Lunar
Analysis
and
Sampling
for
Exploration
and
Research
Mission

PAYLOAD CONCEPT PROPOSAL

LUNATICS

"Crazy for the Moon"

Da Vinci School for Science and the Arts

Team 3

SPRING 2018

1.0 Introduction

The Moon has only been studied for a millennium since the existence of evolved humans over 200,000 years ago. Although it remains the most studied celestial object in our solar system other than Earth, a lot remains unknown about Earth's wonderous natural satellite. Such things include the Moon's magnetic field, the internal structure, and most interestingly "moonquakes". From what is known, these shakes occur out of sudden bursts of energy which turn into seismic waves to release this energy in massive shocks. Questions still stand about what exactly causes these quakes and how severe they can get. For these reasons our team, Lunatics, has collaborated with UAH to create our Cormorant payloads to assist in a lunar scientific mission by conducting research about the lunar quakes. The Cormorant payloads will travel to the Moon aboard the UAH orbiter and will deploy individually as directed, penetrating the surface at each location to acquire the data we will need. The team's name, Lunatics, derives from the folklore back in the medieval times when crazy people who claimed to turn into werewolves at night due to the changes in the Moon's phases, were given the title of lunatics because town folks never believed them. We're crazy about this mission which is why our slogan is "Crazy for the Moon" as it stands to show our team's ambitions about getting to the Moon and completing our objective.

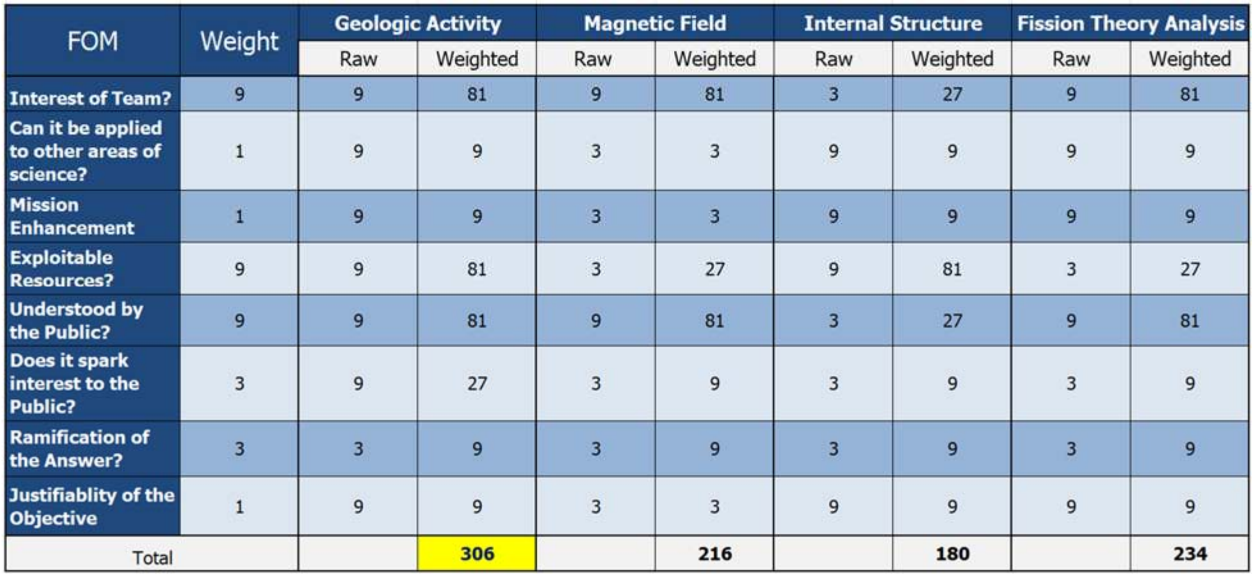
2.0 Science Objective and Instrumentation

