PAYLOAD CONCEPT PROPOSAL

WE'RE LOONEY FOR LUNAR LAVA

Lunartics

Muscle Shoals High School

Muscle Shoals 3

1.0 Introduction

Beneath the Moon’s surface, scientists believe there are large lava tubes that could protect both humans and payloads from the Moon’s extreme environment. The most well known of these lava tubes is located at the Marius Hills Skylight and was discovered when JAXA scientists combined radar data from SELENE with the gravitational field measurements taken from NASA’s GRAIL mission. The team Lunartics, a group of seven physics students at Muscle Shoals High School, has developed a scientific payload *Luna* that will travel onboard the orbiter element of UAH’s Baseline Mission. The payload will deploy from the orbiter and fall into the lava tube where it will determine if the environment inside the tube is safer than on the surface. The name Lunartics was chosen because the word “lunatic” derives from the Roman goddess of the moon, Luna. Additionally, the belief that the moon controls human actions dates back to Greek and Roman times when the Greek physician Hippocrates first theorizes that because the moon controls the tides, it must also control humans because they are 60% water.

2.0 Science Objective and Instrumentation

As a group, the Lunartics decided on three science objectives that elucidated the most interest and were deemed the most important -- gravity, lava tubes, and internal structure. These science objectives were then put through a trade study to determine a winner. In the Trade Study, the Figures of Merit and the weights were given to the team by UAH, and the students assigned each objective a score of 1, 3, or 9. The purpose of the science objective that won, Lava Tubes, is to understand the properties (size, shape, etc) of the lava tube and how well it protects from the environment. If lava tubes do offer protection from the environment, they would advance lunar exploration by allowing both humans and scientific payloads to survive for longer amounts of time on the moon, which would allow for more detailed studies. Additionally, building bases on the moon is the next step to space exploration. The payload *Luna* will house many instruments to determine the environment inside the tubes. A thermocouple will measure the temperature, a pressure transducer will measure the pressure, an IMU will determine the size of the tube, a langmuir probe will determine characteristics of electrons in the area, a scintillation counter will measure the radiation, a magnetometer will measure the magnetic field, and a mass spectrometer will determine the qualities of molecules.

Table 1. Science Objective Trade Study

FOM	**Weight**	**Gravity**		**Lava Tubes**		**Internal Structure**	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	3	27	9	81	3	27
Applicability to other science fields (broadness)	1	9	9	3	3	3	3
Mission Enhancement	1	3	3	9	9	9	9
Measurement Method (easy to obtain)	9	1	9	3	27	9	81
Understood by the Public	9	9	81	9	81	9	81
Creates excitement in the public ("wow factor")	3	3	9	9	27	3	9
Ramification of the answer	3	3	9	9	27	3	9
Justifiability (nice, neat package), (self-consistent)	1	9	9	3	3	9	9
Total			156		258		228

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Lava Tubes	Temperature	Exposed to area (every instrument)	Thermocouples
	Pressure	Exposed to area	Pressure Transducer
	Size of Lava Tubes	Exposed to area	IMU
	Determine characteristics of electrons in area.	Exposed to area	Langmuir probe
	Radiation	Darkness needed	Scintillation Counter
	Magnetic field	Must be isolated	Magnetometer
	Determine qualities of molecules.	Laser must point at the area.	Mass Spectrometer

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime	Frequency	Duration
IMU	0.013	0.22	0.160	2.2 x 2.4 x 0.3	30 min.	Continuous	1 min
Thermocouples	0.020/ meter	N/A	1.0 x 10-4	0.16 dia.	30 days	1 hour	3 min
Scintillation Counter	0.027	7.5	1.5	3 dia x 14.3 cm	30 days	8 hours	4 min.
Magnetometer	0.05	1.5	8.0 x 10^{-4}	2.1 x 1.9 x 0.8	18 days	3 hours	3 min
Pressure Transducer	0.131	0.04	1.0	2.2 dia. x 8.6 len.	30 days	1 hour	3 min
Langmuir probe	0.5	0.5	0.08	4 ant., each 0.05 dia x 2.5 cm	30 days	1 hours	3 min
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	30 min	Continuous	1 min

