Payload Concept Proposal

Artemis Quintus

Da Vinci School for Science and the Arts

Team 1

"Hunting for the Moons core."

1.0 Introduction

The Moon is the 5th largest natural satellite in our solar system. For millennia, this satellite has captured the interest of humanity. Our team's namesake, Artemis, was the Greek goddess of hunting and of the Moon itself. In the past 50 years, it has become possible to go to the Moon with the manned Apollo missions, and numerous unmanned probes. A new unmanned probe, produced in cooperation between NASA and UAH the LASER mission, will explore the Moon. Team *Artemis Quintus* will design a payload for this mission which will complete the scientific objective to discover the nature of the Moon's internal structure and core. To do this, the payload will analyze the Moonquakes and the weak magnetic fields produced by the Moon. Like Artemis, our team is also hunting, but we are hunting for knowledge about the Moon's core; inspiring our slogan "Hunting for the Moon's core". The payloads will "hunt" for the core by traveling with the UAH orbiter and will be deployed to collect data on different parts of the Moon rather than a single location in order to ensure data reliability. The payloads, known as "Crescent", will be gathering data based on the Moon's Moon quakes as well as the Moon's weak magnetosphere to determine the movement of the Moon's core.

2.0 Science Objective and Instrumentation

Artemis Quintus science objective is to research the internal structure of the Moon. While there is no direct mean to measure the internal structure, we plan to measure it by collecting data on seismic activity and magnetic fields. We chose this science objective because not much is known about the internal structure of the Moon, and in order to understand certain things about the Moon we must first understand what is going on below the surface. Conducting research on the internal structure would give us an insight on the Moon's behavior and structure as well as provide us with a solid understanding of the Moon's geologic activity and magnetic fields.

The primary instruments used to determine the internal structure are an Inertial Measurement Unit (IMU), and a magnetometer. To determine internal structure, scientist use seismic wave vibrations to "see" inside a planet. In our payload, the IMU's will measure geologic activity, and the magnetic field will be measured using a magnetometer.

Table 1. Science Objective Trade Study

FOM	Weight	Water-Ice		Internal Structure		Surface Composition		Volatile & Organic Elements	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	1	9	9	81	3	27	3	27
Applicability to other science fields	1	3	3	9	9	1	1	3	3
Mission Enhancement	1	1	1	9	9	3	3	9	9
Measurement Method (easy to obtain)	9	3	27	1	9	9	81	3	27
Understood by the Public	9	9	81	3	27	3	27	3	27
Creates excitement in the public	3	3	9	3	9	1	3	9	27
Ramification of the answer	3	9	27	9	27	3	9	1	3
Justifiability	1	3	3	1	1	9	9	3	3
TOTAL			160		172		160		126

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instruments Selected
Internal Structure	• Magnetic field strength • Seismic Activity	Min 3 Probes dropped from orbiter, spread evenly over Moon's surface	Inertial Measurement Unit (IMU) & Magnetometer

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (days)	Frequency (hour)	Duration (seconds)
Inertial Measurement Unit (IMU)	0.013	0.22	0.160	2.2 x 2.4 x 0.3	30	1	30
Magnetometer	0.05	1.5	0.0008	2.1 x 1.9 x 0.8	30	1	30

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Dimensions (mm)
On-Board Computer	0.094	0.4	2 x 2 GB Onboard Storage	90 x 90 x 12.4
Transceiver	0.085	1.7	9.6 to down-link 1.2 to uplink	90 x 90 x 15
Antenna	0.100	0.02	Same as Transceiver	98
Space Batteries	400 Whr/kg	N/A	N/A	Based on power requirements

3.0 Payload Design Requirements

In order for *Artemis Quintus* to successfully complete the LASER mission, our payload must meet functional, project, and environmental requirements. For functional requirements, our payload must deploy properly from the UAH orbiter, record data autonomously, transmit data, provide its own power, and protect itself from environmental damage.

Project requirements place constraints on size and construction but also provide necessary resources to conduct research. These requirements include a volume limit of 44 x 24 x 28 centimeters, a mass limit of 10 kilograms, an internal temperature of 294 K (70°C) and prevention of damage to the main spacecraft is also necessary.