When deciding which science objective to conduct research on, the team voted to evaluate four objectives, Geologic Activity, Magnetic Field, Internal Structure, and Fission Theory Analysis. The "*Fission Theory Analysis*" was the only objective not given to us by UAH, but rather was created by the team. In short, this science objective would have our team analyze the lunar surface for earth compositions and fossils to determine whether the Fission Theory is correct or not. Lunatics could only choose one scientific mission of the four that we were evaluating. Using the Trade Study matrix to weight the importance of a mission and the interest of the public about each science objective, team Lunatics concluded from the data that we would be researching the geologic activity that takes place on the Moon. The Moon is known to have its own occurring natural events such as moonquakes, but they're not the same as earthquakes because our Moon's geology doesn't include plate tectonics that are like Earth's. During this mission we will assess what specifically causes these moonquakes and measure how intense they can get. Conducting these analyses will provide a more exact understanding of how energy builds within the Moon's core and may lead to the discovery of other types of quakes other than the four which have been discovered already (deep, shallow, thermal, and meteorite impacts).

The study will be executed using an Inertial measurement unit(IMU) to measure seismic waves, and a thermocouple accompanied by a pressure transducer to measure changes in temperature and gas pockets which may also be causing the lunar quakes. These primary instruments will be able to identify the cause and power of the seismic events between the individual data they collect. Supporting equipment such as an on-board computer, transceiver, antenna, and batteries will be the instruments that receive, process, send all data; and power the payload.

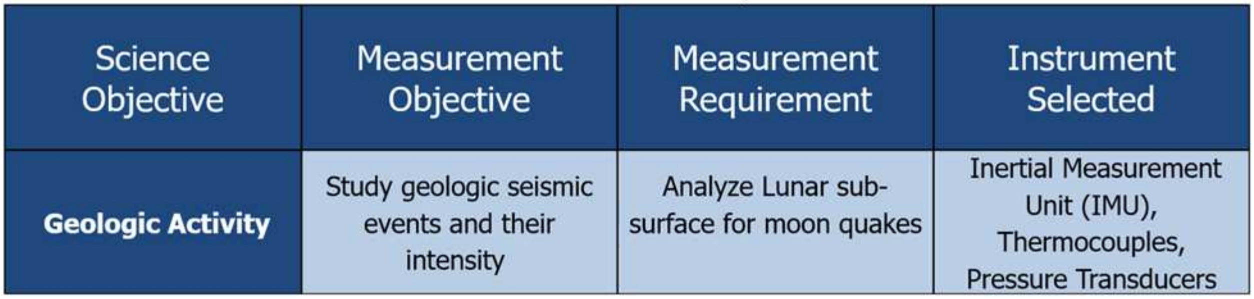
The following charts show our scoring process of the science objectives with figures of merit (FOM) and weights provided by UAH and further information over the instruments that we will be using during our scientific operation.

Table 1. Science Objective Trade Study



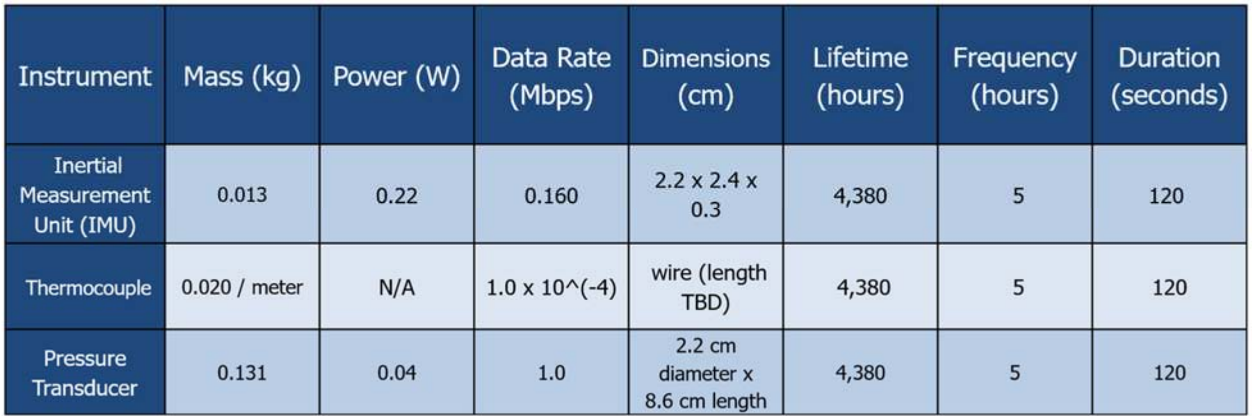
FOM	Weight	Geologic Activity		Magnetic Field		Internal Structure		Fission Theory Analysis	
		Raw	Weighted	Raw	Weighted	Raw	Weighted	Raw	Weighted
Interest of Team?	9	9	81	9	81	3	27	9	81
Can it be applied to other areas of science?	1	9	9	3	3	9	9	9	9
Mission Enhancement	1	9	9	3	3	9	9	9	9
Exploitable Resources?	9	9	81	3	27	9	81	3	27
Understood by the Public?	9	9	81	9	81	3	27	9	81
Does it spark interest to the Public?	3	9	27	3	9	3	9	3	9
Ramification of the Answer?	3	3	9	3	9	3	9	3	9
Justifiablity of the Objective	1	9	9	3	3	9	9	9	9
Total			**306**		**216**		**180**		**234**

