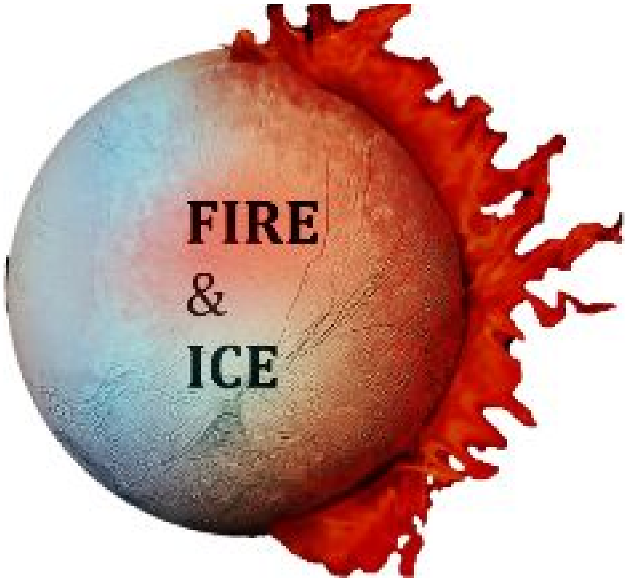

“Studying classic elements for a better understanding of a new world.”

PAYLOAD CONCEPT PROPOSAL

Team Fire And Ice

Sparkman High School

Team 3

1.0 Introduction

Since the dawn of humanity people have desired to progress further into the unknown. With our payload Cook we will once again discover new aspects of yet another untried world. As Team Fire and Ice, the name a reference to Aristotle's classic elements, we strive to extend our knowledge of space and planets by developing a deeper understanding of the core of Enceladus by taking temperature measurements. This correlates directly with our slogan "Studying classic elements for a better understanding of a new world", because we will be studying the temperature of Enceladus in order to expand our knowledge and gain a greater understanding of Enceladus as well as our own moon. We have developed two payloads to compliment the UAH ICEE mission, an orbiter which will remain with the UAH vehicle and a rover which will deploy from UAH's lander on Enceladus. The first payload we developed is a rover called Cook, a reference to James Cook, the discoverer of Antarctica. This vehicle is a sphero type payload that will drop from the UAH lander. It will travel 5 km to Alexandria Sulci and then drop into the crater, using a thermocouple and IMU to get temperature measurements as well as location. These measurements will then be paired with thermal images from our second payload ParaSight, an orbiter which will be located aboard the UAH ICEE mission orbiter. Once the data from our rover, Cook and the orbiter ParaSight have been paired we will be able to create an accurate temperature gradient of Alexandria Sulci. This will give us knowledge that we can apply to our own moon as well as other planets, making further research possible.

2.0 Science Objective and Instrumentation

Team Fire and Ice was provided with eight weighted Figures of Merit (FOMs) from the University of Alabama in Huntsville (UAH) to determine the viability of Fire and Ice's three potential science objectives: Geyser Material Sampling, Tiger Stripe Temperature Measurement, and Testing Core Magnetic Properties. These objectives were given a raw score based on importance, receiving either a 1, 3, or 9 in each category, with 1 representing the least interesting while 9 represented the most interesting. The weights of each category were also determined using this number system. The raw score was then multiplied by the weight to given a weighted score for each FOM. After calculations, Tiger Stripe Temperature Measurement had the highest score, leading us to choose to focus on this objective moving forward. We were confident that Tiger Stripe Temperature Measurement would be a successful mission because of the relevancy to additional research on Enceladus, as well as our own moon and other planets. Our science objective is to take thermal images and temperature measurements of the tiger stripes in order to create a temperature gradient for Alexandria Sulc.

