***E**nceladus's **C**urrent **H**umanistic **O**bservations*

"Discovering echoes of the past for a better tomorrow"

PAYLOAD CONCEPT PROPOSAL

E.C.H.O

Sparkman High School

Team 1

1.0 Introduction

The exploration of the unknown is a key factor in the success of a stable future for humanity and the introduction of knowledge to the younger generation. Our team, E.C.H.O. (Enceladus's Current Humanistic Observations) strives to make this a reality with our payload, Lazzaro, which will accompany the UAH ICEE mission. We plan to set the standard of space exploration by obtaining a better understanding of the moon Enceladus. Our name refers to the unknown we plan to discover as we use IMUs to map the subsurface of the moon and the echo we will leave behind for the future generations. Our slogan, *"Discovering echoes of the past for a better tomorrow",* reflects our desire to create a better tomorrow. E.C.H.O. was tasked with the development of this payload in order to house and launch IMUs onto the surface of Enceladus. On earth we use IMUs to map the subsurface of the earth by measuring vibrations. Due to the harsh conditions of Enceladus and the size of the moon, we have planned to launch the IMUs in a triangulated formation covering a five kilometer radius. Our experimental data will give us an advanced and more in depth study of the features leading into the tiger stripe. This payload is planned to be located aboard the UAH lander, Caesar, which is located five kilometers away from Alexandria Sulci (our pod destination) . This destination will be most beneficial for our team due to the fact that it will allow our team to not map just the subsurface of the moon but the Tiger Stripes temperature as well.

2.0 Science Objective and Instrumentation

E.C.H.O. was provided with eight weighted Figures of Merit from The University of Alabama in Huntsville (UAH) to determine the viability of E.C.H.O.'s three potential science objectives: Subsurface Mapping, Current Measurement, and Organism Observation. The objectives were rated based on importance, either receiving a 1, 3, or 9 in each category. This number system was also applied to the FOM weights, each being weighed 1,3, or 9. After calculations, Subsurface Mapping received the highest score, allowing us to move forward with it as our main objective. We felt confident that Subsurface Mapping would be a successful objective as we could learn the subsurface features that lead into Alexandria Sulci. This is important as it helps us understand how the effects of gravity from Saturn and other moons have created the features under the surface. Our science objective is to measure the vibrations of Enceladus in order to map the subsurface channels. The measurements needed were the measurements of the Inertial Measurement Unit, which will measure vibrations and location, and Thermocouple, which will measure temperature. We also included in our instrument selection the mass, power rate, data rate, and dimensions of each instrument.

Table 1. Science Objective Trade Study

FOM	Weight	Subsurface Mapping		Current Measurement		Organism Observation	
		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	3	3	3	3	3	3
Mission Enhancement	1	9	9	1	1	3	3
Measurement Method (easy to obtain)	9	9	81	1	9	1	9
Understood by the Public	9	3	27	3	27	9	81
Creates excitement in the public ("wow factor")	3	3	9	3	9	9	27
Ramification of the answer	3	9	27	3	9	3	9
Justifiability (nice, neat package), (self-consistent)	1	9	9	3	3	3	3
TOTAL			**246**		**70**		**162**

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Subsurface Mapping	Measure the vibrations within the moon	-IMU must be in contact with the surface of Enceladus -Multiple IMUs	Inertial Measurement Unit (IMU)
Temperature Reading	Measure the temperature in varying locations	Thermocouple must be in contact with the surface of Enceladus	Thermocouple

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Frequency	Duration (hours)	Number of Enceladus days
Inertial Measurement Unit (IMU)	0.013	0.22	0.160	2.2 x 2.4 x 0.3	4 times per day	1	65.6
Thermocouple	0.020/ meter	N/A	1.0 x 10^{-4}	wire embedded in payload shell	4 times per day	1	65.6

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Dimensions (mm)	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	Cubesatshop.com ISIS OnBoard Computer 400 MHz, ARM9 processor
Transmitter/Receiver (Transceiver)	0.085	1.7	Up to 3.4 Mbs	96 x 90 x 15	Cubesatshop.com ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	Up to 3.4 Mbs	98	Cubesatshop.com Deployable Antenna System
Batteries	400 Whr/kg	N/A	N/A	Size varies	Mass calculated by each team, based on power requirements

