PAYLOAD CONCEPT PROPOSAL

Team Osiris

Palmetto Scholars Academy

Team 2

TEAMOSIRIS

TIDES MAY WANE, BUT
THE ANCIENTS REMAIN.

1.0 Introduction

Team Osiris is part of an Integrated Product Team (IPT) with the University of Alabama in Huntsville for the Lunar Analysis for Exploration (LASER) and Research Baseline Mission. The LASER Baseline Mission deploys an orbiter circling 100 km above the moon for 2 years, a lander 100 km away from Shackleton Crater with a lifetime of 1 year, and a rover which travels to Shackleton Crater with a lifetime of 8 months. Our team will be launching off the orbiter.

Osiris is the name of an ancient Egyptian god of many domains, similar to the way in which our team covers many of the domains of our school by consisting of 9th-12th graders. His most famous area was that of life and death, but he was also a Moon deity, which to the Egyptians mirrored the waxing and waning cycles of life and death, like those of the Nile River. The science objective that Team Osiris selected was to perform electrolysis on ice samples found on the Moon. The crook and flail pictured in our logo is one of the symbols of Osiris, the first pharaoh. Team Osiris' slogan ties more parts of the mission in together. "Tides may wane" refers to the tides, which are created by the Moon, as well as to our science objective, which involves lunar water. "The ancients remain" refers to Osiris and the Moon, which are both ancient figures present since before modern times which continue to impact society in big ways.

The payload of Team Osiris will be penetrating the surface of the Moon. The Team Osiris payload is named Bennu after another mythological figure from Egypt which is a figure of rebirth. The deity is also thought to have inspired the Greek phoenix, our school's mascot. Hieroglyphics of Bennu resemble a heron, a common water bird of South Carolina, which dips its beak under the surface of water bodies to catch its objective of food. In a similar way our payload will be dipping under the surface of the Moon to catch its objective of water.

2.0 Science Objective and Instrumentation

Team Osiris selected three potential science objectives for this year's destination: study ice found in or near Shackleton Crater (Lunar Electrolysis Objective); study compounds within the lunar crust (Early Solar System Objective); or study solar particles hitting the surface of the Moon (Solar Energetic Particles Objective). Depending on the results of our mission, the Lunar Electrolysis Objective would allow us to look at the possible viability of using the elemental components of lunar ice to make rocket fuel on a body that would require 1/6 as much fuel to leave its gravitational influence. For the Early Solar System Objective, studying early solar system compounds in the Moon's crust would allow us to understand the old solar system better than we do now. The Solar Energetic Particles objective would give us a better idea of the dangers posed by solar bombardment to astronauts on the Moon or other celestial bodies within our solar system.

Our team used a trade study to find the objective that best met the requirements set forth by InSPIRESS and our team preferences. We quantitatively ranked the three above Science Objectives according to eight different Figures of Merit (FOMs) and their weights provided by UAH. As a team we evaluated and discussed these FOMs for each science objective and then assigned raw scores of 1, 3, or 9 (1 being lowest, 9 being highest) to each FOM for each objective. We then multiplied our raw scores by the weights of 1, 3, or 9 provided by UAH, resulting in weighted scores. We then added all weighted scores for a grand total for each objective. We compared these totals and determined that the Lunar Electrolysis Objective achieved the highest score, showing that it was the objective which best met both InSPIRESS requirements and team preferences.