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	ISIS On Board Computer 400 Mhz, ARM9 processor
Transmitter/Receiver (Transceiver)	0.085	1.7	Up to 9600 bps down-link; up to 1200 bps uplink	ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	(see above)	Deployable Antenna System
Batteries	400 Whr/kg	N/A	N/A	Based on power requirements

3.0 Payload Design Requirements

While designing the project, the Lunartics considered and ensured compliance with the project and functional requirements defined by UAH. Additionally, *Luna*, must survive the environment at the Marius Hills Skylight.

Table 5. Payload Design Requirements

Project	Functional	Environmental
Mass: no more than 10 kg	Deploy	Endure Temperature: 123C^0 to -238C^0
	Provide Power	
Volume: 44cm x 24cm x 28cm	Take Measurements	
	Collect Data	Survive impact
Cause no harm to UAH craft	Transmit Data	
	House Instruments	

4.0 Payload Alternatives

In order to develop alternative concepts, Lunartics divided into two groups. The Design Lead led the group that developed Concept One while the Chief Engineer led the group that developed Concept Two. The Project Manager oversaw the progress of both groups. Each group independently developed a concept after considering all requirements, assumptions, and goals for the objective. The two groups then came together and explained each concept before choosing a final concept.

4.1 Concept 1

Concept 1 involves a protective aluminum alloy sphere with an aluminum cube enclosed inside. This cube would contain the instruments and provide additional support to ensure the instruments do not shake as much during deployment and impact. Once the capsule comes to a resting point, the sphere will open and the cube will fall open, allowing the instruments to be exposed to the environment and accurately collect data. The data will be transmitted to the orbiter via an antenna once the orbiter travels over the skylight.

4.2 Concept 2

Concept 2 is a Drop Pod that will absorb the majority of the force of deployment impact, while the instruments, further cushioned with aerogel, remain intact inside. The tip of the pod will pierce the ground before coming to a resting point. Once coming to a complete rest, small hatches on the side of the pod will release, opening the payload and allowing the instruments to collect data. This concept will also send data back to the orbiter via an antenna that will be placed on the top of the pod.

4.3 Concept 3

After the two groups came back together, Lunartics developed a derivative of Concept 1 that involves removing the cube in order to preserve mass and decrease overall complexity. In this derivative, only the capsule must open to allow the instruments to collect data. Because the cube is no longer absorbing the impact, it was decided to add additional layers of aerogel placed on both the inside and the outside of the spheres to absorb the force of impact.

Figure 1. Concept 1

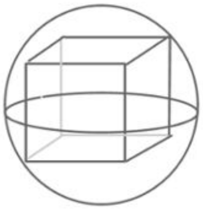
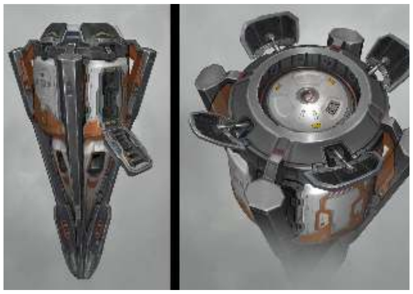


Figure 2. Concept 2

Figure 3. Concept 3



5.0 Decision Analysis

In order to determine which alternative concept for the payload would be most effective and be selected as the final concept, Lunartics developed figures of merits for a decision analysis. The first seven figures of merit were given to the team by UAH and the last three that were developed by Lunartics were (1) Instrument Damage from impact (2) Redundancy, how many payloads are able to be deployed, and (3) Predictability. The team was tasked with assigning a value of 1, 3, or 9 to each figure of merit based on importance, with 9 being the most important. It was determined that the science objective, project requirements, mission success, and instrument damage were the most vital to the mission; therefore, these figures of merit were assigned a 9.