Table 2. Science Traceability Matrix



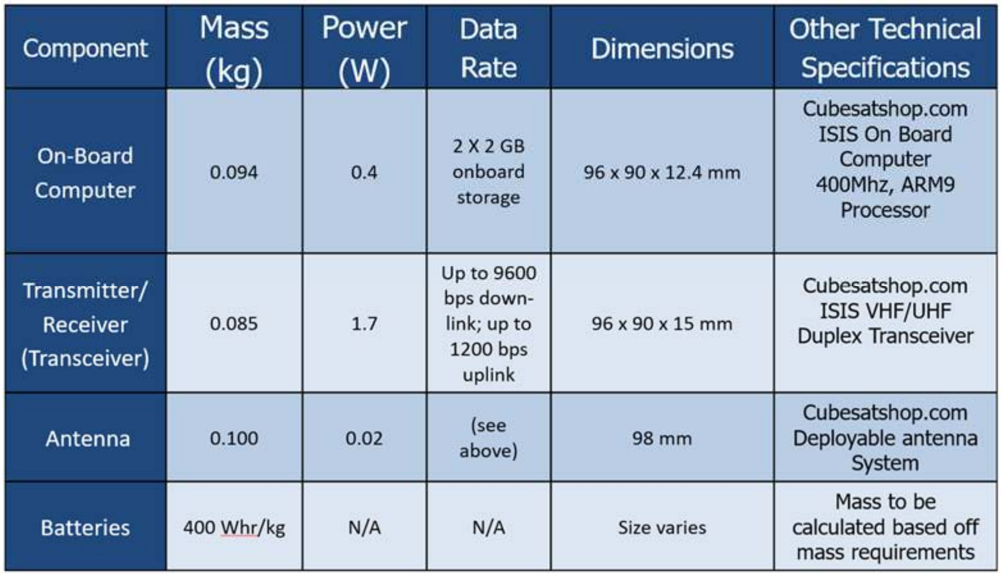
Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Geologic Activity	Study geologic seismic events and their intensity	Analyze Lunar sub-surface for moon quakes	Inertial Measurement Unit (IMU), Thermocouples, Pressure Transducers

Table 3. Instrument Requirements



Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (hours)	Frequency (hours)	Duration (seconds)
Inertial Measurement Unit (IMU)	0.013	0.22	0.160	2.2 x 2.4 x 0.3	4,380	5	120
Thermocouple	0.020 / meter	N/A	1.0 x 10^(-4)	wire (length TBD)	4,380	5	120
Pressure Transducer	0.131	0.04	1.0	2.2 cm diameter x 8.6 cm length	4,380	5	120

Table 4. Support Equipment



Component	Mass (kg)	Power (W)	Data Rate	Dimensions	Other Technical Specifications
On-Board Computer	0.094	0.4	2 X 2 GB onboard storage	96 x 90 x 12.4 mm	Cubesatshop.com ISIS On Board Computer 400Mhz, ARM9 Processor
Transmitter/ Receiver (Transceiver)	0.085	1.7	Up to 9600 bps down-link; up to 1200 bps uplink	96 x 90 x 15 mm	Cubesatshop.com ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	(see above)	98 mm	Cubesatshop.com Deployable antenna System
Batteries	400 Whr/kg	N/A	N/A	Size varies	Mass to be calculated based off mass requirements

3.0 Payload Design Requirements

Getting to the Moon is no easy task as there have been a total number of 55 failed out of 114 total missions. To ensure the likelihood of mission success we had to meet the project, functional, and environmental payload requirements given by UAH.