Table 1. Science Objective Trade Study

FOM	Weight	Lunar Electrolysis		Early Solar System		Solar Energetic Particles	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of team	9	9	81	1	9	3	27
Applicability to other science fields (broadness)	1	9	9	1	1	3	3
Mission enhancement	1	9	9	9	9	1	1
Measurement method (easy to obtain)	9	9	81	9	81	3	27
Understood by the public	9	9	81	1	9	9	81
Creates excitement in the public ("wow factor")	3	3	9	1	3	9	27
Ramification of the answer	3	9	27	3	9	1	3
Justifiability (nice, neat package), (self-consistent)	1	9	9	3	3	1	1
TOTAL		**Sum**	**306**	**Sum**	**124**	**Sum**	**170**

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Lunar Electrolysis	Find ice for electrolysis analysis	Payload must be positioned within crater wall	LIBS (Laser Induced Breakdown Spectroscopy) System

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (Days)	Frequency (Per hour)	Duration (Minutes)
LIBS	1	1.5	22.4	0.45 x 0.50 x 0.80	44.1	1	1
IMU	0.013	0.22	0.16	2.2 x 2.4 x 0.3	44.1	1	1
Electrolyzer	0.07	3	N/A	5.4 x 5.4 x 1.7	44.1	1	1
VIS	0.47	5	10.24 per image	3.5 x 3.5 x 3.5	44.1	1	1

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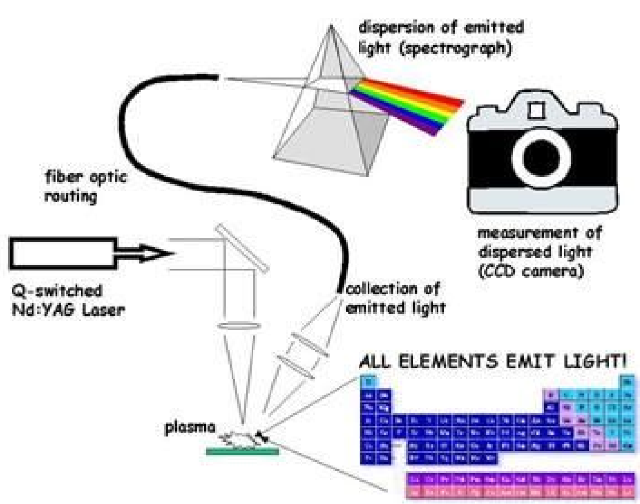
Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Dimensions (cm)	Data Rate
ISIS On Board Computer	0.094	0.4	9.6 x 9 x 1.24	N/A
Batteries	5	N/A	2 x 2 x 2	N/A
Transceiver	0.085	1.7	9.6 x 9 x 1.5	Downlink = .0012 Uplink = .0015
Antenna	0.1	0.02	9.8	Up to 9600 bps down Up to 1200 bps up

Figure 1. LIBS System.



3.0 Payload Design Requirements

UAH set several functional and project requirements for our payload. The Bennu can have no more than 10 kg of mass, must fit within a volume of 44 x 24 x 28 cm, and must cause no harm to the main spacecraft. Some additional requirements include the ability to deploy from a UAH vehicle and to house the payload. Our payload also must be able to access the data delivery system so we can send the data we are required to measure and collect. To have a successful mission, our payload must also survive the environmental conditions. These consist of wildly variant temperatures from 100 - 300 K, permanent darkness due to being underground, and low gravity (1.622 m/s^2). Atmospheric influences were not an issue as the Moon's atmosphere is virtually nonexistent. These environmental factors have prevented our design from using solar power, as we need to provide power to the payload. It also introduced the need for thermal protection of certain instruments.

4.0 Payload Alternatives

Concept 1 is a penetrator that would be launched downwards from an orbiter to land inside of the sloped crater wall, where a hatch would open in the back of the payload to allow the sample to be collected. Concept 2 is a sphere that would be launched from a rover to roll and bounce down the crater, taking images. Concept 3 is a smaller rover that would be deployed from the UAH rover to travel to Shackleton Crater and image the ground.

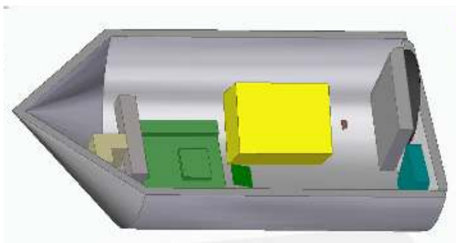


Figure 2. Concept 1.

