the shape of an egg. The SOLID has to be oriented in an upright position, so the egg-shaped payload is self-correcting when landing at the south pole.

2.0 Science Objective and Instrumentation

Team MELT was challenged to create 3 potential science objectives for the ICEE Baseline Mission. The team’s 3 potential objectives consist of the following: searching for signs of life on Enceladus by collecting a sample of cryovolcanic ejecta via the SOLID; measuring the composition of Saturn’s E-ring using a mass spectrometer; and observing and measuring the conditions of Saturn’s magnetosphere using a flux magnetometer. A trade study was used to help our team select the science objective that best met the goals of the ICEE Mission and Team MELT. Using Figures of Merit (FOMs) and weights of 1, 3, or 9 provided by UAH, the team analyzed each objective according to the FOMs and assigned a raw score to each science objective. The raw score was multiplied by the assigned weight to create the weighted score. The final weighted score was determined by adding up all the weighted scores for a total. We compared all totals and determined that searching for life on Enceladus scored highest with a total score of 264 points. The “Life on Enceladus” science objective received a higher score largely based on 2 FOMs: Interest of the Team and Understood by the Public. The team was intrigued by the idea of life existing on the icy moon and the methodology of the SOLID, so it achieved a higher score with this FOM. The team also decided that this science objective would be easy to explain to the public and would complement the ICEE Baseline Mission, so it achieved a higher score with this FOM.

Table 1. Science Objective Trade Study

FOM	Weight	Life on Enceladus		Composition of Saturn’s E-ring		Conditions of Saturn’s Magnetosphere	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	9	81	1	9	3	27

Applicability to other science fields (broadness)	1	9	9	3	3	3	3
Mission Enhancement	1	9	9	1	1	1	1
Measurement Method (easy to obtain)	9	3	27	9	81	9	81
Understood by the Public	9	9	81	3	27	1	9
Creates excitement in the public ("wow factor")	3	9	27	1	3	1	3
Ramification of the answer	3	9	27	9	27	9	27
Justifiability (nice, neat package), (self-consistent)	1	3	3	9	9	9	9
TOTAL		**Sum**	**264**	**Sum**	**160**	**Sum**	**160**

The selected science objective is to search for signs of life at the south pole of Enceladus at the Alexandria tiger stripe by analyzing cryovolcanic ejecta from active geysers. In 2005 the spacecraft Cassini gathered data about Enceladus and discovered that organic compounds were emitted via cryovolcanoes at the south pole. Cassini found evidence of a liquid ocean under the icy surface believed to be the source of these organic compounds. Thus, there is the possibility that life on Enceladus may exist based on three factors: the presence of these compounds, tidal heating from gravitational interactions between Saturn and Enceladus, and the presence of liquid water. Team MELT wants to use the SOLID to target this cryovolcanic ejecta to run 10,080 tests on it, looking for signs of life with this astrobiological instrument. Even though it only takes 2 hours to complete all tests with the SOLID, our team decided to keep the instrument on for 3 hours as a precautionary measure to ensure that it worked for a full cycle.

The SOLID (pictured below) is the central instrument of our Egghead payload. It is comprised of a Sample Preparation Unit (SPU) and a Sample Analysis Unit (SAU). The SPU gathers samples through 10 extraction chambers and then sends the cryovolcanic ejecta to the SAU for analysis, running 10,080 tests for signs of life. The SAU has antibodies on its arrays. These antibodies must be kept at ambient temperature for the time of flight to Enceladus. Once the SAU receives the sample of the cryovolcanic ejecta, it undergoes a process to scan it called fluorescence sandwich immunoassay methodology. In this process, the sample is put on a glass plate which is affixed with antibodies. A detecting fluorescent antibody is placed on top of it, sandwiching the sample. Through lasers and an optics unit in the SAU, the sample is analyzed to look for antigens. The presence of antigens would confirm that the antibodies reacted to the sample and created molecules to counter the sample. Antigens would only be present if the sample had living substances in it, causing the antibodies to react.