To comply with project requirements, the payload design itself may not exceed a volume of 44x24x28cm or mass of 10kg. We will have to successfully deploy from the chosen UAH spacecraft, the orbiter, without harming the spacecraft in any way. Most importantly after enduring the impact of penetrating the surface, the payload will have to survive the environment in which it lands in.

The Moon's surface differentiates vastly between the low and higher regions which is why our Cormorant payloads will penetrate through the softer sections of the regolith within the four distinct destinations that we have chosen (Selenean Summit, Antoniadi Crater, Peary Crater, and Shackleton Crater). Since we will be penetrating to conduct research in the sub-surface of the Moon, our materials in the design will have to be strong enough to withstand impact and protect the interior mechanics to ensure all the instruments still function after impact. Using such materials for the design will also protect the payload meanwhile it is burrowed under the surface of the Moon absorbing all the seismic activity that it will be collecting.

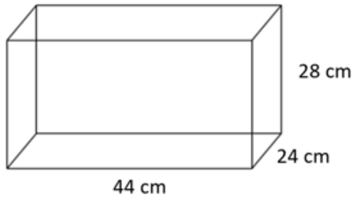
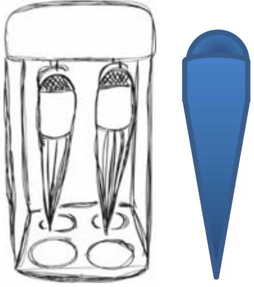


Figure 1. Project Requirement

4.0 Payload Alternatives

Mission success is the most important factor about any mission because if a design fails, no mission can be accomplished. For this reason, Lunatics split into two groups to design our mission payloads and increase our chances of having one well thought-out design. With four members in each group, the Design and Engineering team were divided and placed into separate groups to help the other members of the team design a payload. Once the two layouts were developed by both groups, they were compared and evaluated regarding which design would best enhance our mission success. Both designs would carry the same primary instruments and supporting equipment, group decisions and design were based on how to name, shape, size, and weigh each payload.

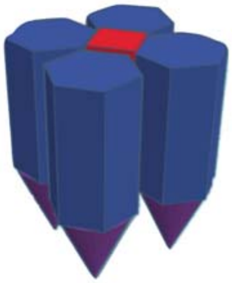
Figure 2. Terrabreacher



Preliminary design

Named and designed by group one, the name Terrabreacher can be interpreted as "breaching the Moon's surface" because that is what the payload will be accomplishing. This design was completed for the purpose of boosting the mission studies. Since we will be targeting four locations of the Moon's subsurface this payload is small and compact with a maximum weight of 1.25kg each to allow for the creation of several payloads. With this weight, eight of these payloads can be built and sent aboard the orbiter. Two payloads will drop over each destination, with distance between each impact point, doubling the data and analysis the team will collect just from one location providing us with more accurate results throughout the collection period.

Figure 3. Cormorant



Preliminary design

Named and designed by group two, Cormorant is named after the bird species that surface dives into the water which metaphorically represents how this payload will dive into the subsurface of the Moon. The Cormorant payloads are bigger and heavier with a maximum mass of 2.4kg each and includes a center pillar with a mass of .4kg. This design was the conservative approach with a goal to better the chances of mission success. Having a heavier mass means more material or stronger material can be used to house the instruments in a well reinforced way. With only four payloads in this design, held together by a center pillar in the orbiter, one payload will drop over each destination as the orbiter moves above the targeted location. The payload's bulky and sharp figure also increases the chances of it sustaining less damage as it breaks through the surface of the Moon.

5.0 Decision Analysis

Choosing the most suitable payload was not simply something we could vote on. Using a decision analysis matrix was the proper process on how to select the payload with the best qualifications for this mission. With both payload designs already meeting all the requirements we judged solely on the mission enhancement and capabilities of the design. In the chart below, the first seven FOM's and weights were given to us by UAH, the weight scaled on a rank of 1, 3, and 9 with one being the lowest and nine being the highest. The final three FOM's were created by Lunatics which include scoring on the research capabilities, durability, and battery capacity of each payload. Everything was cautiously evaluated by the entire team deciding together on each raw score that was given for each FOM.