Table 1. Science Objective Trade Study

FOM	**Weight**	**Geyser Material Sampling**		**Tiger Stripe Temperature Measurement**		**Testing Core Magnetic Properties**	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	3	27	9	81	1	9
Applicability to other science fields (broadness)	1	3	3	3	3	9	9
Mission Enhancement	1	3	3	9	9	1	1
Measurement Method (easy to obtain)	9	9	81	3	27	1	9
Understood by the Public	9	3	27	9	81	1	9
Creates excitement in the public ("wow factor")	3	1	3	1	3	9	27
Ramification of the answer	3	3	9	9	27	1	3
Justifiability (nice, neat package), (self-consistent)	1	9	9	3	3	1	1
TOTAL			**Sum: 162**		**Sum: 234**		**Sum: 68**

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instruments Selected
Tiger Stripe Temperature Measurements	• To get the temperature of and take thermal images of Alexandria Sulci	• IMU and Thermocouple must be inside Alexandria Sulci • Thermal image system must be in orbit around Enceladus	• Thermocouple • IMU • Thermal Imager

Table 3. Instrument Requirements

Instrument	**Mass (kg)**	**Power (W)**	**Data Rate (Mbps)**	**Dimensions (cm)**	**Lifetime (months)**	**Frequency (runs)**	**Duration (minutes)**
Thermal Imager (Orbiter)	2.0	5.0	10.240 per image	10x10x10	1	4	6
Thermocouple (Rover)	0.020/meter	N/A	1.0×10^{-4}	Wire	1	1	120
Inertial Measurement Unit (IMU) (Rover)	0.013	0.22	0.160	2.2 x 2.4 x 0.3	1	1	120
Motor (Rover)	0.9	60.0	N/A	5.0 x 3.0 x 4.0	1	1	180

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Dimensions	Other Technical Specifications
Antenna	0.100	0.020	Up to 3.4 Mbps downlink	98 mm	cubesatshop.com Deployable antenna system
On-Board Computer	0.094	0.400	2 x 2 GB onboard storage	96 x 90 x 12.4 mm	cubesatshop.com ISIS on board computer 4 MHz, ARM9 processor
Transmitter/ Receiver	0.100	5.000	Up to 2 Mbps	96 x 90 x 15 mm	CPUT S-Band CubeSat Transmitter
Battery	TBD	400 Whr/kg	N/A	Size varies	Based on power requirements

3.0 Payload Design Requirements

UAH provided six payload design requirements: deployment from the UAH mission vehicles, taking measurements, collecting and sending data, providing its own power, and housing the payload. The payload itself was also constrained to a maximum of 10 kilograms of mass, maximum volume of 44 cm by 24 cm by 28 cm, and it had to deploy from the UAH vehicle and have access to the data delivery system. The payload could not cause harm to the UAH vehicle and had to be able to survive the lunar environment. The environmental conditions included a 20-25 km thick ice shell that thinned to 1-5 km at the tiger stripes and a heavily cratered surface, as well as an extremely low gravity. The atmospheric conditions, which were relevant to our orbiter payload, included no pressure, a temperature of -250℃, and an atmosphere comprised of 91% water vapor, 4% nitrogen, 3.2% carbon dioxide, and 1.7% methane. Taking into account all of these requirements, constraints, and conditions, we created our alternative concepts, which we then improved upon to create our final concept, a pair of payloads consisting of an orbiter and a rover.

The types of usable materials were drastically decreased and the methods of mission execution were difficult to design around. However, these complexities were addressed and solutions were developed, resulting in our payload alternatives and then, eventually, our final payload. Our payloads were created from carbon fiber and aerogel insulation to overcome the harsh environmental conditions of Enceladus. Our payload dimensions are as follows: a thermal imager that is 10cm x 10cm x 10cm in size, and a rover with a radius of 12cm and a height of 24cm. We will be using batteries for power on the rover, and the power on the orbiter will be provided by UAH. We have ensured that neither of our vehicles will cause harm to the UAH vehicles.

4.0 Payload Alternatives

After selecting our objective, we turned our focus towards developing viable mission payloads. The first of our payload concepts is concept Parasight, which will work in conjunction with a second payload design which would deploy from UAH's lander. ParaSight will stay aboard the UAH orbiter and will contain a thermal imager to take thermal images of Alexandria Sulci that we will pair with temperature readings from our rover payload to gain a better understanding of the surface and core properties of Enceladus. The main feature of this concept is its ability to get a clear thermal image of the crater as it orbits above Alexandria Sulci. To get a temperature reference for the thermal images, we will be using a second payload concept to take temperature readings.