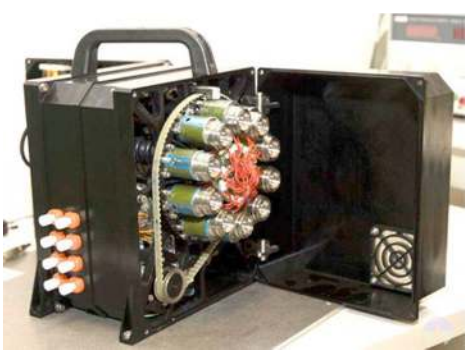


Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Searching for life	To use the SOLID to scan for life in cryovolcanic ejecta of geysers	• Land in Alexandria tiger stripe and collect ejecta from cryovolcano • SOLID cannot be upside down and must be at least partially upright	Signs of Life Detector (SOLID)

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime	Frequency	Duration
Signs of Life Detector (SOLID)	5.7	23	27	21.5 x 21.5 x 21.5	3 hours	One cycle	3 hours

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other technical specifications
On-Board computer	0.094	0.400	2x2 GB onboard storage	Cubesatshop.com ISIS On Board Computer 400 MHz, ARM9 processor
Transmitter/ Receiver	0.085	1.700	Up to 9600 bps down link; up to 1200 bps uplink	Cubesatshop.com ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.020	Up to 9600 bps down link; up to 1200 bps uplink	Cubesatshop.com Deployable Antenna System
Batteries	400 Whr/kg	N/A	N/A	Mass calculations based on power calculations
IMU	0.010	0.220	0.16	N/A
Cryogenic solenoid valve	0.37	0.200	0.14	Normal closed valve

3.0 Payload Design Requirements

Team MELT had to meet project, functional, and environmental requirements when designing their payload for the ICEE mission. Project requirements include that the mass of the payload is under 10 kilograms when stowed and that the volume fits within a 44cm x 24cm x 28 cm space. In addition, our Egghead payload must survive the environment, do no harm to the main spacecraft, and have the ability to access the data delivery system.

Functional requirements include a method of deployment from the UAH vehicle. It must take measurements with its selected instruments and support equipment. The payload should collect data and provide power to its instruments. The payload should have the ability to send data back to the UAH spacecraft. Finally, the team must create appropriate housing to protect the payload.

It's important that the payload is able to handle the environmental requirements for the icy south pole of Enceladus. These environmental requirements consist of an average temperature of -210º C. Geysers erupt from the surface at 33 m/s, and the salt water being ejected is extremely basic with a pH of 11-12. Gravity is very low at 0.113 m/s^2, and trace amounts of pressure exist on the surface. A subsurface ocean is believed to be a few kilometers below the surface and the source of the basic saltwater. Finally, internal heating has been detected in this region and is believed to be the result of tidal heating.

4.0 Payload Alternatives

Team MELT was challenged with developing 2 different concepts to create their payload and meet the requirements of the ICEE Mission. Because Team MELT was satisfied with their Egghead payload, they focused their different concepts on the spacecraft that would host and deploy Egghead to the target location at the Alexandria tiger stripe. The 2 concepts they created were entitled "Scrambled" and "Over Easy," both puns based off their egg-shaped payload. The Scrambled Concept would deploy Egghead from the orbiter and deploys to the surface of Enceladus from 100 kilometers above the surface. The Over Easy concept would deploy Egghead from the lander located on the surface of Enceladus.

Figure 1. "Scrambled"

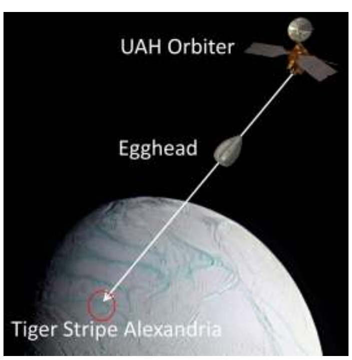


Figure 2. "Over Easy"

5.0 Concept Selection Trade Study

A concept selection trade study was used to help select the concept that best met our team objectives for the mission. The pros and cons of each concept were analyzed for each FOM. The trade study included 6 FOMs provided by UAH, but Team MELT was challenged with creating 3 of its own FOMs and assigning all of the FOM weights of 1, 3, and 9 for the trade study. The 3 FOMs created by the team were Survivability, Orientation, and Accuracy of Location. Survivability took into consideration the ability of the payload to survive the mission. Orientation was designated as a FOM by the team because it was important that the SOLID instrument not land upside down on the surface. It cannot function if in an upside down orientation. Accuracy of Location was the final FOM created by the team because of the importance to the team of landing Egghead within Alexandria.