Table 5. Payload Decision Analysis

FOMs	Weight	Terrabreacher		Cormorant	
	1, 3, or 9	Raw Score	Weighted Score	Raw Score	Weighted Score
Science Objective	9	9	81	9	81
Likelihood Project Requirement	3	9	27	9	27
Science Mass Ratio	1	3	3	9	9
Design Complexity	3	3	9	9	27
ConOps Complexity	3	9	27	9	27
Likelihood Mission Success	9	9	81	9	81
Manufacturability	1	9	9	3	3
Research Capablities	9	9	81	9	81
Durability	3	3	9	9	27
Battery Capacity	9	3	27	9	81
TOTAL			**354**		**444**

The final calculations resulted with Cormorant being our chosen alternative. Lunatics figured the most vital raw score given was the battery capacity score because with the more batteries a payload can fit, it directly changes the lifetime of the payload to do more research. By being able to expand the time till power loss with the Cormorant payloads and not with the Terrabreachers, it meant that numbers in payloads didn't apply because we will be able to collect data in equal proportion to what we would have collected with the Terrabreachers. It also allows us to analyze whether the time of year, which changes the placement of the Moon, has any sort of effect as to why moonquakes occur.

6.0 Payload Concept of Operations

Establishing a basis for any mission is like laying a foundation, it should always be first. Our mission has several phases which will be repeated 4 times because the Cormorants will not be deploying simultaneously. Our valuable payloads will be conducting research in the North, East, South, and West regions of the Moon at our four locations which were previously mentioned in the payload design requirements. At our final drop the center pillar will fall from the orbiter with the last Cormorant but because its survival does not pertain to the mission, it will burst upon impact. Lunatics' mission is divided into 4 sections, the operations the Cormorant payloads will undergo are as follows;

- <u>Initial Conditions:</u> The four Cormorant payloads will be stowed aboard the orbiter from takeoff and until the orbiter reaches safe orbital travel above the Moon. The payload's housing will also not harm the orbiter throughout its orbit and will not take up more space than the 44cmx24cmx28cm volume requirement we were given.
- <u>Deployment:</u> As the orbiter travels over each of our four distinct locations which cover all four parts of a compass, our payloads will individually be deployed with a propelled helium launch facing downwards.
- <u>Trajectory:</u> Meanwhile in trajected descent towards the targeted location on the Moon, the Cormorant payload will be experiencing a constant gravity, no drag, and no change in horizontal velocity.
- <u>Ending Conditions:</u> Reaching the end of its flight time, the Cormorant will have had its high-impact penetration into the lunar subsurface. Remaining burrowed under the surface the payload will begin to collect data after impact.

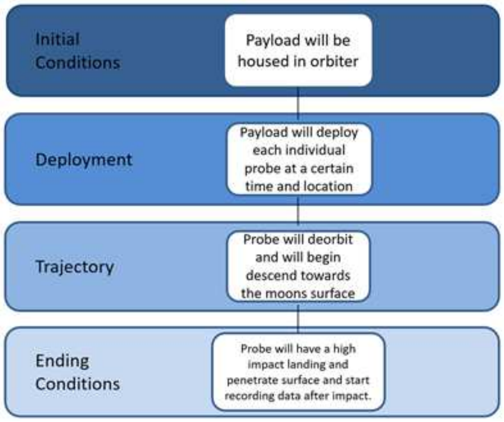


Figure 4. Con Ops Flow Chart

Figure 5. Con Ops Graphic

7.0 Engineering Analysis

Several parameters had to be understood and evaluated for the course of our concept of operations. Lunatics analyzed and calculated various numbers to assure a successful deployment from the orbiter and impact into the lunar subsurface. To begin all our analysis, we had to keep track of what all our knowns and givens were, then we made our assumptions such as there is a constant gravity and no drag. Finally we would move to the end of each calculation and get our solution. Our givens for the calculations included; that the Moon has a constant gravity of 1.62m/s², mass of 7.347 x 10^22 kg, radius of 1,737km, that there is universal gravitational constant of 6.67 x $10^{-11}\ m^3\ kg^{-1}\ s^{-2}$, that we'd have an orbital altitude of 100km above surface, and finally that we would deploy using muzzle velocity out of a barrel of 44 cm.

