PAYLOAD CONCEPT PROPOSAL

Gravitron

Muscle Shoals High School

Team #2

1.0 Introduction

The Moon is Earth's sole natural satellite. Because of the unequal distribution of mass in the Moon's internal structure, acceleration due to gravity on the moon differs across the surface. The University of Alabama at Huntsville will be sending an orbiter, as well as a lander and rover to the Moon. Team Gravitron will be be sending a payload containing eighteen inertial measurement units on the orbiter and a gravimeter on the rover in order to measure gravity at various locations on the Moon. By dropping IMUs at different locations on the Moon and using the gravimeter on the rover, Gravitron will broaden scientists' knowledge of gravity on the Moon.

2.0 Science Objective and Instrumentation

Team Gravitron's science objective is to measure gravity and its variation on the moon and to eventually expand exploration. The science trade study helped the team come to a consensus for the objective of this mission through the analysis of the figure of merits which are topics that this assignment focuses on. Team Gravitron came to a completely unanimous agreement that gravity won in the application to other science fields, mission enhancement, and public understanding. It won in these FOMs because gravity is what keeps the Earth and other planets in orbit and humans alive, and in order to advance human colonization of space, scientists need to understand gravity in every aspect. Everyone knows the function of gravity, but there are still some mysteries about gravity that humans don't understand. Gravity lost in creating a "wow factor" in people, measuring method, ratification of answer, and justifiability. The lost in these areas was due to the fact that general information about gravity is known by everyone. Gravity tied in team interest with lava tubes because both are keys in future space missions and life.

Table 1. Science Objective Trade Study

Figure of Merit	Weight	Gravity		Internal Structure		Lava Tubes	
		Raw	Weighted	Raw	Weighted	Raw	Weighted
Interest of Team	9	9	81	3	27	9	81
Applicability to Other Science Fields	1	9	9	3	3	3	3
Mission Enhancement	1	9	9	3	3	1	1
Measurement Method	9	3	27	9	81	3	27
Understood by the Public	9	9	81	1	9	3	27
Creates Excitement in the Public	3	1	3	3	9	9	27
Ramification of the Answer	3	3	9	9	27	9	27
Justifiability	1	3	3	9	9	3	3
Total			**222**		168		196

The measurement needed to complete this mission is completed by the IMU which measures gravity in the area at several different spots on the moon. After receiving the data from the several IMUs from low and high gravity point on the moon, the variation of gravity can be mapped. The gravimeter measures gravity at several points creating a gravity map of 100 km from UAH Shackleton to the UAH lander. These maps will be combined and create a map of the gravity taken on the surface of the moon. Both of these instruments will be on a payload, along with the support equipment. The grav-ball will be on the orbiter and the GMD will reside on the rover.

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
To measure gravity and its variation	Gravity at a point	To measure gravity at that place for a period of time	Gravimeter
	Variation in the gravity	To measure gravity on impact	IMU

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	One hour	Once	Continuous
Gravimeter	1	1	0.01	10 x 10 x 10	30 days	20 min	1 sec

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
Processor	0.094	0.4	2 x 2 GB onboard storage	ISIS On-board Computer 400 MHz/ARM9 Processor
Transmitter/ Receiver	0.085	107	Up to 9600 bps downlink/ up to 1200 bps uplink	ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	(See above)	Deplorable Antenna System
Batteries	400Whr/kg	N/A	N/A	Depends on Power Requirement

3.0 Payload Design Requirements (1/2 page)

There are many conditions that the gravitron payloads designs have to meet to successfully complete this mission. First, one of the payloads must deploy successfully from the

UAH spacecraft. Both of the payloads need to automatically collect the data, transmit data, power itself, and survive long enough to complete the science objective.

To ensure the survival of the instruments in the grav-ball, the sphere was designed to endure the moon's temperature range of approximately 100°C to -173°C. The team has to include an insulator to protect the equipment from outside temperature and other unknown moon environmental influences. Additionally, the metal used to make the shell of the sphere can not collapse since the grav-ball needs to bounce for 895m.