Figure 1. ParaSight orbiter

Our first rover design concept, named Glacier in reference to the icy surface of Enceladus, would have been comprised of multiple IMU and thermocouple pods. The payload would have dropped from the UAH lander and then traveled the 5 km to Alexandria Sulci, where the IMU and thermocouple pods would have been ejected into the Tiger Stripes. This concept would have used a scatter bomb approach, launching multiple pods into the crater upon arrival to Alexandria Sulci. One of the main features of this payload was the use of multiple instruments to ensure successful collection of data. We would also be using carbon fiber frame as well as Aerogel to help withstand the environment on Saturn's moon.

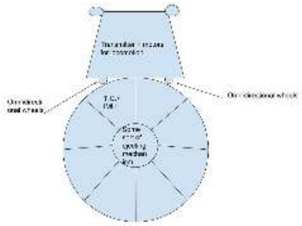

Figure 2. Glacier Rover

Our second rover design concept is named Kelvin. It would have dropped from the UAH lander and then travelled the 5 km to Alexandria Sulci where it would have used helium to shoot thermocouple and IMU pods into Alexandria Sulci. This data would have then been transmitted back to the UAH lander. This concept would not have had to travel the total distance to the crater but could have shot the instruments from a distance away. A key attribute of this design was the ability to get the pods into the crater without having to fall into Alexandria Sulci itself.

Figure 3. Kelvin Rover

Our third and final rover design, named Cook, was an improvement upon our first design. It would have two parts, and after dropping from the UAH lander and traveling the 5 km to Alexandria Sulci, the top piece which would consist of a a motor and transmitters, would disconnect from the bottom section. The bottom section, which would be a thermocouple and an IMU, would then roll into the Tiger Stripe and take temperature measurements as it falls, and the data would then be transmitted back to the UAH lander. The biggest difference from our first design is that Cook itself would take the measurements as one large payload, and Glacier was going to disperse numerous pods in multiple directions. Since the payload has size and mass constraints, the group felt that using multiple pods within a main payload would require too much volume and mass and a single payload with the same instruments could provide the same data for comparison with ParaSight's orbital thermal images. Therefore the main feature of this concept was its ability to reach the desired location and still be able to take the required data. It would be made of a carbon fiber frame and insulated with Aerogel to withstand the harsh environment.

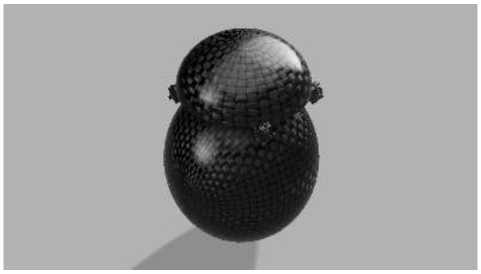

Figure 4.CAD Rendered Cook Rover

5.0 Concept Selection Trade Study

Team Fire and Ice used the 7 Figures of Merit (FOM) provided by the University of Alabama in Huntsville (UAH) and we decided on 3 more in order to analyze our potential concepts. The concepts we decided on were: Battery Sustainability, which is important because our payload is traveling around 5 km and battery life plays a huge role; Data Accuracy, which would be necessary for the payload to transmit the data back to the UAH lander; and Compactability, as the size of the payload affects its ability to fall into Alexandria Sulci. The concept trade study determined which concept would most effectively execute our science objective. We judged our concepts Glacier, Kelvin, and Cook based on the numbers 1, 3 and 9, with 1 not meeting the standard of the FOM and 9 meeting it exceptionally. Once we collected all of the scores and weighted them accordingly, it was concluded that Cook had the highest likelihood of successfully executing our potential science objective.