The last requirement is to survive the environment of the Moon. The temperature varies greatly from light to shadow, being both extremely cold and extremely hot. The Moon's atmosphere is extremely thin. When creating the payload, the team must make sure it can withstand the environment, in order to be able to retrieve information for a prolonged period of time. Although these restrictions placed by UAH proved to make designing a payload capable of successfully conducting research a difficult task, it allowed the team of *Artemis Quintus* to expand its creativity and strive to create a proper payload.
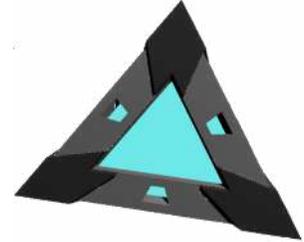
4.0 Payload Alternatives

In order to best plan for mission success, multiple designs had to be created. To create these designs, the design team was divided into two different groups with one headed by the Chief Engineer, and the other by the Design Leader. Each of these two groups created preliminary designs for the payload and were then compared to each other. The following payload designs are similar in many ways, but they do differ in minute differences which could affect mission success.
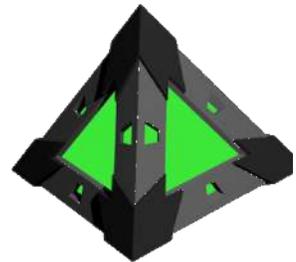
Our first concept, **Eclipse**, deploys from the orbiter backwards and lands on the lunar surface. The design called for the release of multiple payloads which would each measure moonquakes using an IMU as the sole measurement instrument. Each payload would have an IMU and the necessary support equipment to allow it to send data over a month. The main advantage of this payload is that it measures the internal structure in the most direct way on the lunar surface.

Figure 1. Concept 1: Eclipse

The second concept, **Gibbous**, is a design which deploys backward from the orbiter and lands on the lunar surface. This design called for the release of multiple payloads, each measuring moonquakes and including magnetic fields. This will allow for the internal structure to be measured by both seismic activity and how molten iron in the Moon's core flows to create a magnetism effect. Gibbous is similar to Concept 1 but in addition to an IMU it has a magnetometer, this instrument adds an additional measurement objective, magnetic fields.

Figure 2. Concept 2: Gibbous

Our final concept, **Crescent**, is a combination of Concept 2 and Concept 1. Though this revision of the concept employs no alterations to either concept, it does alter the number of payloads. Specifically, this design uses an equal number of payloads made to the specifications of both Concept 1 and Concept 2. This allows there to be a number of payloads, which can measure both Moonquakes and magnetic fields. And it includes a number of payloads which only measure moonquakes but do so for a greater length of time as they do not have a magnetometer as a power load and can have the spared mass designated to additional battery mass.

Figure 3. Concept 3: Crescent

4.1 Shape of an Impacting Payload

These designs require a payload that impacts the lunar surface and must survive for an extended period of time to complete its mission. For this, a shape of the payload had to be chosen to best survive the forces of impact. For this reason, a square pyramid was chosen as it allows pressure to disperse across all sides of the payload if it lands on a corner. A square pyramid was chosen as opposed to a triangular pyramid because it allows for greater utilization of the payload volume as all instruments and support equipment are given dimensions which are rectangular prisms.

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5.0 Decision Analysis

In order to choose the ideal payload and payload shape to accomplish our science objective, we created a decision matrix. The figures of merit (FOM) or criteria provided a model for what was most important in our desired payload. We used this criterion to rate each of our designs. Taking into consideration the various functions each design was expected to complete, we ranked them based on how well they perform said function. The designs were carefully analyzed and considered based on possible scenarios as well as in worse case scenarios. Based on the results from the decision matrix, the concept we chose is "Crescent." It ranked the highest on the matrix, as it met the criteria better than all of the other design choices and met the six functional requirements the best. The shape that was chosen for our payload, a rectangular pyramid, is most likely to survive impact and the instruments are better accommodated within the payload.