To conclude, the UAH InSPIRESS also gave some mission requirements and restrictions that are essential for the creation of the payload design. All equipment must fit inside of a 44x24x28 box and be less than 10 kg. Furthermore, at least one payload must deploy from any UAH spacecraft and it can not harm the spacecraft

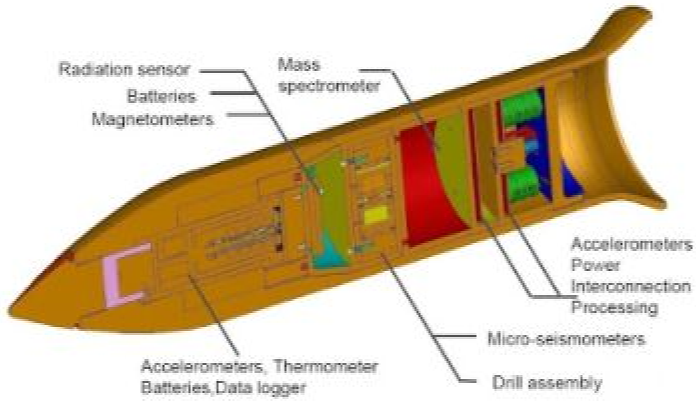
4.0 Payload Alternatives

5.0 Team Gravitron has created two concepts, one is called Land and Bounce the other is called crash. There mission is to measure gravity on the surface of the moon.

Figure 1. Concept 1- land and bounce

For the land and bounce concept there will be two measurement devices, the gravimeter and IMUs. The Gravimeter will be on the UAH rover. It will be measuring gravity from Shackleton to the UAH lander. The IMUs will be shot from the orbiter which will bounce on impact, and the gravimeter will stay riding on the UAH rover. The IMUs will be housed inside a sphere called the grav-sphere that will be lined with aerogel for insulation. As the sphere bounces, the gravity will be measured by the difference between the height of each bounce.

Figure 2. Concept 2- crash



The second concept, Crash, has only one main instrument for measuring gravity. For Crash, we will be utilizing IMUs to penetrate the moon's surface. The IMUs will be shot from the UAH orbiter. Gravity will be measured by the penetration depth of the IMUs. The payload that will house this concept is shaped like a dart.

6.0 Decision Analysis

In order to decide which concept is better equipped to measure gravity and its variation, Team Gravitron came up with three figures of merit in addition to the seven figures of merit provided by UAH. The Land and Bounce concept won in Science Mass Ratio, Accuracy, and Deployment. This is so because this concept could potentially calculate additional information that can be useful for UAH and because it has the simplest design. Both concepts tied in Science Objective, Likelihood Project Requirement, and Mission Success because they both were designed so that they would complete these requirements. However, Land and Bounce lost ConOps Complexity since there are more steps and calculations than in Crash. Furthermore, it lost in manufacturability and energy consumption considering one of the main instruments, the gravimeter, is a newly invented device by an English scientist, Richard Middlemiss. This 1kg device burns large amounts of energy, which is why this concept has a disadvantage in the figures of merit. Overall, the advantages of the land and bounce concept compensated for the disadvantages it collected, therefore, this concept was chosen due to its immense benefits

Table 5. Payload Decision Analysis

Figure of Merit	Weight	Land and Bounce		Crash	
		Raw	Weighted	Raw	Weight
Science Objective ⬆	9	9	81	9	81
Likelihood Project Requirement ⬆	9	9	81	9	81
Science Mass Ratio ⬆	3	9	27	3	9
Design Complexity ⬇	1	1	1	3	3
ConOps Complexity ⬇	3	3	9	9	27