Because the payload design was the same for both concepts, the concepts tied for the FOMs of Science Objective, Science Mass Ratio, Design Complexity, and Manufacturability. Design Complexity and ConOps Complexity were given a weight of 1 because the team decided that complexity was not a desirable feature of a payload because more problems can occur with a complex payload. Thus, a higher score in this category meant less complexity. The Over Easy Concept got a higher score for ConOps Complexity because the team believed that it was less complex to launch the payload a few meters above the surface of Enceladus than 100 kilometers above the surface. The Over Easy Concept also had a higher score for Likelihood of Mission Success and Survivability because it was being launched from the surface. The Scrambled Concept did receive higher scores for Orientation and Accuracy of Location. Because of its deployment above the surface, the team would have their choice of tiger stripe on the south pole and could position the payload to land in the exact orientation by deploying it above the surface with little bounce and skidding across the surface. With Over Easy the team is limited to the Alexandria tiger stripe because it would be closest to the lander, and the payload may skid up to 30 meters to slow down to a halt. After the final scores were tallied, Team MELT chose Over Easy with its score of 480 points for the payload concept. It was the safer option with a higher chance of success for the ICEE Mission.

Table 5. Payload Concept Selection Trade Study

FOM	Weight	Concept 1 Scrambled		Concept 2 Over Easy	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	9	81
Likelihood Project Requirement	9	3	27	9	81
Science Mass Ratio	9	9	81	9	81
Design Complexity	1	3	3	3	3
ConOps Complexity	1	1	1	9	9
Likelihood Mission Success	9	3	27	9	81
Manufacturability	3	9	27	9	27
Survivability*	9	1	9	9	81
Orientation*	9	9	81	3	27
Accuracy of Location*	3	9	81	3	9
TOTAL		**Sum**	**418**	**Sum**	**480**

* Represents a FOM created by Team MELT

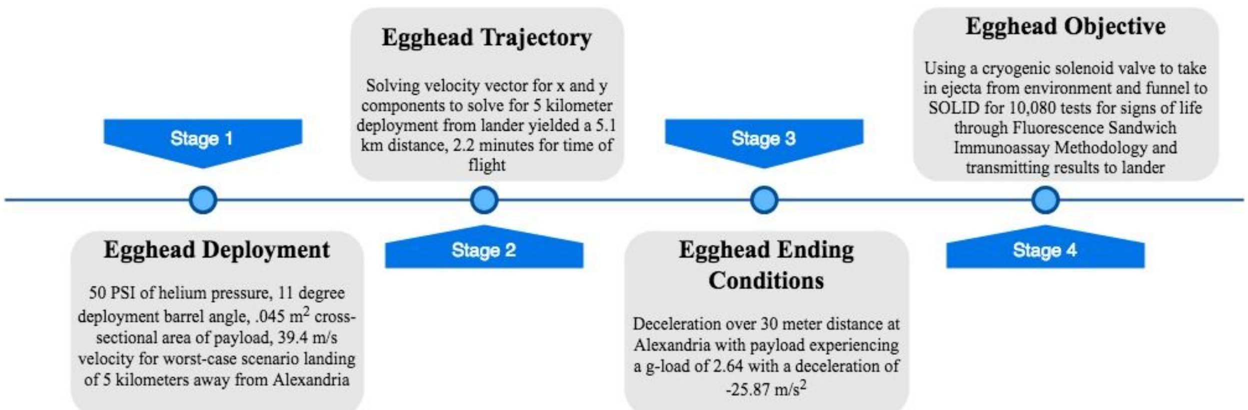
6.0 Payload Concept of Operations

Team MELT's mission revolves around deploying Egghead on the south pole of Enceladus from a UAH lander. Assumptions regarding the lander include that it would be within 5 kilometers of the