Table 5. Payload Shape Analysis

FOMs	Weight	Triangular Pyramid		Sphere		Cube/Box		Rectangular Pyramid	
	1, 3, or 9	Raw Score	Weighed Score	Raw Score	Weighed Score	Raw Score	Weighed Score	Raw Score	Weighted Score
Survival of impact	9	9	81	3	27	1	9	9	81
Complexity of design	1	3	3	1	1	9	9	9	9
Landing sides	3	1	3	3	9	1	3	3	9
Instrument location	9	3	27	1	9	9	81	9	81
Mass of structure	9	3	27	3	27	1	9	9	81
Deformation of structure	3	9	27	3	9	1	3	9	27
Manufacturability	1	3	3	1	1	9	9	3	3
Internal supports	3	9	27	3	9	1	3	9	27
Volume	9	1	9	9	81	3	27	3	27
Instrument placement	1	3	3	1	1	9	9	9	9
TOTAL			**264**		**174**		**162**		**354**

Table 6. Payload Analysis

FOMs	Weight	Eclipse		Gibbous		Crescent	
	1, 3, or 9	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Science Objective	9	3	27	3	27	9	81
Likelihood Project Requirement	9	9	81	9	81	9	81
Science Mass Ratio	3	1	3	9	27	3	9
Design Complexity	1	9	9	3	3	1	1
ConOps Complexity	3	9	27	9	27	9	27
Likelihood Mission Success	9	3	27	3	27	9	81
Manufacturability	1	9	9	9	9	3	3
Data Collected	9	1	9	9	81	3	27
Longevity	3	9	27	1	3	9	27
Payload Consistency	3	9	27	9	27	3	9
TOTAL			**246**		**312**		**346**

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6.0 Payload Concept of Operations

Crescent operates in several different stages. The payload itself operates very simply in that it deploys, collects data on the surface and transmits it back for observation. However, our mission includes 8 different payloads which disperse across the entire Moon from the orbiter. In addition, four of the payloads have a magnetometer and four of them do not. Although it might seem insignificant, this difference in effect will cause the four payloads without the magnetometer to last much longer than the others with the instrument, because of the saved mass and power contributing to additional battery life for the same mass.

Phase 1 Deployment
Crescent will contain 8 payloads which will all disperse backward with pressurized helium from the orbiter. The 8 probes deploy from the orbiter equally apart from each other throughout the orbit of the UAH vehicle. The probes with a magnetometer will disperse at the north pole, the south pole and the equator. The probes without a magnetometer will disperse into regions roughly equally between these locations.

Phase 2 Combined data collection
Once all the payloads have reached the surface, meaningful data collection may begin. All of these probes will measure for moonquakes consequently. All of the payloads should be able to measure at least a single moonquake using their IMUs during this phase of the mission. Also during this time, the four payloads will measure the Moon's magnetic field.

Phase 3 Extended mission duration
After about a month of operation, the payloads with a magnetometer will experience power failure. During this period, the probes which do not have a magnetometer will continue to operate using their extra battery mass until these payloads also experience power failure. This phase should take roughly another month.

7.0 Engineering Analysis

In order to better understand the performance of the payload while in operation, *Artemis Quintus* found it crucial to analyze the payload. Areas of interest included: the orbital velocity, deployment, trajectory, ending conditions, and battery mass. Because the team's objective is to measure internal structure or the indicators thereof, the team has chosen it best to use **8 payloads**, each of which will disperse across the lunar surface. This gives the team a mass limit of **1.25 kilograms (kg) per payload** with a volume of **2,400 cm^3**, which is a total mass of 10kg and 19,200 cm^3. The dimensions of our payloads are 20cm by 20cm by 18cm.

7.1 Orbital Velocity

In order to understand the initial conditions of the payload, orbital velocity was calculated as it is a necessary figure to calculate the deployment of the payload, and the pressure which will be needed to do so. To calculate our orbital velocity, we used the following: Universal Gravitational Constant, mass of the Moon, and the radius of the Moon. The orbital velocity of the UAH orbiter and our payload was calculated at **Vi=1,633.66m/s**
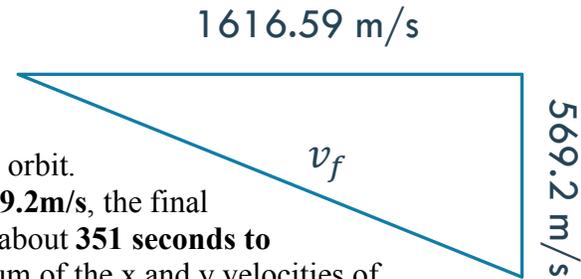
7.2 Deployment