Concept 1, the Capsule, received a 9 in science objective, project requirement, science mass ratio, ConOps complexity, and Manufacturability because the capsules are small and do not require much mass. Concept 2, the Capsule without the cube, received a 9 in all the same figures of merit and also design complexity and redundancy because this is a derivative of Concept 1 and involves decreasing both complexity and mass with the removal of the cube. Both of the capsules received a 3 for predictability and instrument damage because they could be affected by surface anomalies and because the drop pod design is focused primarily on protecting the instruments, so the capsules are less protective in comparison. The total scores for these concepts are close because one is a derivative of the other; however, Concept 2 was the overall winner.

Concept 3, the drop pod, received a 9 in science objective, ConOps complexity, instrument damage, and predictability. This concept was eventually determined to be too heavy, as it received a 3 in project requirements, science mass ratio, and mission success, and the team did not want to risk failing to comply with project requirements.

After completing the decision analysis, Lunartics selected Concept 2 as the final concept.

Table 6. Payload Decision Analysis

Figure of Merit	Weight	Capsule		Capsule, no cube		Drop Pod	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	9	81	9	81
Project Requirement	9	9	81	9	81	3	27
Science Mass Ratio	3	9	27	9	27	3	9
Design Complexity	1	3	3	9	9	1	1
ConOps Complexity	3	9	27	9	27	9	27

Mission Success	9	3	27	3	27	3	27
Manufacturability	1	9	9	9	9	3	3
Instrument Damage	9	3	27	3	27	9	81
Redundancy	3	3	9	9	27	1	3
Predictability	3	3	9	3	9	9	3
Total			300		324		286

6.0 Payload Concept of Operations

The UAH orbiter has an orbital velocity of 1633 m/s and a lifetime of two years. During month eight of the first year, the payload of four capsules will be launched from the orbiter in a backwards direction once the orbiter is around 522 km in the x direction from the Marius Hills Skylight. Once deployed, the capsules will fall 100 km before skipping across the surface of the moon. One capsule is intended to remain on the surface of the moon while the remaining three capsules will land in the lava tubes. After 30 minutes, the capsules should have reached their stopping point, and the spheres will open in order to allow the instruments to be exposed to the area and begin taking measurements and collecting data. This data will be stores on the computers and transmitted to the orbiter via antennas. The satellite period is about every 2 hours.

7.0 Engineering Analysis

The Lunartics analyzed several parameters that would affect the design of this mission and separated them into sections: initial conditions, deployment, trajectory, ending conditions, and batteries.

7.1 Initial Conditions

For the initial conditions, Lunartics was given an orbital altitude of 100 km, the moon's radius of 1738.1 km, and the moon's mass which is 7.348×10^{22} kg. In order to complete the calculations, the team assumed the satellite is in a stable, circular orbit and a constant altitude. From the given information and the assumptions, Lunartics determined the orbital velocity to be 1633 m/s.

7.2 Deployment

In order to complete the deployment calculations, Lunartics assumed the payload was a perfect fit in the launch barrel, there is constant pressure in the barrel, no friction, and neglected gravity. Because the science objective requires multiple different instruments, the team divided the instruments and placed them in two sets of two differently sized capsules. Lunartics then determined the mass and diameter of each sized capsule. The radius of the larger capsule was used to determine a cross section area of the barrel of 2.01×10^{-2} meters. The deployment length was decided to be one meter because this length would increase the deployment velocity of the capsules. In order to determine an acceptable g-load and flight distance, the Design Lead and Chief Engineer completed multiple g-load calculations with varying psi. After these calculations, Lunartics decided to use a helium pressure of 70 psi to launch the payload. The final solutions were determined to be a deployment velocity of 136.8 m/s, horizontal velocity after deployment of 1496.1 m/s, and deployment g-load of 977.4

7.3 Trajectory

When calculating the trajectory, our assumptions were that there will be constant gravity at 1.62 m/s^2 with minimal drag. With the gravity of 1.62 m/s^2 at an altitude of 100 km, the velocity in the y was calculated to be 569.2 m/s. Since we found the velocity in the y, we determined the resultant velocities

(Avg. 1600.7 m/s at 20.8 degrees), the time of flight (5 minutes and 51 sec), and the average distance the capsules traveled in flight (526 km).