7.1 Structure Mass Analysis

Having constraints for our payload mass meant calculating the precise mass and volume of our payload a priority. Knowing we could not exceed a total volume of 44x24x28cm and that we had an octagonal prism, which would be the body, our chief engineer calculated all the geometric measurements and concluded each payload could not exceed a volume of 44x11.95x11.95cm. To ensure we were well under the constraint for mass we subtracted .4kg from the total 10kg leaving that .4kg for the mass of the center pillar. Then we divided our result of 9.6kg by four to conclude our maximum payload weight of 2.4kg per payload.

7.2 Initial Conditions

Having decided as a team the that best option for accomplishing our mission and science objective was to deploy from the UAH orbiter, the next step was finding the conditions the Cormorants would be in aboard the Orbiter. The engineering team did this by using the formula $V = \sqrt{\frac{GM}{r}}$, in which "G" is the Universal Gravitational Constant, times "M" the mass of the Moon divided by "r" the radius of the Moon, plus the radius of orbit (100 km), and everything to the square root. This calculation gave us the resultant that the orbital velocity would be **V=1,636 m/s**.

7.3 Deployment

The deployment of the payload was first figured out by understanding the circumstances. Knowing that the deployment muzzle will be 44 cm in a downwards position so that we may penetrate, we had to calculate the velocity Cormorant would deploy at. The team needed to work backwards, and first solve for the final vertical velocity since the team was trying reach an angle of penetration 21 degrees or greater(this process will be further explained in section 7.4 Trajectory). For the sake of calculating the deployment velocity, we knew that the ending velocity would be 628 m/s. Knowing that we could use the formula $v_i^2 = v_i^2 - 2(a)(d)$,which tells what velocity is needed for deployment to reach the desired final velocity, where v_f^2 is 628 m/s, "a" is the Moon's gravity (1.62 m/s^2), and "d" is 100,000 m, which would solve for the velocity the probe needed to reach, answer being 265 m/s. Next, we needed to know the pressure and g-load Cormorant would be experiencing at deployment. For acceleration we used the formula $v_f^2 = v_i^2 + 2(a)(d)$, and solve for "a", a=79981 m/s^2. Finally, the pressure was calculated using the equation $P = \frac{m(v_f^2 - v_i^2)}{2dA}$, where p would be P=5,608,481 pascals or 813 Psi.

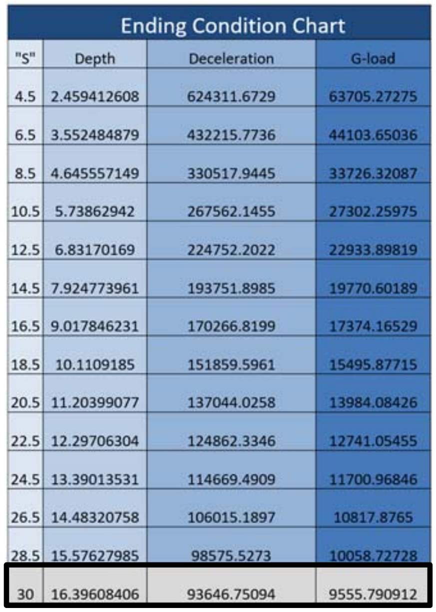
7.4 Trajectory

The trajectory of the payload is fairly simple, it consists of the vertical velocity, horizontal velocity, and the sum of the velocities when descending towards the Moon. Solving for the velocity started with the team knowing the angle the probe needed to penetrate, 21 degrees. The team created a triangle the represented the velocities, and used basic trigonometric functions to figure out the vertical velocity, $\tan(21) = \frac{v_y}{1636}$, v_y= 628 m/s. Then to solve for the sum vector velocity, we used Pythagorean theorem, $V_{xy} = \sqrt{(1636)^2 + (628)^2}$, $V_{xy} = 1752\ m/s.$ Finally, to solve for the flight time we used the equation $t = \frac{(628-265)}{1.62}$, t= 224 seconds.

