“Lighting Our Way Through the Depths of The Moon”

Payload Concept Proposal

Lunaris Enkata

Da Vinci Team 2

1.0 Introduction

Earth's Moon, is the fifth largest satellite in our Solar System and is a widely beautiful and spectacular part that makes Earth continually unique. While man was able to touch the surface of the moon, the internal structure of the moon is still extensively unexplored and complex. Team Lunaris Enkata, in partnership with UAH, has made it our goal to discover more about the internal structure of the moon. Our payload concept, the **Endurance**, will be launched alongside 28 of its counterparts to land on the surface of the moon scanning with IMUs and other instruments to map out the inner framework and shed light on the internal structure of the Moon.

- Our team name, Lunaris Enkata, is a Greek translation of "Lunar Depths," which relates back to our science objective being the exploration of the Internal Structure of the moon. The Greek is a representation of our relation to the Moon Goddess of Greek mythology, **Selene** who lights her way through the depths of the moon just as Lunaris Enkata will.
- Our slogan, "Lighting our Way through the Depths of the Moon," relates to our team shedding light on the internal structure of the moon and to our Greek Goddess, **Selene's** motive of keeping the moon under her protection and light.

2.0 Science Objective and Instrumentation

Our team, Lunaris Enkata, has chosen Internal Structure as our final science objective; this will enable us to further discover the inner framework of the Moon. We specifically chose this science objective to assist scientists and the UAH in capturing a "mapped" image of the moon and its inner features, due to the fact that a large portion of the Moons inner structure is unknown. Our payload concept, **Endurance**, will have a set of probes that will be deployed from the Orbiter to form a triangular shaped network. We will do this by landing our Inertial Measurement Units (IMU) probes on the lunar surface near the Lander in the southern polar region. Each probe will sense seismic activity gather data then that data will be transmitted to the Lander. We plan to use the Lander as our gateway communication to the Orbiter, which will then be transmitted back to Earth. The data will be monitored and studied by scientists on Earth.

Whenever seismic activity occurs each probe will store and transmit the data locally on the probe and then transmit the data at a regularly scheduled time. We will use a fleet of 28 probes to establish a Low Power Wide Area Network (LPWAN). The probes use a LoRa protocol (high frequency transmission combined with small data packet size) to allow communication ranges up to 22km if the sender and receiver nodes have Line of Sight (LOS) between them. It will be important to maximize the distance between probes because the triangulation distance directly corresponds to the depth we can sense into the lunar surface. Maximizing the triangular distance between probes on the surface will in turn maximize the depth of sensing.

Figure 1. Internal Structure

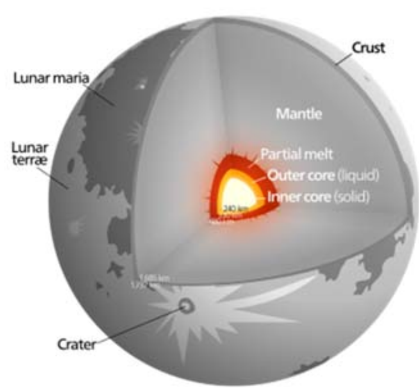


Table 1. Science Objective Trade Study

Figure of Merit	Weight	Surface Composition		Internal Structure		Volatile & Organic Elements	
		Raw Score	Weight	Raw Score	Weight	Raw Score	Weighted
Interest of Team	9	3	27	9	81	9	81
Applicability to other science fields (broadness)	1	3	3	9	9	3	3
Mission Enhancement	1	1	1	3	9	9	9
Measurement Method (easy to obtain)	9	3	27	3	27	3	27
Understood by the Public	9	9	81	9	81	9	81
Creates excitement in the public ("wow factor")	3	9	27	3	9	3	9
Ramification of the answer	3	3	9	3	9	3	9
Justifiability (nice, neat package), (self-consistent)	1	3	3	3	9	1	1
TOTAL			178		234		220