Alexandria tiger stripe and that it may have a potential pitch of 12° upon landing. Team MELT has calculated every velocity, helium pressure, deployment barrel angle, and time of flight in order to find the values needed to launch the payload from 0 to 5 kilometers away from the Alexandria tiger stripe. The team started with the worst-case scenario of the lander being 5 kilometers away from the tiger stripe. To travel this distance, the selected velocity would be 39.4 m/s with an 11° deployment barrel angle and a helium pressure of 50 PSI. The time of flight would be 2.2 minutes, landing Egghead at Alexandria. If the lander has a pitch, then the deployment barrel could be remotely adjusted to achieve the 11° deployment angle. For ending conditions, the payload will skid 30 meters with a deceleration of -25.87 m/s^2 before slowing to a halt, experiencing a g-load of 2.64.

Once Egghead is at Alexandria, the tiger stripe will be covered in a layer of ejecta and snowing down with fine, dust-like ejecta which will be taken into the payload through the cryogenic solenoid valve. It will be transferred to the SOLID and arrive at the SPU for preparation. The ejecta will then be funneled to the SAU to run 10,080 tests, scanning for signs of life using fluorescent sandwich immunoassay methodology. The data will be sent back to the lander via the transmitter/receiver.

Figure 3. Team MELT's ConOps Flow Chart



7.0 Engineering Analysis

No calculations were necessary for the initial conditions for deployment from the lander. The givens for the Lander ICEE Mission included that it would stay at the south pole for 90 days. Its exact location would not be known, but it would be within 5 kilometers of the Alexandria tiger stripe. The lander could have a pitch up to 12° in any direction, so the deployment angle's final calculations would have to occur remotely after the exact position of the lander was known.

The payload would have to deploy 10 meters from the lander, and the lander's height was 1 meter. Because the exact lander location is unknown, Team MELT was challenged to calculate all possible lander locations from 10 meters to 5 kilometers. The team decided to solve for the worst case scenario and work backward to a simpler deployment distance. They achieved their selected velocity for a 5- kilometer distance by adjusting barrel length, barrel angle, and helium pressure. A barrel length of 0.5 meters was selected because Egghead would fit inside this length, and increasing this length increased the velocity of Egghead. Velocity had to be minimized to avoid overshooting the tiger stripe. A barrel deployment angle of 11° was the optimal angle because an increase in barrel angle increased velocity as well. Helium pressure of 50 PSI allowed the payload to travel safely without destroying it or overshooting the target. After substituting these values into the UAH equation, a velocity of 39.4 m/s achieved the desired 5-kilometer range.

Using this velocity, we started our trajectory analysis starting by creating and solving a 2D projectile motion problem by breaking down the velocity vector in its X and Y components. It was found that a 2.2-minute flight at 39.4 m/s would take Egghead for 5.1 kilometers. All calculations are listed in Table 6.

The ending conditions included solving for the deceleration of the payload after varying the distances necessary for the payload to skid to a halt. By selecting a distance of 30 meters, we calculated that the deceleration was -25.87 m/s^2 and that the payload would experience a g-load of 2.64. All calculations are listed in Table 6.

The battery mass was calculated by multiplying the power of each instrument by the operational time in hours needed by the payload. Since the SOLID only takes 2 hours to complete a full cycle of tests, the team kept it on for 3 hours as a precaution to make sure it didn't shut off during testing. Only one cycle was needed for all testing. Once the total power was calculated, it was divided by 400 Watt-hours/kg of mass to find the mass of the batteries needed by Egghead. The total amount was 0.19 kilograms. All calculations are listed in Table 6.