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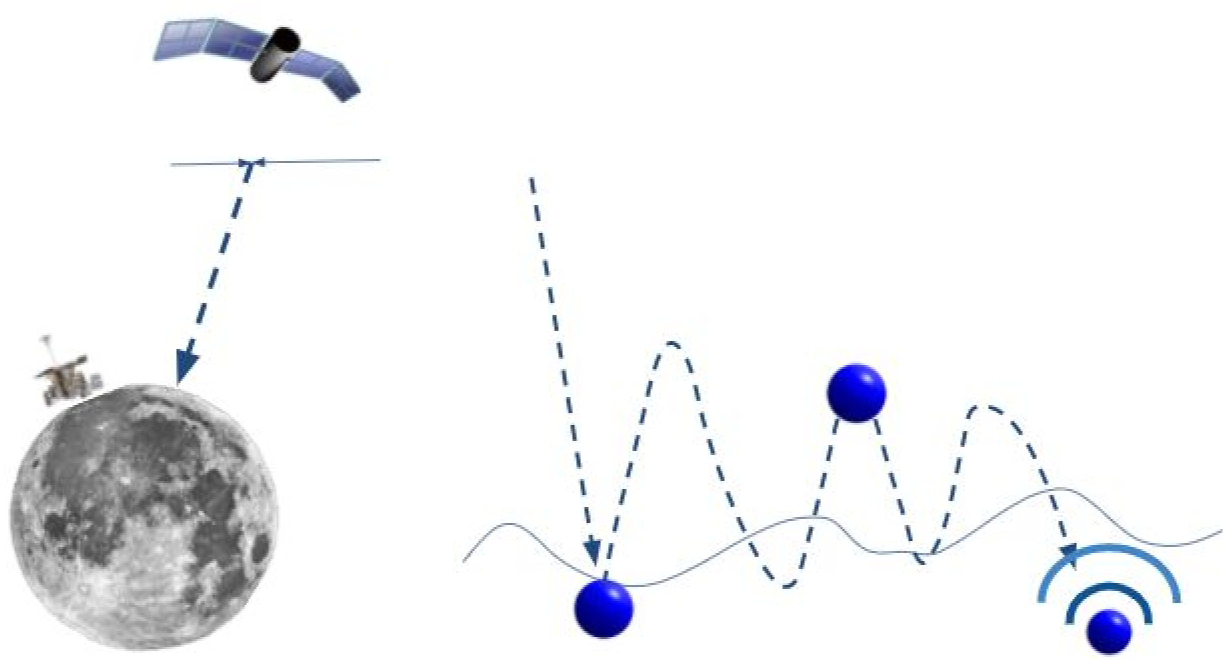
Likelihood Mission Success ↑	9	9	81	9	81
Manufacturability ↓	1	3	3	9	9
Accuracy ↑	9	9	81	3	27
Energy consumption ↓	3	3	9	9	27
Deployment ↑	3	9	27	3	9
Total			400		354

7.0 Payload Concept of Operations

Team Gravitron will have two types of payloads one will deploy while the other will stay on the UAH spacecraft. The first type of payload is called grav-sphere. There will be 18 of this payload. This payload will deploy from the orbiter and each will aim for a high or low gravity point on the moon. The trajectory will be calculated for each destination. After impact, it will bounce for 1 km. The difference in the height of each bounce will be the same, which is the gravity value of that area. The second payload is called the gravimeter, the main equipment one this payload is the gravimeter it will be on the UAH rover taking gravity measurement every 20 min. It will be stationed on the rover until the mission is complete.



8.0 Engineering Analysis

In order to calculate the final mass, trajectory, and volume, a certain order of calculations was followed. The calculations were for orbital velocity, size of deployment spheres, velocity of impact, and g-load during impact.

In order to calculate the orbital velocity of the spacecraft, the team began by multiplying the mass of the Moon (7.346×10^{22} kg) and the gravitational constant (6.674×10^{-11} m^3 kg^{-1} s^{-2}), the product of which was then divided by the distance of the orbiter from the Moon's center, or the radius of the moon (1.7374×10^6 m) added to the altitude of the orbiter (100 km). The square root of this number gave an orbital velocity of 1633.5 m/s.

Next, to calculate the deployment velocity, the team found the cross sectional area of the barrel which the deployment spheres would be launched out of. To do this, the team calculated the that a sphere with a radius of 7.12×10^{-2} m could fit the transmitter/receiver (96 x 90 x 15 mm), inertial measurement unit (22 x 24 x 3 mm), antenna (98 mm), and outer casing (5 mm thickness). The volume of the outer casing was found by subtracting the volume of a sphere with a radius of 7.12×10^{-2} m from a sphere with a radius of 6.62×10^{-2}, which was then multiplied by the metal's density (0.9 mg/cm^3) to find a mass. The total mass of the support equipment, IMU and metal shell for one sphere was found to be 0.198 kg.

A deployment barrel with the same radius as the sphere has a cross sectional area of 1.593×10^{-2} m^2. Assuming a helium pressure of 71 psi and a deployment length of 0.4 m, along with the assumptions given by UAH, the team found that the initial velocity of the sphere would be 178 m/s after being launched from the orbiter. Assuming constant gravity at 1.62 m/s^2 and no drag, this would cause the sphere to impact the ground at 747.2 m/s in the vertical direction and 1.80×10^3 m/s total. By taking the inverse tangent of the vertical velocity at impact divided by the horizontal velocity, which is unchanged from its launch, the angle of impact was calculated to be 24.6°.