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Internal Structure	Seismic Activity	Probes dropped from orbiter within communication distance of the Lander (approx. 20km) to listen to all seismic activity.	Inertial Measurement Unit (IMU)
Internal Structure	Locate lunar quake epicenters	Establish series of probe deployments a maximum of 20km apart. Use probes as both sensors and relays.	Inertial Measurement Unit (IMU)

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (Hours)	Frequency	Duration (mins)
IMU	0.0010	0.0036	TBD	0.2500 x 0.3000 x 0.0900	8760	During Seismic Activity	10

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate (mbps)	Other Technical Specifications (cm)
Processor	0.0100	0.0005	N/A	1.2000 x 1.2000 x 0.1300
Transmitter/ Receiver Transceiver	0.0200	0.0720	0.0005	0.4 x 0.4 x 0.05
Antenna	0.0005	0.0150	N/A	0.05 x 0.02 x 0.015
Batteries	0.1930	N/A	N/A	2 (r) x 0.4 (h)
SRAM	0.0003	0.0360	17.6	1.2000 x 2.0000 x 0.1000

3.0 Payload Design Requirements

There are many requirements that our payload must perform to conduct a successful mission. These requirements consist of deploying from the UAH spacecraft of our choice, autonomously collect and transmit data, while at the same time powering itself, and surviving the environment at which, it will be exposed to on the Moon. All of these were provided UAH functional requirements

To accomplish the latter, we must analyze the surface and composition and environment of the Moon. The Moon has a thin atmosphere, which we must assume to be non-existent. The Moon's surface density is said to vary due to the different composition of the surface on the diverse regions of the Moon. The temperature of the Moon Is 220 K (-53.15°C).

The requirements given by the InSPIRESS are also vital to being able to properly generate a functional payload design. These requirements are, that the payload must be able to be contained within a space of 44cm x 24cm x 28 cm and must not exceed a total mass of 10 kg. Finally, most of the mission must be performed while detached from the UAH vehicle and the payload may not harm said UAH vehicle.

4.0 Payload Alternatives

Lunaris Enkata has a total of three payload concept designs, each varying in instruments and in collection of data. Each of these was created to accomplish the team's science objective, Internal Structure. When coming up with ideas for the different payload the team split up in two groups and came up with the two initial ideas, **Selene** and **Ignis Saxum**. After debating and analyzing what must be done to accomplish the mission, the teams rejoined and combined both **Selene's** and **Ignis Saxum's** main aspects to make sleeker more efficient final design. Once all ideas were implemented, we decided to name this new payload the **Endurance**. This payload both conducted the research directly, while maximizing the range of the probes. All the concepts where designed to deploy form the UAH orbiter and carry out our science objective, all probes, with the exception of **Selene**, would be deployed in the South pole of the moon.

Figure 2. Selene

The first concept, **Selene,** was one of the team's original concepts. **Selene** was designed to deploy from the UAH orbiter, and become an orbiter itself, while releasing Langmuir probes to conduct research on the Internal Structure of the Moon. This payload integrated a mesh relay of data, widening our range between the probes launched by the orbiter after the release of the main payload. The design would be dormant, while the orbiter spread the probes around the desired area allowing for a longer life-span. After a certain amount of time, the device would be deployed and start orbiting around the Moon while relaying the data collected by the probes to the UAH vehicle.

Figure 3. Ignis Saxum

The second concept, **Ignis Saxum,** was the second of the original concepts. **Ignis Saxum** consisted of three payloads designed to deploy from the orbiter and plummet towards the moon. Eventually these three payloads would arrive at the surface of the Moon and bury beneath the surface. Each payload contained IMUs and Heat Probes. The IMUs would allow us to map the Internal Structure, while the Heat Probes would provide data on the size of the Moon's core. There are three payloads due to the size of the heat probes which limited us to this small amount. After conducting the research on battery usage, the payload would eventually deplete its battery supply becoming inoperable.