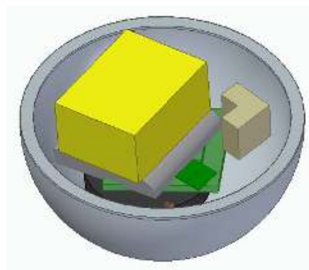


Figure 3. Concept 2.

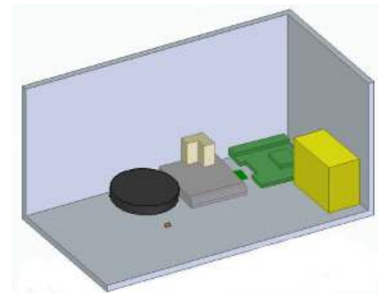


Figure 4. Concept 3.

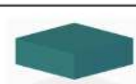
Payload Part Legend	
	VIS
	Batteries
	Transceiver
	IMU
	LIBS
	Mass Spectrometer
	Antenna
	Electrolyzer
	ISIS On-Board Computer

Table 5. Payload Part Legend.

5.0 Decision Analysis

Our decision analysis process was similar to our Science Objective Trade Study. We were given 7 FOMs by UAH but had to create 3 of our own FOMs as well. The FOMs created by the Osiris team are highlighted in blue (see table 5). We assigned a weight and raw score with a 1, 3, or 9 in the same manner as our science objective trade study. Science objective, likelihood of fulfilling project requirements, and likelihood of mission success were all weighted with 9 because all 3 of those FOMs had to do with our ability to get the results needed to accomplish the LASER Mission. The three FOMs that we created were added to increase relevance. All three of the FOMs we created were given a raw score of 3. We gave cost a weight of 3 because we were given a theoretical infinite budget, but we want to be realistic about how much our payload would cost. We gave public interest a weight of 3 because we want the public to know about our mission and what we are doing, yet throughout history the largest scientific advancements were not common knowledge until years later. Lastly, we gave accuracy and precision a weight of 3 because in all three of our concepts, we will more than likely only be getting data from a fixed position. The fixed position will only allow for a specific number of samples. Once we added up all of our weighted scores, Concept Bennu won.

Table 5. Payload Decision Analysis

FOM	Weight	Bennu		SpectroBall		Mini-Rover	
	1,3, or 9	Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	3	27	1	9
Likelihood Project Requirement	9	9	81	3	27	1	9
Science Mass Ratio	1	9	9	3	3	1	1
Design Complexity	1	9	9	3	3	1	1
ConOps Complexity	1	9	9	1	1	3	3
Likelihood Mission Success	9	9	81	3	27	1	9
Manufacturability	1	9	9	1	1	3	3
Cost	3	9	27	1	3	3	9
Public Interest	3	1	3	3	9	9	27
Accuracy and Precision	3	9	27	1	3	3	9
TOTAL	**Sum**		**336**		**104**		**80**

6.0 Payload Concept of Operations

Bennu will use its laser system on the Visible Imaging System (VIS) to look for ice deposits on the Moon crater sides while stowed in the UAH orbiter. Once Bennu finds ice, it will deploy downwards, using helium pressure at 1% of orbital velocity. If any more helium were used, the team was concerned that Bennu might hit the UAH orbiter. It will then proceed to fall for 340 seconds before hitting the crater wall at an angle inclined 10 degrees against a flat lunar surface. The impact will submerge the probe about 10 meters underground and cause the probe to experience the force of 1550 g. The g-force will force back a tray with the electrolyzer on it. The electrolyzer will then engage and begin electrolyzing ice which falls from above. Bennu will then activate its LIBS system and analyze the rock surrounding it. The VIS will continue running, dimly lighted by the laser from the LIBS. Data loss will be held in check during transmission, with measurements transmitting constantly and being copied as many times as possible before new data arrives. This is to counteract the data loss incurred by being within rock.