3.0 Payload Design Requirements

UAH provided E.C.H.O. with six payload design requirements: deployment from the UAH mission vehicles, taking measurements, collecting and relaying data, and self sufficiency in power and payload housing. The payload was constrained to a maximum of 10 kilograms of mass in a maximum volume of 44 centimeters by 24 centimeters by 28 centimeters. It can not cause any harm to the UAH vehicle, and it must survive the harsh environment. Enceladus's environment posed a significant challenge with the extreme temperatures ranging around -210 Celsius and gravity of 0.113 m/s^2. Enceladus has a surface of mostly ice and water with thermal vents that are prevalent throughout the moon. The intense cold temperatures, low gravity, and composition of Enceladus greatly influenced our alternative payload concepts. Many of our concepts and methods of execution were considered infeasible. However, these complexities were addressed and solutions were developed, resulting in our final payload.

E.C.H.O.'s final payload meets all of the requirements and constraints that UAH presented. It has a launcher, which is housed on top of the lander, that will shoot pods with helium. These pods contain an

IMU and thermocouple that will measure the subsurface and temperature of Enceladus' surface and send that data back to the trans-receiver of the main payload. The launcher has a height of 34 cm with a diameter of 30 cm and a mass of 5.35 kilograms, which computes with the mass of the sensors of 4.15 to a total of 9.5 kilograms. This falls well within the required constraints and a mass of 10 kilograms. It does not cause any harm to the UAH vehicle, and in order to survive the harsh environment E.C.H.O. designed the payload with a composition of carbon fiber insulated with aerogel. Also, we adjusted the launching angle and helium output of the launcher in account of the environment in order to obtain maximum amount of data with very little risk of failure.

4.0 Payload Alternatives

To begin the concept process, E.C.H.O divided itself into two design teams to determine what payload would be the most efficient and beneficial to our science objective. The first team designed the Lazzaro concept, this concept featured a launcher that would deploy IMUs onto the surface of Enceladus. The launcher would be stationed on top of the UAH lander, Caesar. The second design team created the rover payload Reverb. This payload would deploy from the lander and drop IMUs onto the surface whilst travelling the modified path.

Launcher Payload Lazzaro

This concept will be attached to the top of the UAH lander Caesar. This payload will launch two sets of three IMUs into a triangulated pattern on the surface of Enceladus. IMUs will then measure the vibrations within the icy crust to determine the leading features into the Tiger Stripes. A key feature of this concept is the stability it has remaining aboard the UAH lander. It also has a wide data range since the pods will be launched in a triangular formation using the provided helium.Our launcher will have a height of 34 cm and a diameter of 30cm, which will house all six of our pods in a scrolling pattern down the launcher similar to a screw. Each pod will have a radius of 4 cm which is sufficient for holding the IMU, computer and antenna. The thermalcouple will be within the carbon fiber frame itself.

Figure 1. Lazzaro

Moving Payload Reverb

This concept is a rover payload. The rover will be stored aboard the UAH lander and deploy once it has made contact with the surface. Once deployed, the rover will travel a designated path and deploy IMUs at varying distances. These IMUs will measure the vibrations within the moon to determine its subsurface features. This concept has more mobility than our first concept which is its major advantage.

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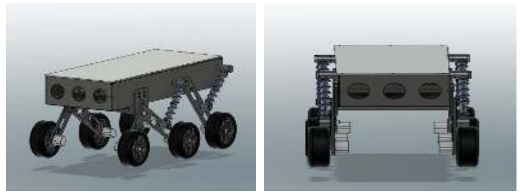
Figure 2. Reverb



5.0 Concept Selection Trade Study

To determine which payload should be selected, UAH provided 7 figures of merit(FOM) to measure the payloads against. E.C.H.O. created 3 additional FOM's: energy efficiency, coverage, and durability. Energy efficiency was particularly selected by E.C.H.O. because of the importance of the battery mass to coverage ratio. We wanted to use the least amount of battery power, but still have the maximum amount of coverage that we needed. Coverage was a crucial factor to our concepts due to how the IMUs operate: the farther the distance from each IMU, the deeper the IMUs measure into the surface. The final FOM that E.C.H.O. chose was durability. The harsh environment on Enceladus stresses the significance of having a strong, enduring payload. If our payload cannot survive the severe climate, then our mission cannot be executed.