Ignis Saxum translated directly from Greek, means fire and stone, which follows directly under the lines of what this payload can accomplish. Ignis, fire, resembles the Moon's molten core, while Saxum, rock, resembles the Moon's Composition.

Figure 4. Endurance

Lunaris Enkata's third and final concept **Endurance** is essentially a mixture of the main aspects of both of the first concepts. This concept consists of 28 probes designed to deploy from the UAH orbiter and begin decent toward the surface of the earth where they will begin collecting data. The 28 probes will communicate with one another via the same mesh relay system proposed in **Selene**, while conducting research on the surface following the same concept of operations as **Ignis Saxum**. These probes although not required to bury, do retain the conical shape at the tip, to maintain the opportunity of this happening.

Endurance was named after the team delved deeper into the background behind the destination of the 28 probes, which would be near the Shackleton crater. When researching the Shackleton crater located on the South Pole, we discovered it was named after Ernest Shacklelton. an Antarctic explorer who was famous for his journeys to the poles. One of the facts that stood out is his voyage to the Arctic, which was conducted with the original **Endurance**. Although we found out that the ship eventually sunk rendering this expedition a failure, we decided to continue using the name because of the positive connotation the word itself contains.

5.0 Decision Analysis

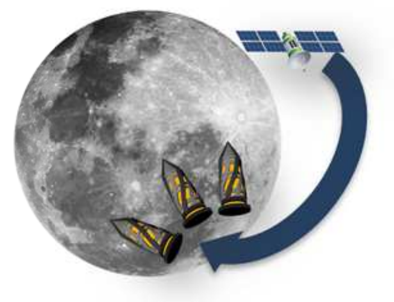
In order to choose the ideal payload to successfully accomplish our chosen science objective, we have created a decision matrix to help determine the best possible payload concept for our mission. The figures of merit (FOMs) provide a model for the key aspects of our desired final payload. We employed these FOMs to rate each of our concepts. Based on our results we chose the **Endurance** as our final payload concept, as it ranked the highest on the matrix, and met our seven given FOMs as well as our three personalized FOMs. The vast majority of the FOMs were provided by InSPIRESS, but we decided that survivability, triangulation size, and data integrity were the essential FOMs which we could weight to come up with the best results.

Table 5. Payload Decision Analysis

Figure of Merit	Weight	Selene		Ignis Saxum		Endurance	
Science Objective	9	3	27	9	81	9	81
Likelihood Project Requirement	9	9	81	3	27	9	81
Science Mass Ratio	1	9	9	3	3	9	9
Design Complexity	3	1	3	9	27	3	9
Con-Ops Complexity	3	3	9	3	9	3	9
Likelihood Mission Success	9	3	27	3	27	9	81
Manufacturability	1	9	9	9	9	3	~~3~~
Survivability	9	3	27	9	81	9	81
Triangulation size	3	1	3	3	3	9	27
Data Integrity	9	1	9	3	27	9	81
TOTAL			**258**		**294**		**462**

6.0 Payload Concept of Operations

To begin our mission, the **Endurance** will be deployed from the UAH Orbiter using pressurized helium to eject it from the spacecraft at a downward angle. Our angle of 19.24 degrees will ensure that our payload will land on the surface in proper condition. Once deployed, the **Endurance** will enter the atmosphere and continue a downward motion with the assumption of **no drag**.



Upon landing and skipping on the surface of the Moon, the **Endurance** payloads will come to a stop and begin to transmit and collect data on the internal structure of the Moon using IMUs. Our team assumes that our payloads will travel no less than 100 m and no farther than 500 m. Our mesh relay enables our payloads to transmit data up to 22 km but we are providing a safe cushion of 10 km to ensure the best and safest results. This data collected by all 28 probes will be transmitted back to the lander, which will send data up to the orbiter and back to Earth for us to analyze.