7.4 Ending Conditions

The ending condition was the part of the analysis that manipulated the rest of the analysis, hence the importance of this phase. The most important factor was making sure the probe would penetrate at an angle of 21 degrees. To calculate, the team made the following chart that demonstrates; "S" the penetrability number, what depth it would penetrate, what deceleration it would have, and the g-load on the probe. The chart was created by increasing the "S" in the equation $D = .000018SN\left(\frac{m}{A}\right)^{.7}(v - 30.5)$, which solves for depth, and therefore we can get the deceleration using the formula $a = \frac{v_i^2}{2d}$, and the g-load using, $g - load = \frac{a}{g_{earth}}$. See Table 6 for reference.

Table 6. Ending Conditions



Ending Condition Chart			
"S"	Depth	Deceleration	G-load
4.5	2.459412608	624311.6729	63705.27275
6.5	3.552484879	432215.7736	44103.65036
8.5	4.645557149	330517.9445	33726.32087
10.5	5.73862942	267562.1455	27302.25975
12.5	6.83170169	224752.2022	22933.89819
14.5	7.924773961	193751.8985	19770.60189
16.5	9.017846231	170266.8199	17374.16529
18.5	10.1109185	151859.5961	15495.87715
20.5	11.20399077	137044.0258	13984.08426
22.5	12.29706304	124862.3346	12741.05455
24.5	13.39013531	114669.4909	11700.96846
26.5	14.48320758	106015.1897	10817.8765
28.5	15.57627985	98575.5273	10058.72728
30	16.39608406	93646.75094	9555.790912

7.5 Battery Mass

To calculate the battery mass, the team first had to know what instruments would be used by the probes, the instruments include an IMU, Pressure Transducer, Thermocouple, Computer, Antenna, and Transmitter/Receiver. These instruments were split into two groups, that the instruments in the group would be operating simultaneously: Group 1(IMU, Pressure Transducer, Thermocouple), Group 2 (Computer, Antenna, and Transmitter/Receiver). Group 1 will have a duration of 120 seconds, and a frequency of 5 hours. Group 2will have a duration of 1 hour and a frequency of 21 days. The total power is 38.164 W-hr, the battery mass is .095 kg, and the total lifetime is 6 months or 4380 hours.

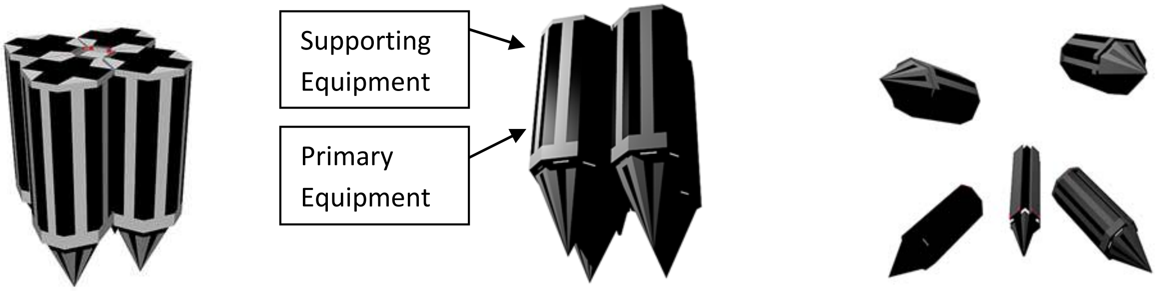
8.0 Final Design

Cormorant was the chosen payload design because of the high total score it got in the decision analysis matrix. The design of the structure is made up of a straight-edged octagonal prism that forms the body and is completed with a short-tipped octagonal pyramid that forms the nose. This shape increases the tolerance the payload will have at impact with the Moon's surface as the nose perforates through the surface allowing for the body to slide through the gaps made by the nose more proficiently than other shapes. This feature also allows for the better sheltering of the interior equipment as the payload penetrates the subsurface. The dimensions of each Cormorant are 44x11.95x11.95cm, and the octagonal prism has surface area of 1,346cm^2 and the octagonal pyramid had a surface area of 230cm^2, meaning a total surface area of 1,576cm^2 .When grouped, a center gap is formed for the placement of the center pillar which will have a volume of 44x4.95x4.95cm. Each payload, having a mass of 2.4kg, permits us to have a total of four payloads that will drop in our four designated locations; the Selenean Summit, Antoniadi Crater, Peary

Crater, and Shackleton Crater. The probe will be made up of a **Titanium nose, and the body of Aluminum 8090 Alloy.**

As the orbiter hovers over each destination one Cormorant will deploy using pressurized helium to eject downwards into a trajected descent. Upon impact each payload will begin its studies and data collecting until power loss which is 6 months after deployment. These diverse landing locations and prolonged lifetime for the payload enhance the research we will be able to conduct throughout our lunar mission.