The FOM's were weighted by E.C.H.O in a way similar to the Science Traceability Matrix: weights of 9 were considered important, followed in importance by 3 and 1. As a team, we assigned each FOM with a raw score and calculated the final weighted scores. For each concept, the weighted scores were all added together, with Lazzaro receiving a total score of 432 and Reverb receiving a score of 168. Table 5 illustrates this process as well as the design process that E.C.H.O. performed, with Lazzaro not scoring less than Reverb in any of the FOM categories.

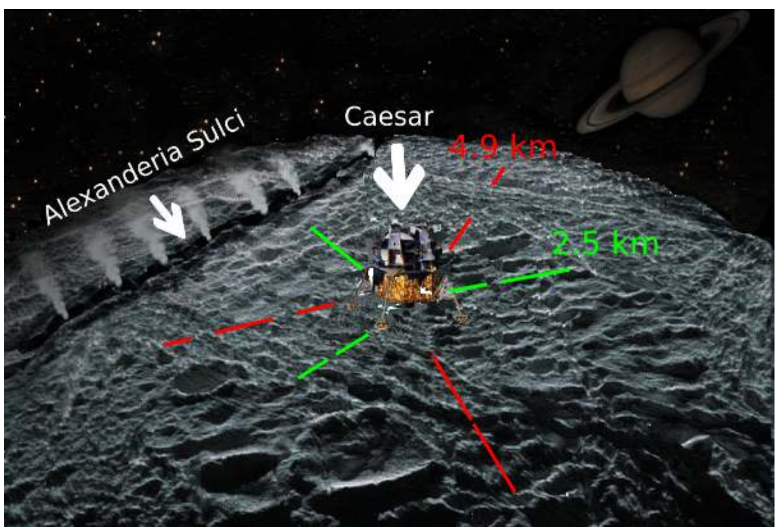
Table 5. Payload Decision Analysis

FOM	Weight	Lazzaro		Reverb	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	1	9	9	3	3
Likelihood Project Requirement	3	9	27	9	27
Science Mass Ratio	3	9	27	9	27
Design Complexity	9	9	81	3	27
ConOps Complexity	3	3	9	1	3
Likelihood Mission Success	9	9	81	1	9
Manufacturability	3	3	9	3	9
Energy Efficiency	9	9	81	1	9
Coverage	9	9	81	3	27
Durability	3	9	27	9	27
TOTAL			**432**		**168**

6.0 Payload Concept of Operations

The Lazzaro mission begins on the ICEE lander, where its pods are contained within the launcher tubes until deployment. At a distance of 5 km from the outer tiger stripe Alexandria Sulci, the Lazzaro launcher will fire 6 IMUs into a triangulated pattern centered around the ICEE lander. The first set of three IMUs will be launched at a distance of 4.9 km to form the outer triangle, this will give us a reading of the features leading into Alexandria Sulci. We chose this distance to ensure that we don't land inside of the tiger stripe due to potential measurement corruption and transmission difficulties that we may experience within it. The second set of three IMUs will be launched at a distance of 2.5 km, this will give us a more accurate reading around the lander. The reason we chose sets of three is because an IMU needs triangulation to ensure accurate data. With these two sets of IMU launches, we will be utilizing the helium reserves of the ICEE vehicle. Upon impact with the surface, the IMUs will measure the vibrations within Enceladus, much like how scientists do it on Earth, to survey the subsurface features of the crust. The thermocouple will provide data to determine the correlation between the temperatures and the channels located beneath the surface. We will then collect all data and transmit it back to the ICEE lander where we will then study the extent of the subsurface channels.

Figure 3. Lazzaro Concept of Operation



7.0 Engineering Analysis

To ensure that the mission would be completed as described, E.C.H.O. made several calculations to verify that the payload complies with the UAH requirements, deploys out of the barrel, travels the desired distance, survives impact, and has enough battery life to power its instruments.