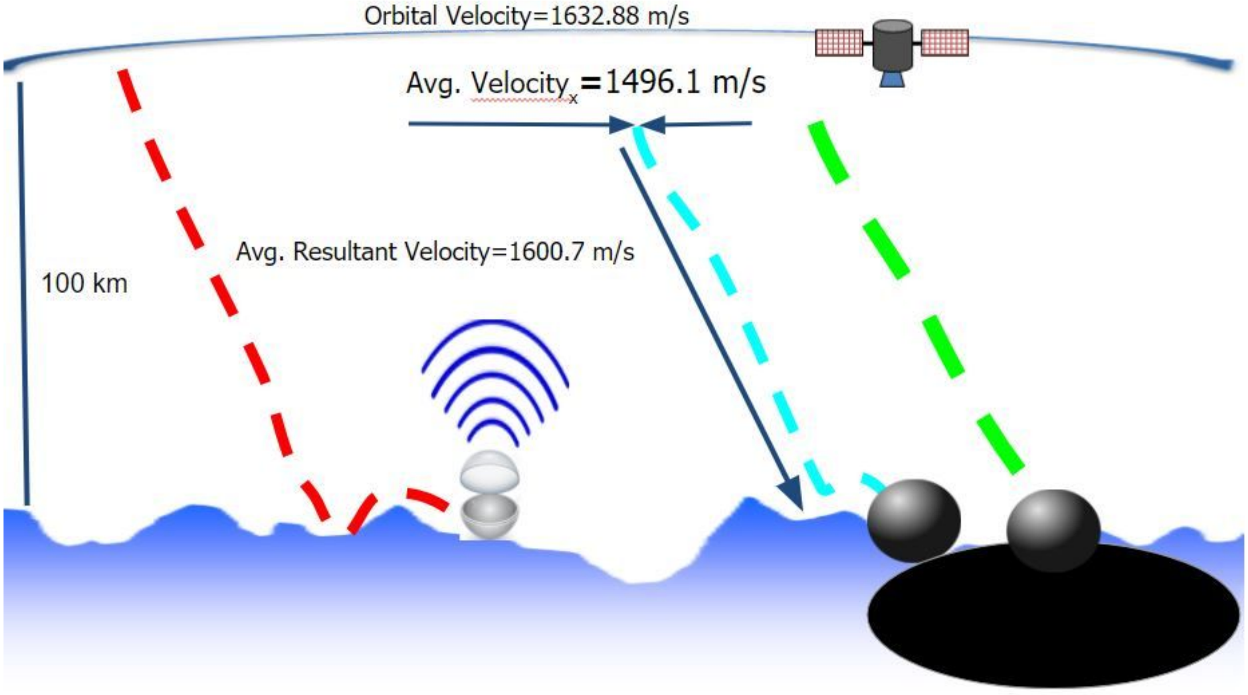
7.4 Ending Conditions

For the ending conditions, the team was given that the surface area is 8.04 x 10^{-2} and the average mass is 1.11 kg. In order to complete the calculations, it was assumed that gravity is 1.62 m/s^2, deceleration distance is 150 m, the surface is flat, and the spheres will skip in a straight line. The distance of 150 meters was chosen because it would decrease the g-load that the payload experiences. Using the final velocity^2=initial velocity^2 + 2ad formula, the team calculated that the average deceleration the capsules will experience to be -8542.3 m/s^2 ad tge average g-load to be 871.7.