Figure 5. Flow chart of Concept of Operations

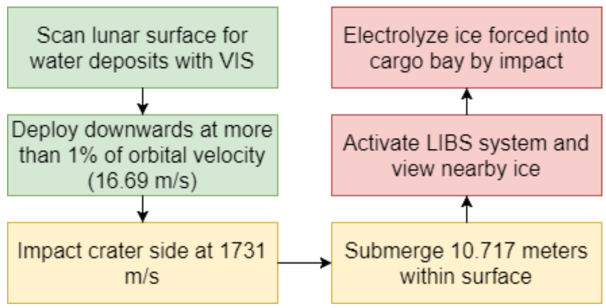
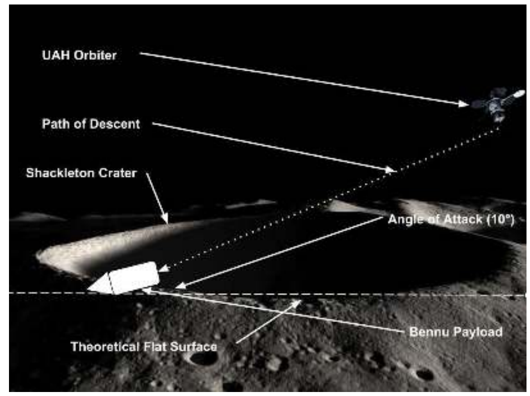


Figure 6. Diagram of Concept of Operations



7.0 Engineering Analysis

Table 6. Calculations Table

Design Stage	Variable	Equation	Calculation	Result
Initial Conditions	Orbital velocity	$\therefore v = \sqrt{\frac{GM}{r}}$ m= Mass of payload (10 kg) M= Mass of planet (7.3 $x10^{22}$kg) r= Radius of entire orbit (1,836,000m) v=Velocity G= Universal gravitational constant ($6.67*10^{-11}$ m^3 kg^{-1} s^{-2})	$\sqrt{\frac{(6.67x10^{-11} m^3 kg^{-1} s^{-2})(7.3*10^{22} kg)}{1,836,000m}}$	v = 1634.3 m/s
Deploy-ment	Deploy-ment Velocity	v^2_i= Initial payload velocity (0 m/s) v^2_f:Final payload velocity upon deployment (16 m/s) d:distance of barrel (0.44 m/s) P: Helium Pressure (7000 Pa) A: Cross sectional Area (0.0452 m^2) m: payload mass (10 kg) $v^2_f = v^2_i + 2(\frac{PA}{m})d$	$v^2_f = v^2_i + 2(\frac{PA}{m})d$ $= \frac{2((7000kg\ m^{-1}s^{-2})(0.0452m^2))*0.44m)}{10kg}$ $= \sqrt{\frac{2((7000kg\ m^{-1}s^{-2})(0.0452m^2))*0.44n}{10kg}}$	v = 17 m/s
Trajec-tory	Final Velocity Time of	$v^2_{f,y} = v^2_{i,y} + 2ad$ $v_f = v_i + at$ $a^2 + b^2 = c^2$ a: acceleration (1.625m/s^2)	$v^2_{f,y} = v^2_{i,y} + 2ad$ $v^2_{f,y} = 278.5561 +$ $2\ (1.625m/s^2)(100,000m)$	$v_{f,y}$= 570 m/s Time =340.7s

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	Flight	d: distance (100,000m) Initial velocity (v_i): 16.69 m/s Final orbital velocity ($v_{f,x}$): 1634 m/s Time of flight = (v_f - v_i)/a Final velocity = square root ($v^2_{f,x}+v^2_{f,y}$)	Final velocity= $\sqrt{(1634)(1634)+(570)(570)}$ Time = $\frac{570-16.69}{1.625}$	Final velocity = 1731m/s
Ending Con-ditions	Penetration Depth G-forces	D=.000018SN(m/A)$^{0.7}$*(v-30.5) Initial velocity (v_i): 1731 m/s Penetrability number (S): 8 Nose cone coefficient (N): 1 Final velocity (v_f): 0 m/s Gravity of Earth (g): 9.81 m/s^2 Mass (m): 10 kg Cross-sectional area (A): 0.045 m^2 D: Penetration Depth Pa = (acceleration*mass)/area	D=.000018*8*1(10/0.045)$^{0.7}$*(1731-30.5) g-load= acceleration/g-force Pa = (-15175.9*10)/0.045	D = 10.7 m g-load= 1547 Pressure = 4MPa