Table 6. Calculations Table

Design Stage	Variable	Equation	Calculations	Result
Initial Conditions	NA	NA	NA	NA
Deploy-ment	Deploy-ment Velocity	$v^2_f = v^2_i + 2(\frac{PA}{m})d$ v^2_i = Initial payload velocity (0 m/s) v^2_f = Final payload velocity .upon deployment d = Distance of barrel (0.5 m) P = Helium Pressure (50 PSI/344,738 Pa) A = Cross sectional Area (0.045 m^2) m= payload mass (10 kg) 11°=Deployment barrel angle $v^2_f = v^2_i + 2(\frac{PA}{m})d$	$\frac{2((344{,}738\ kg\ m^{-1}s^{-2})(0.045m^2))*0.5m)}{10kg}$ $\sqrt{\frac{2((344{,}738\ kg\ m^{-1}s^{-2})(0.045m^2))*0.5m)}{10kg}}$	v = 39.4 m/s
Trajec-tory	Magnitude of Y Change in Velocity Time of Flight Distance Traveled or Displace-ment in X	Magnitude of Y = Velocity * sinθ Δv_y= -Final Velocity - Initial Velocity Time of Flight (ToF) = Δv in Y Direction/Enceladus' Gravity (0.113m/s^2) (ΔVelocity * cosθ) * ToF = Distance Traveled or X Displacement)	sin11°=0.19 39.4 m/s *0.19 Δv_y = -7.52 m/s - 7.52 m/s ToF = $(v_f - v_i)/a$ ToF= (-15.04) / -0.113 m/s^2 cos11°=0.98 Distance Traveled = (39.4 m/s* 0.98) * 133 s	v_y=7.52 m/s Δv_y=-15.04 m/s v =1730 m/s ToF = 133 seconds Distance Traveled = 5138 m =

	Direction			5.1 km
Ending Conditions	Decelerat-ion G-load	$-a = \frac{v^2}{2d}$ -a = Deceleration Value v = Selected Velocity d = Distance of Deceleration G-load = $\frac{-a}{-(Earth's\ gravity)}$	$-a = \frac{39.4^2}{2(30)}$ 30 = Selected Deceleration G-load = $\frac{-25.87}{-9.807}$	$-a=-25.87$ m/s^2 G-load = 2.64
Battery Mass	Mass of Batteries	$m_{batteries} = \frac{(ab+cb+db+...)W-hr}{400\ W*hr/kg}$ a, c, d...=Power of instruments b=Duration in hours	$\frac{(23*3 + 0.4*3+1.7*3+.020*3+.220*3+.20*3)}{400\ W*hr/kg}$	$m_{batteries}$ = 0.19 kg

8.0 Final Design

A key feature of Egghead's design is its egg or ovoid shape. In order to use the SOLID for our science objective, it could not be oriented upside down or it would not function correctly. Our initial design to overcome this obstacle was to create a gimbal to maintain an upright orientation of the SOLID inside the payload. However, there was concern that the gimbal would break upon impact with the surface. The ovoid shape was then adopted by the team because the shape and weight being situated in the bottom of the shell would let the payload right itself. Even if the egg were partially wedged in a crevice, the SOLID would be operational, and it is believed that the egg-shape would help the payload land in the most upright position possible for the different surfaces at the south pole. The housing will be made of a high-density polyethylene polymer, which is used to line cryogenic containers and can withstand the icy temperatures on Enceladus. A cross-sectional, 1:1 scale model of the Egghead housing using a similar HDPE polymer has been created by the team and is shown in Figure 5 below. A mold was cut out by a CNC router, and the polymer was melted and shaped around the mold to create an ovoid shape. Finally, space-grade, foam insulation that has been used on the space shuttle will cradle the SOLID and support equipment to ensure its safe arrival at the Alexandria tiger stripe.

Table 7. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Helium pressure and deployment barrel	Provided by UAH
Measure	Cryogenic solenoid valve	0.37
Collect Data	Signs of Life Detector	5.70
Provide Power	Batteries	0.19
Send Data	Transceiver, receiver, antenna	0.19
House/Contain Payload	HDPE plastic, space-grade, polyurethane foam insulation	3.55
Total		10.0

Figure 4. Egghead Payload CAD Model

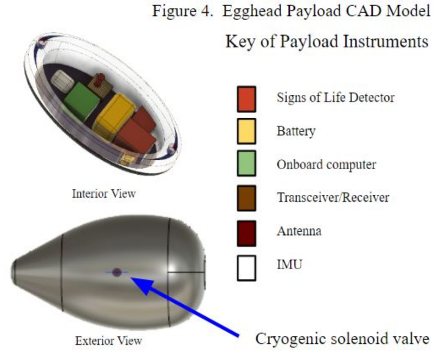


Figure 5. Egghead HDPE Housing

Figure 6. Polyurethane foam insulation