Table 6. Engineering Analysis Calculations

	Assumptions	Equation	Solution
Initial Conditions	Lander is stationary, Payload is secure, Constant inclination angle	$V_r = \pi r^2 h^3$ $m = m_{pod} + m_{llauncher}$	$V_r = 24021cm^3$ m = 9.5 kg
Deployment	Constant pressure and acceleration in the barrel No friction, Perfect fit, Gravity neglected	$A = \frac{1}{2}\pi r^2$ $a = PA/m$ $v_f^2 = v_i^2 + 2ad$	$A = 0.0025m^2$ $v_{exit\ max} = 48.96m/s^2$ $P_{max} = 23.5m/s$
Trajectory	No air resistance Constant, horizontal velocity	$d=(v_f^2-v_i^2)/a$ $t=(v_f-v_i)/a$ *TOF=2t $h=d\tan\Theta-(gd^2)/(2v_i^2\cos^2\Theta)$	d=4900m t=208s *TOF=416s h=1782m
Ending Conditions	Constant gravity, Pod contact, Less than 20 degree impact angle	$V_f^2 = V_i^2 + 2ad$ g-load = a/g F = ma	$a = 7.75m/s^2$ g-load = 0.779 F= 5.34N
Battery Mass	Thermocouple power negligible, Barrel connected to UA	m_{batt}=(ab+cd+..W*hr)/(400W*hr/kg)	$m_{batt} \cong 1.74$ kg

8.0 Final Design

Our team chose the concept Lazzaro as our final design. This concept met all of the parameters set by UAH and has the best potential to accomplish the science objective. Lazzaro is a stationary launcher with 6 deployable pods. We have created pods that hold an IMU, a thermocouple, an on-board computer, a transmitter, and a battery. The provided helium on the UAH launcher will allow us to launch the pods in a triangular form ensuring triangulation needed for IMU measurement. We will be shooting our pods with a constant pressure of 135 kPa, at a 20 degree angle, traveling a maximum horizontal distance of 4.9 km. Triangulating the pods allow us to map features under the surface. With a total mass of 9.5 kg and a design created so as to pose no threat to UAH's mission our team E.C.H.O. has developed a payload concept that follows the guidelines set forth by UAH. E.C.H.O.'s final payload, Lazzaro, seems to be the most efficient out of our concepts, while also adhering to the constraints presented by UAH. Our first payload design, Reverb, was a mobile rover design which was designed to drop the sensors while traversing Enceladus's terrain. The biggest difference between the two designs is that Lazzaro is a stationary launcher and Reverb is a mobile vehicle that will deposit our sensors while traveling Enceladus. We felt that Lazzaro had a higher probability of success.

Figure 4. E.C.H.O.'s Mission

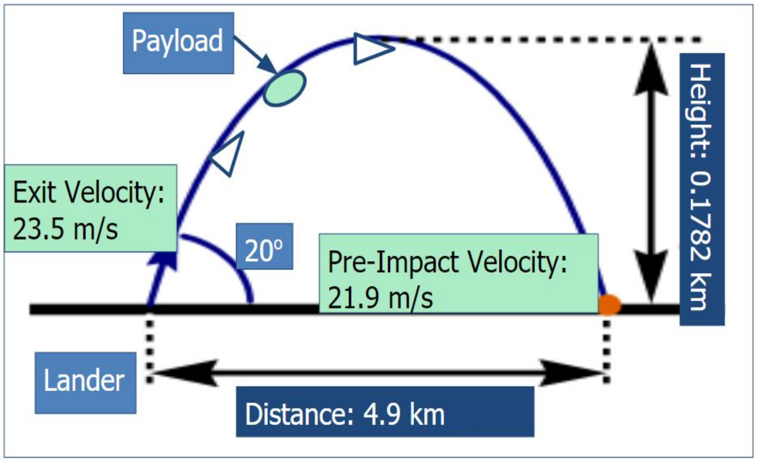


Figure 5. Lazzaro Schematic Design

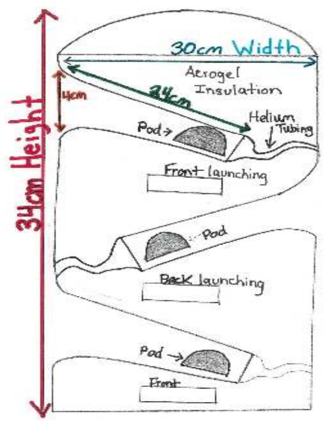


Table 7. Final Design Mass Table

Components	Function	Mass
Battery-per sensor	Supply Power	0.289 kg per sensor
Antenna	Send Data	0.10 kg
Transmitter	Send Data	0.085 kg
IMU	Collect Data	0.013 kg
Thermocouple	Collect Data	0.10 kg
Computer	Compute Data	0.094 kg
Launcher	House Sensor	5.354 kg
Carbon Fiber Frame	House Payload	0.10 kg
Mass per Sensor		0.691 kg
Total Mass of Sensors		4.146 kg
Total Mass of Payload		9.5 kg