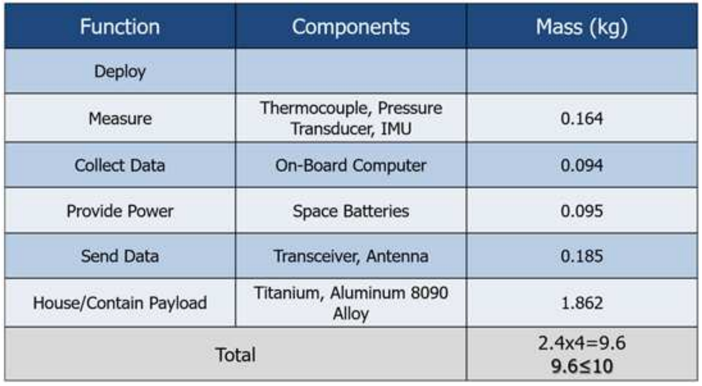
Figure 6. Cormorant / Lunatics' Mission



Although more may be better at times, taking the conservative payload design will maximize what it is we can learn about moonquakes because we will be able to study them for a longer period.

The following chart expresses which instruments will be used during each phase of the con ops and includes the mass for each instrument to show that we did meet our payload mass requirement.

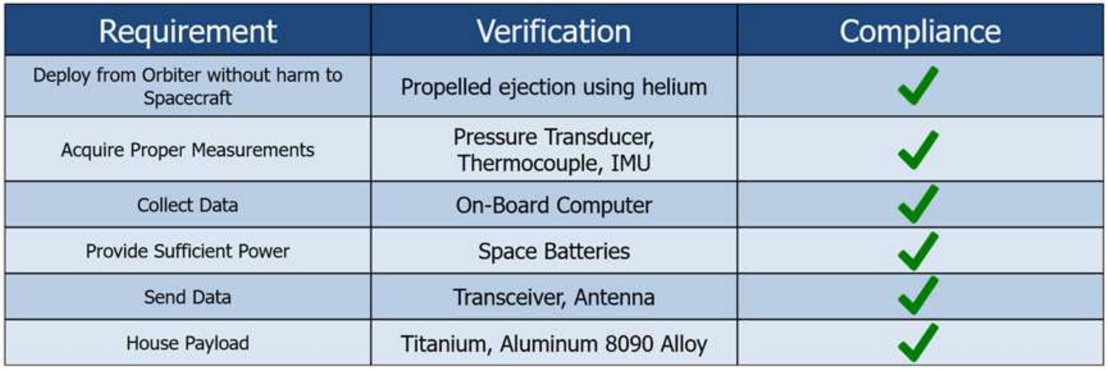
Table 7. Final Design Mass Table



Function	Components	Mass (kg)
Deploy		
Measure	Thermocouple, Pressure Transducer, IMU	0.164
Collect Data	On-Board Computer	0.094
Provide Power	Space Batteries	0.095
Send Data	Transceiver, Antenna	0.185
House/Contain Payload	Titanium, Aluminum 8090 Alloy	1.862
Total		2.4x4=9.6 **9.6≤10**

What was important to Lunatics was making sure we complied with everything for the mission which included the project, functional, and environmental requirements as displayed in table 7.

Table 8. Requirements Compliance Table



Requirement	Verification	Compliance
Deploy from Orbiter without harm to Spacecraft	Propelled ejection using helium	✓
Acquire Proper Measurements	Pressure Transducer, Thermocouple, IMU	✓
Collect Data	On-Board Computer	✓
Provide Sufficient Power	Space Batteries	✓
Send Data	Transceiver, Antenna	✓
House Payload	Titanium, Aluminum 8090 Alloy	✓