In order to reduce the acceleration that is placed upon the payload as much as possible, *Artemis Quintus* has chosen to deploy backwards. This will reduce the angle at which the payload hits the Moon and will bounce across the surface of the Moon before coming to a rest. The minimum velocity needed to deploy is about 1% of the orbital velocity, or **16.33 m/s.** To solve for the required deployment pressure, the equations $v_f{}^2 = v_i{}^2 + 2ad$ and $a = \sqrt{\frac{PA}{m}}$ were combined to make the equation $v_f{}^2 = v_i{}^2 + 2(\frac{PA}{m})\, d$, which can solve for pressure. The pressure required to be provided by the UAH vehicle for our payload to deploy is **23,293.2 Pa**, which is a low pressure, at about 3 psi. The reason the payload is able to deploy with such a low pressure is partially related to the shape of the payload. The square base of the payload allows it to be pushed out with a low pressure over a wide area.

7.3 Trajectory

After the payload has deployed, it will begin to approach the lunar surface. The horizontal velocity will be 99% of the orbital velocity at **1,617.32m/s** due to the payload deploying against the orbit. During the descent of the payload, it will accelerate from 0 to **569.2m/s**, the final velocity of the payload in the y-direction. The payload will take about **351 seconds to reach the surface.** Using the Pythagorean theorem, the vector sum of the x and y velocities of the payload can be calculated to be **1,714.5m/s.** This is the velocity which the payload will impact the lunar surface. Using the trigonometric Law of Sines, the angle to which the payload will approach the Moon can be calculated. The payload will intersect the Moon at a **20° angle relative to the lunar surface.**

1616.59 m/s

v_f

569.2 m/s

7.4 Landing

After the payload has deployed, it will land upon the surface of the Moon at a shallow angle and it will bounce across the surface until it can come to rest on the surface. By landing this way, the payload will experience the lowest acceleration that is possible from falling from the orbiter. In order to find the deceleration and G-load that our payload would experience, the team needed to assume the distance the payload will skip the surface of the Moon. *Artemis Quintus* decided to conduct a trade study analyzing the different deceleration and G-load's the payload would experience based on different distances. However, *Artemis Quintus*, assumed a **distance of 200m**.This means that the payload will not experience very high acceleration, or a high G-load.

Distance (m)	Deacceleration (m/s^2)	G-load
50	29,377.96	2,994.70
100	14,688.98	1,497.35
150	9,792.65	998.23
200	7,344.49	748.67
250	5,875.59	598.94
300	4,896.33	499.12
350	4,196.85	427.81
400	3,672.25	374.34
450	3,264.22	332.74
500	2,937.80	299.47

7.5 Battery Mass

In order to satisfy the science objective, the mass of the battery must be found. Because Moonquakes last much longer than earthquakes, several hours to be exact, and occur once a month, our payload will need to last for an extended period of time. However, it must be inactive for a large portion of that time. The battery mass was calculated to be **0.116kg**, enough power to operate the payload for a month. Specifically, the instruments will operate 60s/hr for 30 days. This proves to be effective because Moonquakes are often detectable for several hours after they happen.

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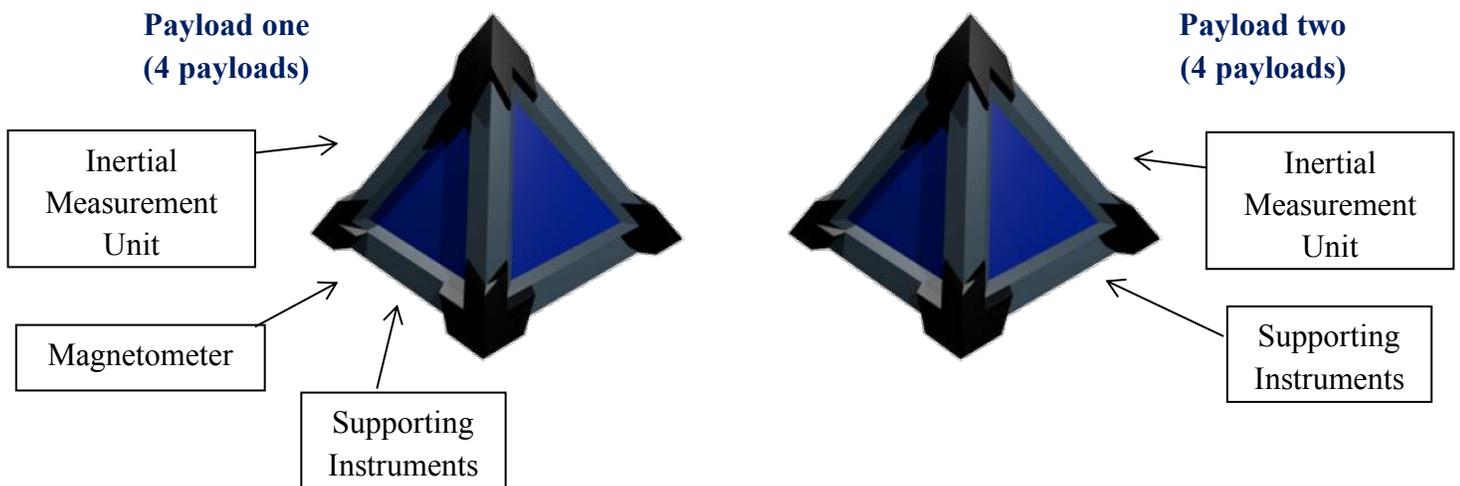inSPIRESS