7.0 Engineering Analysis

7.1 Design Analysis

In order to further find out the specifics of our mission, we must calculate and determine the conditions our payloads will be experiencing. This includes using our mass, size and other aspects that will allow us to determine specifics. The Engineering Analysis, while always intriguing, challenged us to use all of our knowledge from previous years of physics, calculus and other subjects to solve for such conditions.

Endurance consists of 28 identical payloads that will be deployed from the orbiter on a singular basis. These payloads weigh in at .35 kilograms, with the dimensions of .15 meters (m) in height and .5 meters (m) in diameter. Each payload has a conical shape for the tip, and a cylindrical body, ending with a stopper to complete it. This shape contains groves within its entirety, allowing the probes to maintain an optimal trajectory. Our instruments minimal mass allows our payload to be lightweight and enable our team to deploy several payloads for maximum coverage and confirmation of multiple payloads landing successfully to obtain data.

When finding velocity and other conditions of deployment, our team had to focus on finding the orbital velocity, the acceleration from orbit towards the surface of the Moon, and finally calculating the deceleration due to the impact on the surface of the Moon.

7.2 Deployment

After finding orbital velocity our mission required us to de-orbit and land on the surface below. In order to exit out of orbit and decent downward toward the Moon, UAH required us to use a velocity of at least 1% of the orbital velocity. The orbital velocity of the UAH orbiter is approximately **1633.37 m/s**, allowing us to have a minimum velocity of approximately 17 m/s to use for deployment. We decided to aim for a higher final deployment velocity, assuming our deployment out of the orbiter to be **30 m/s.** With formulas provided by UAH, we were able to find our pressure to achieve this velocity resulting in **126.04 PSI** (868963.2 Pascals). With this we attained an acceleration of **1551.72 m/s^2** which gave us a total of **158.18 G's.** Successfully surviving this specific stage of our mission.

7.3 Trajectory

Next, we went on the second stage of this process. This consisted of finding final velocity by taking into account acceleration due to gravity, which gravity being **1.62 m/s^2** on the moon. By taking the **30 m/s** from the past stage, and using it as our initial velocity (V_i) for our fall sequence, we found that we were attaining a final velocity of **570 m/s.** We found this by following the formula $\boldsymbol{v_f^2 = v_i^2 + 2ad}$**.** In order to find our final velocity, we were required to make use of vectors, the y-vector being the **570 m/s** stated before, and our x-vector being our orbital velocity of **1633.37 m/s**. To apply these vectors, we used the Pythagorean Theorem, which produced a final velocity of **1729.97 m/s.**

7.4 Ending Conditions

Lastly, since our mission does not require us to bury underground, we decided to land and skip on the surface of the Moon. While our payload concepts and their helpful IMU instruments can send data up to 10 kilometers, we assumed that our payloads would not travel on the surface less than **100 meters** and no more than **500 meters**. From this we calculated deceleration and G-impact at each distance for each scenario at intervals of 100 m. By doing this we were able to determine exact conditions our payload would be facing when landing on the surface of the vast Moon. We calculated our deceleration, which ranged from **-14963.98 m/s^2,** to **-2992.79 m/s^2,** and our G-Load, which ranged from **1525.38 G's** to **305.07 G's.** Proving that our payloads are capable of successfully landing on the surface of the Moon to collect data.

Table 6. Acceleration and G-load Range

Distance	Acceleration	G-Load
100 m	-14963.988 m/s^(2)	1525.381 G's
200 m	-7481.994 m/s^(2)	762.690 G's
300 m	-4987.996 m/s^(2)	508.460 G's
400 m	-3740.997 m/s^(2)	381.345 G's
500 m	-2992.798 m/s^(2)	305.076 G's

7.5 Time

Once ending conditions were determined, we moved on to finding the amount of time that our payload would take from deployment to arriving on the surface. Utilizing yet another formula provided by the UAH, we determined that our time would be approximately **333.33 seconds** (s), or **5.55 minutes** in total assuming **no drag**, as stated before.