Table 7. Battery Mass

Equation	Calculation	Result
$m = \frac{(ab+cd+ef..)W*hr}{400\ W*hr/kg}$	$\frac{((1.501*1hr)+(0.22*1hr)+(3*1hr)+(5*1hr)+(0.4*1hr)+(1.7*1hr)+(0.02*1hr))}{400\ W*hr/kg}$	5 kg

The Bennu is penetrating into the surface of the Moon from the orbiter. In our engineering analysis we calculated our initial conditions, deployment velocity, trajectory, and ending conditions. To calculate the orbital velocity in the x direction, we found the overall orbital velocity of the spacecraft, since we assumed that gravity was the only force acting on the payload, which only acts in the y-direction. As we are deploying downwards, deployment velocity is solely in the y direction. Our initial y-velocity is 0 because we assumed a stable circular orbit, and thus there is no movement in the y-direction. We used the maximum possible barrel length, payload mass, and payload size, then used a spreadsheet to calculate our y-velocity using various helium pressures and chose the one we found most realistic.

To find the final y-velocity, we used the given trajectory equation. The only variable not given was initial velocity, which we calculated in the previous equation. To find our total velocity, we used the Pythagorean Theorem with the side lengths being our x and y velocities. The angle of impact we obtained was below the threshold for penetration if we hit a flat surface, requiring us to hit a crater wall so that our angle to the ground was enough to penetrate. Our final numbers were a penetration depth of 10.7 m, a g-load of 1550, and an angle of attack of 10.2 degrees.

8.0 Final Design

Concept of Operations

Our final design is going to drop off the orbiter with about 70,000 Pascals of helium pressure from a 44 cm barrel provided by UAH. After that, the payload will fall toward the lunar surface at a rate of approximately 1700 m/s and impact a 20-degree crater wall within Shackleton Crater, assuming a 10-degree angle of attack. On impact with lunar ice, the force will be enough to penetrate 10 meters down and free up some ice to go into the back hatch of our payload. Once inside, we will be free to utilize our electrolyzer to test the ice and electrolyze the sample that we collect.

Key Design Features

One of the key design features of Bennu, our selected payload design, is the implementation of the LIBS system. LIBS stands for Laser Induced Breakdown Spectroscopy. This means that the instrument shoots a laser at an sample, and since all elements emit light, it detects the amount of light emission and can identify what elements are present. This system can help us find the right place to deploy from and prevent us from getting lost in an area without lunar ice. Another key feature is the payload housing shape. Our missile shaped design allows us to penetrate deeper into the Moon and have enough force to achieve our science objective. The payload housing is made with A517 steel, which has a yield strength of 690 MPa and is used as a building material for high-pressure vessels. As there are 4 MPa of pressure on our vessel, it is not prone to plastic deformation. Another unique part of our final design is the inclusion of an Electrolyzer. This is to test water/ice on the Moon and carry out our science objective. Our payload weighs 10 kg and meets the weight threshold. It also can withstand the harsh conditions of the Moon. It sends and receives data and is compliant with all requirements set forth by InSPIRESS.

Table 8. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	A517 Steel	3.168
Measure	Batteries	5
Collect Data	Electrolyzer, IMU, LIBS, VIS	1.553
Provide Power	Computer	0.094
Send Data	Antenna,Transceiver	0.185
House/Contain Payload	Barrel, Helium	(Provided by UAH)
Total		10 kg