The team assumed that the spheres would bounce across the surface because the angle of impact was between 20 and 30 degrees. The team also assumed a flat surface and a stopping distance of 895 m. Solving for acceleration in the equation $a = \frac{v_i^2}{2D}$ using a velocity of 1.80×10^3 m/s gave an acceleration of 1810 m/s2, which was then divided by 9.81 to find the g-load of 185, which is below the threshold that could damage the equipment. The team also used the equation $v_f = v_i + at$ with a final velocity of 0 m/s to calculate a stopping time of 0.994 seconds.

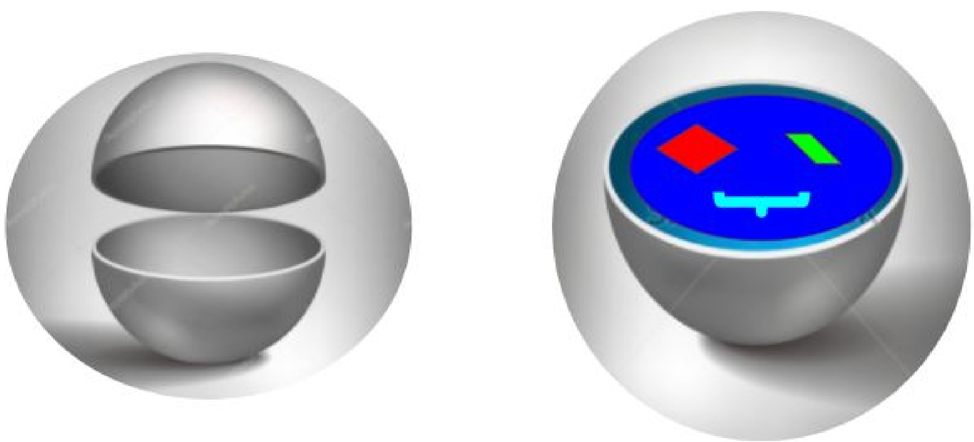
To calculate the mass of the batteries for the spheres, the team used an operational time of the IMUs of 1 second, because that was the length of time over which the spheres would stop and an operational time of 2 seconds for the transmitter/receiver, antenna, and processor in order to give them enough time to communicate. The operational time for each piece of equipment in hours was multiplied by its respective power usage in watts to find each pieces' W-hr. The total W-h for all the equipment in the spheres (0.0223 W-hr) was divided by 400 Wh/kg to find a mass of 5.6×10^{-5} kg. The mass of the battery used for the gravimeter was calculated separately. An operational time of 6 hours was used for the gravimeter, with half an hour for both the transmitter/receiver and antenna. When the operational time for each piece of equipment was multiplied by its respective power usage in watts, the total W-hr was found to be 6.86 W-hr. When divided by 400 W-hr/kg, the team calculated a mass of 1.7×10^{-2} kg.

9.0 Final Design

Team Gravitron's final design is the grav-sphere and GMD (Gravity Measuring Device). The gravimeter is going to stay on the UAH rover and the Gravitron ball will be deployed from the orbiter to a predestined area. These designs were decided by the team because of their efficiency and ability to protect the equipment within.

The gravitron ball is a hollow sphere that has a 5 cm diameter. There will be a maximum of 18 of these payloads due to weight restrictions. It would be launched from the orbiter which means it has to withstand high temperatures. The instruments are insulated by the aerogel that is covering the inside of the sphere. And the metallic microlattice can withstand hundreds of degrees itself. Furthermore, the payloads main objective is to measure the height of each bounce to measure gravity. Due to this, the payload itself has to have rubber qualities. These qualities are given by metallic glass that is covering the outer parts of the gravitron ball. Additionally, all the equipment on board this payload will be able to withstand the high g-load.

Figure 3. Gravitron ball



The gravimeter is an 11 x 11 x 11 cm payload. It will stay on the rover throughout the course of this mission. Its main objective is to map out the gravity from Shackleton to the lander while staying on the rover. Since this payload is not deploying form the rover protective equipment is not necessary. To operate this payload only needs batteries, an antenna, and a transmitter. All other equipment are built into the gravimeter.

Table 6. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Barrel	N/A
Measure	18 IMUs, Gravimeter	1.234kg
Collect Data	Processor	0.094kg

Provide Power	Batteries	0.017kg
Send Data	19 Antennas, 29 Transceivers	3.515kg
House/Contain Payload	18 Capsules	0.00481kg
Total		4.865 kg