7.5 Battery Analysis

In order to calculate the amount of batters that would be required for this mission, the team used UAH's battery template and the numbers we determined for the lifetime, frequency and duration. This template allowed the Lunartics to determine how much power would be used. After determining that 187.6 Whr of power would be consumed, the team assumed that the specific mass of each battery to be 400 Whr/kg and used that specific mass to find the total mass required for batteries which was found to be 0.469 kg. Additionally, Lunartics calculated the mass of batteries that would go with each capsule, considering which instruments that capsule would enclose. The masses of the batteries were taken into account when calculating the deployment, trajectory, and ending conditions.

Figure 4. Payload Concept of Operations



8.0 Final Design

The final design of the mission consists of 4 capsules that serve as the housing the payload. While being protected by the capsules, they will be shot out of the orbiter in the backwards direction, allowing the capsules to skip across the surface of the moon. When they come to a resting point, they will open via the electric lock, allowing the instruments to start gathering data. This data will then be transmitted to the passing orbiter through the antennas.

Figure 3. Lunartic's Mission

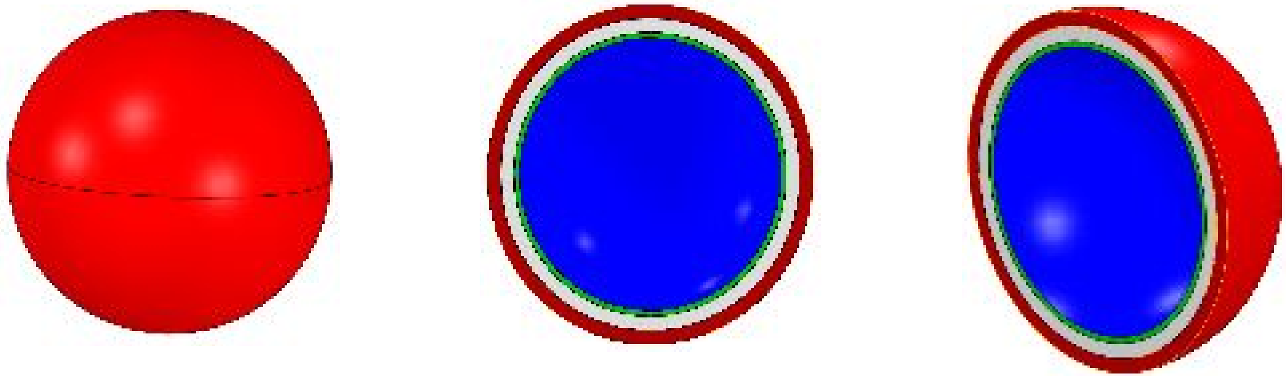


Table 7. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Barrel	N/A
Measure	IMU, thermocouples, scintillation counter, 2 magnetometers, pressure transducer, langmuir probe, mass spectrometer	1.02 kg
Collect Data	4 On-board computers	0.376 kg
Provide Power	Batteries	0.469 kg
Send Data	2 Antennas and 2 transceivers	0.37 kg
House/Contain Payload	2 Capsules (0.39 kg) and 2 capsules (0.72 kg)	2.22 kg
Total		4.455 kg

Table 8. Payload Design Compliance

Requirement	**Verification**
Mass: No more than 10kg	4.445kg
Volume: 44cm x 24cm x 28cm	32cm x 16cm x 28cm
No harm to spacecraft	No incendiary process
Deploy	Deploy from aluminum launcher using pressurized helium
Take Measurements	IMU, Thermocouples, Scintillation Counter, Magnetometer, Pressure Transducer, Langmuir Probe, Mass Spectrometer
Collect Data	On Board Computer
Send Data	Antennas
Provide its Own Power	Assuming Specific Mass = 400 Whr/kg
House Payload	Protective Capsule
Endure Temperature: $123C^0$ to $-238C^0$	Insulated with aerogel
Survive Impact	Protected by aerogel and aluminum alloy