7.6 Payload structure mass

The payload must be adequately protected from impact on the Moon. In order to do this, the payload will be housed with **aluminum lithium alloy**, which has a density of 0.534 g/ cm³. The payload has a wall thickness of **1cm** on all surfaces. As a result, the structure will have a mass of **0.540kg.**

8.0 Final Design

Crescent is the concept that *Artemis Quintus* has chosen based off the results from the decision matrix. Each payload will be a square pyramid whose base is 20cm x 20 cm and whose height is 18cm. In addition, each payload will have a mass of 1.25 kilograms, allowing the team to have a total of 8 payloads. They are in the shape of a square pyramid to survive impact while effectively housing all our necessary equipment. With this compact design, the payload can protect our scientific instruments from critical damage when entering the Moon's environment.

All of these payloads will be propelled from the UAH orbiter backwards towards the Moon, each at a different location. Upon impact, the payload will begin collecting data on seismic activity and magnetic fields. The payloads will be deployed at different locations to acquire multiple points of data. This is done to allow us to better understand the internal structure of the Moon.

Figure 5. Final Crescent /Artemis Quintus Mission

Payload one (4 payloads)
- Inertial Measurement Unit
- Magnetometer
- Supporting Instruments

Payload two (4 payloads)
- Inertial Measurement Unit
- Supporting Instruments

It is important to remember that Crescent consists of two different types of payloads. While both payloads look similar, they differ in their instruments. One contains an IMU and magnetometer while the other only contains an IMU (as seen on figure 5). Having this design will allow us to measure more data over a prolonged period of time. As previously mentioned, each payload will be 1.25kg in mass. With that being said, our team must design it to house everything necessary for the success of our mission and keep the total mass less than 10 kilograms. Also, we had to make sure our payload met the functional requirements given to us. For example, we have to have a strong housing material in order for our payload to withstand the Moon's elements, but it also had to be light enough to meet the mass requirement. The equipment that makes up this mass is listed on Table 7.

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Table 7. Final Design Mass Table

Function	Components	Mass (kg)
Deploy	N/A	N/A
Measure	IMU and Magnetometer	0.624
Collect data	On-board Computer	0.094
Provide power	Space Batteries	0.002
Send data	Transceiver and Antenna	0.185
House payload	Aluminum Lithium Alloy	0.980
Ballast Weight	Extra weight	0.115
Total		**1.25**

Artemis Quintus, has taken into account all of the requirements our payload needs to abide by, and in this case, they are the project, functional, and environmental requirements. All of our compliances are displayed on Table 8.

Table 8. Requirements Compliance Table

Project	Environmental	Functional
1.25 kg of mass (10 kg total)	Payload reinforced by aluminum lithium alloy	Deployed by free falling from orbiter
Powered by the usage of space batteries	Multiple payloads to increase likelihood of mission success	IMU and Magnetometer
V = 20 cm x 20 cm x 18 cm	Low mass allows for a slower descent	Collect data with On-board Computer
Aerogel insulation to keep internal temp. at 294 K	More than 3 payloads to collect seismic activity	Provide power with Space Batteries
Does not harm UAH spacecraft		Send data with Transceiver and Antenna
		House payload with Aluminum Lithium Alloy