7.6 Battery Mass

To determine battery mass, we analyzed the amount of power usage for each instrument. We then added up the power needed for each instrument and found that out total power was **77.21Watt-Hrs.** Now that we have established the needs of our equipment we are now able to determine the size and mass of our battery. Thanks to advancements in computer hardware technology many of the instruments on board each probe requires a minimal amount of power in order to operate. In addition, several of the instruments onboard each probe also come equipped with sleep mode functionality, as a result our payloads battery size has also decreased significantly.

Table 7. Battery Analysis

Device	Mode	Watts	Amps	Volts	Duration (Hrs)	Watt-Hrs	Assumptions
SRAM	Operating	0.03600000	0.012000000	3	9.0000	0.3240000	1) COM: 0.59 Hrs/mon 2) IMU Processing: 10 min/mon or 0.16 Hrs
	Idle	0.00003600	0.000012000	3	8751.0000	0.3150360	Idle
Micro Control Unit	Watch Dog Timer	0.00000081	0.000000270	3	8751.0000	0.0070883	Watch Dog Timer Mode
	Run	0.00053400	0.000178000	3	9.0000	0.0048060	1) COM: 0.059 Hrs/mon 2) IMU Processing: 10 min/mon or 0.16 Hrs
LoRa Transceiver	Receive	0.01650000	0.005500000	3	0.8520	0.014080	1 Event is 6000 IMU measurements Transmitted, each will receive 2Byte ACK, Multiply Rx by 8 b/c Acting as a relay
	Transmit	0.07200000	0.024000000	3	862.8000	62.1216000	1 event per month `(2142.86 sec tx time), plus 0.5 sec/day Daily report (15 sec tx time) Multiply Tx time by 8 b/c Acting as a relay
	Sleep	0.00005400	0.000018000	3	7896.3480	0.4264028	Sleep mode
Antenna	Operating	0.01500000	0.005000000	3	863.6520	12.9547800	
IMU Invensense MEMs Low Power INV- 20600	Run	0.00012000	0.000040000	3	8760.0000	1.0512000	Gyro Disabled, Low Power Mode running continuously
			Total Operation Watt-Hrs			**77.21897**	
			Battery Size (kg)			**0.1305**	

8.0 Final Design

Endurance will be deployed from the UAH orbiter with helium, the orbiter being at an altitude of 100 km. Once **Endurance** deploys, it will begin its descent toward the surface of the moon, with an initial velocity of **30 m/s** in order to arrive to the south pole's surface with an angle which will allow us to skip the surface, eventually seizing to move. Once it reaches this stage, it will collect data when seismic activity is present, when there is no seismic activity the probes will go into an idle mode to conserve battery. As stated previously, we decide to follow this concept to maximize our coverage. Our shape allows us to skip the ground, but in the case of penetration, the stopper at the end would prevent us from penetrating deep enough to lose communication. This design's IMU has a data ready capability allowing us to gather the data immediately. It also contains Watch Dog times which allow us to set up communications in a scheduled fashion.

Figure 5. Endurance

Figure 6. Lunaris Enkata's Mission

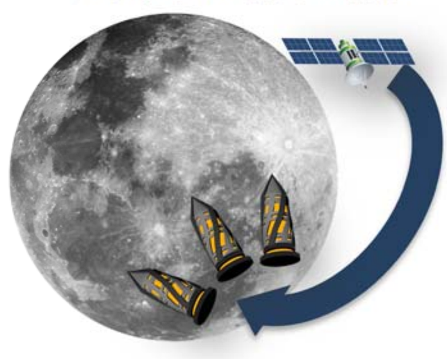


Table 8. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	IMU	0.0010
Measure	SRAM, Circuit Board for Mounting	0.0013
Collect Data	Microcontroller	0.0100
Provide Power	Space Batteries	0.0700
Send Data	Transceiver, Antenna	0.0700
House/Contain Payload	Aluminum Lithium Alloy	0.2000
Total	X28	9.8644

The total mass per payload is .35 kg which when multiplied by the 28 payloads gives the total mass of 9.8644 kg.