Table 5. Payload Concept Selection Trade Study

FOM	Weight	Glacier		Kelvin		Cook	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	1	9	9	81	3	27
Likelihood Project Requirement	9	1	9	3	27	9	81
Science Mass Ratio	3	1	3	3	9	9	27
Design Complexity	3	1	3	9	27	3	9
ConOps Complexity	3	1	3	3	9	9	27
Likelihood Mission Success	9	3	27	1	9	9	81
Manufacturability	3	1	3	3	9	9	27
Battery Sustainability	3	1	3	3	9	9	27
Data Accuracy	3	9	27	1	3	3	9
Compactibility	1	3	3	1	1	9	9
TOTAL			**Sum:90**		**Sum:184**		**Sum:324**

6.0 Payload Concept of Operations

Cook’s mission begins on the ICEE rover, where it will deploy from the bottom and, upon activation, will roll the 5km to Alexandria Sulci, dropping its spherical bottom into Alexandria Sulci and leaving its head atop the crevice. Our payload is similar in design and function to a Sphero. It has a maximum velocity of 1.67 m/s and will take 3 hours to travel to its destination. It will have a carbon fiber frame and be insulated with Aerogel in order to overcome the hostile environment of Enceladus. As the sphere drops, it will use its external thermocouple and IMU to take temperature measurements and provide payload location. Cook will then use its onboard computer and antenna to transmit the data to the “head,” which then transmits the data back to the UAH orbiter.

ParaSight, our second payload, shall remain on the orbiter while Cook travels to Alexandria Sulci. While Cook takes temperature measurements, ParaSight will be taking thermal images. The readings from Cook shall be used to provide reference for the thermal images taken by ParaSight. The images will be paired with the data from Cook in order to create a thermal gradient of Alexandria Sulci. This will hopefully give us a better understanding of the effect of the pressure of Saturn on Enceladus.

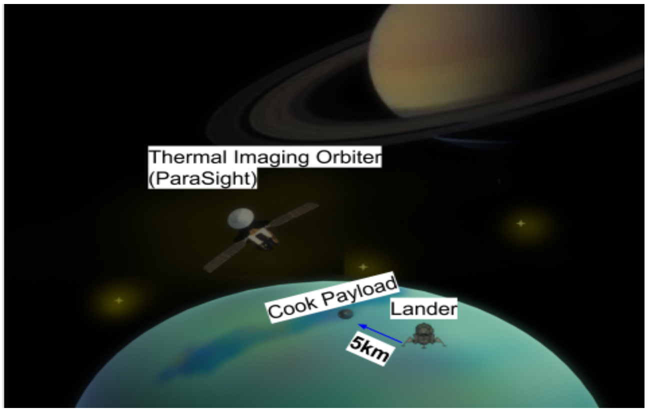

Figure 6: Concept of Operations

7.0 Engineering Analysis

Our analysis on the ICEE mission; en tandem with our payload, Cook, is separated into 5 stages: initial conditions, deployment, transportation, ending conditions, and the battery mass. To ensure that the ICEE mission would work successfully, we made several calculations to make sure that Cook survives deployment, arrives at the destination with enough battery, and that it survives hitting the bottom of Alexandria Sulci.

Table 6: Engineering Analysis Calculations

	Assumptions	Equation	Solution
Initial Conditions: Orbiter	No altitude changes, circular orbit	$\therefore v = \sqrt{(GM/r)}$ $V = l * w * h$ $T_{orbiter} = 100km/\therefore v$	Orbital velocity: 20425.5m/s Orbiter volume: $1000cm^3$ $T_{orbiter}$=5.64min
Initial Conditions: Rover	No atmosphere, low gravity, payload is stationary, payload is secure	$V_r = (4/3)\boldsymbol{\pi} r^3 + (2/3)\boldsymbol{\pi} r^3$ $m = m_r + m_o$	Rover volume: $10857.3cm^3$ m = 10 kg
Deployment	Flat landing space, payload begins startup, initial velocity = 0	$F_{dep} = ma$	Impact force: 0.904N
Transportation	No air friction, horizontal velocity is constant, clear pathway	$T_{battery} = t * 60W$ $t = d/v_{avg}$	Battery usage: 180.982 W-hr t = 2.99 hr
Ending Conditions	No obstructions, constant acceleration, negligible water pressure, 90 degree impact angle	$F_{imp} = ma$ $a = (v_f^2 - v_i^2)/d$ G-force= a/gravity	$F_{imp} = 0.97N$ $a = 0.127m/s^2$ G-force = 0.128
Battery Mass	Thermocouple power negligible	$W_{total} = 60W * t$ $M_{battery} = 400Whr/kg$	W_{total} = 180.982 W-hr $M_{battery}$ = 3.02 kg

8.0 Final Design

Cook is an improved version of our first concept, Glacier. It consists of a sphere of carbon-fiber that is connected to a smaller hemisphere that has an omnidirectional wheel. The two halves will be connected together via magnets, and the payload will be insulated by aerogel. By eliminating the process of breaking the payload apart into separate IMU and thermocouple pods, we greatly increased our chances of success and mitigated the chances of the payload getting stuck in small crevices. This was the biggest difference between our first concept, Glacier, and our final design, Cook. Our final design efficiently executes our science objective while complimenting the ICEE mission. Both of our rover designs work in tandem with our orbiter concept, ParaSight, which will be taking thermal images of Alexandria Sulci. Once we have collected the temperature data from Cook and the thermal images from ParaSight, we will combine the data to create a complete temperature gradient. This will give us a better picture of Saturn's effect on Enceladus.

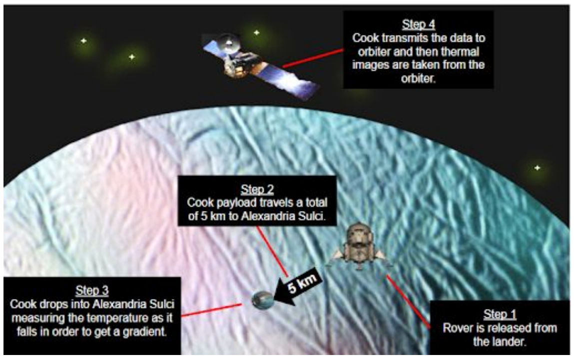

Figure 7: Team Fire and Ice's Mission

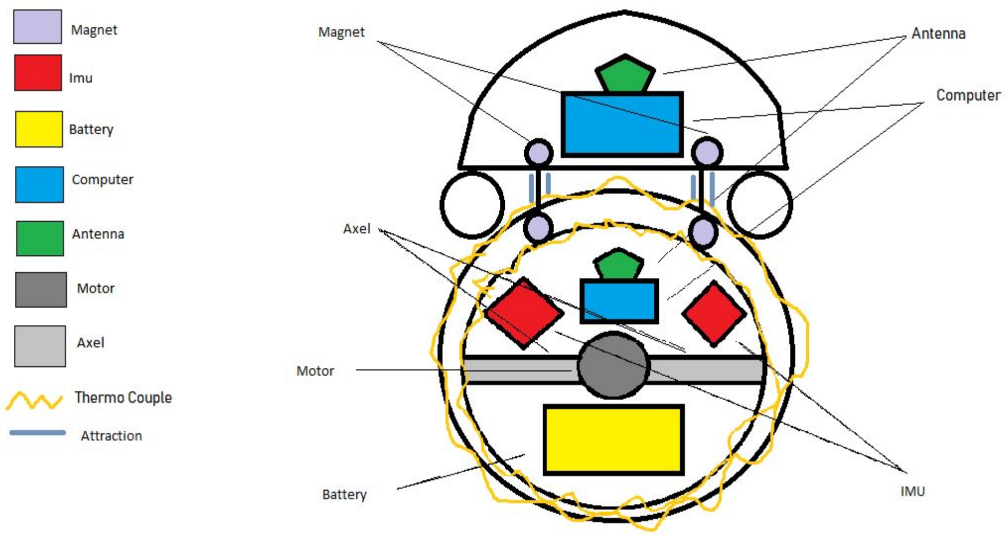

Figure 5: Schematic view of Cook Rover

Table 7. Final Design Mass Table

Function	Components	Mass (kg)
Supply Power	Battery- Orbiter Payload	Power provided by UAH
	Battery- Rover Payload	3.02
Measure	Thermocouple	0.02
	Thermal Imager	2.00
	IMU	0.013
Send Data	Antenna	0.10
	Transmitter	0.10
Collect Data	On-Board Computer	0.094
Payload Structure	Carbon Fiber Frame	4.75
Total Mass of Payload		10.0kg