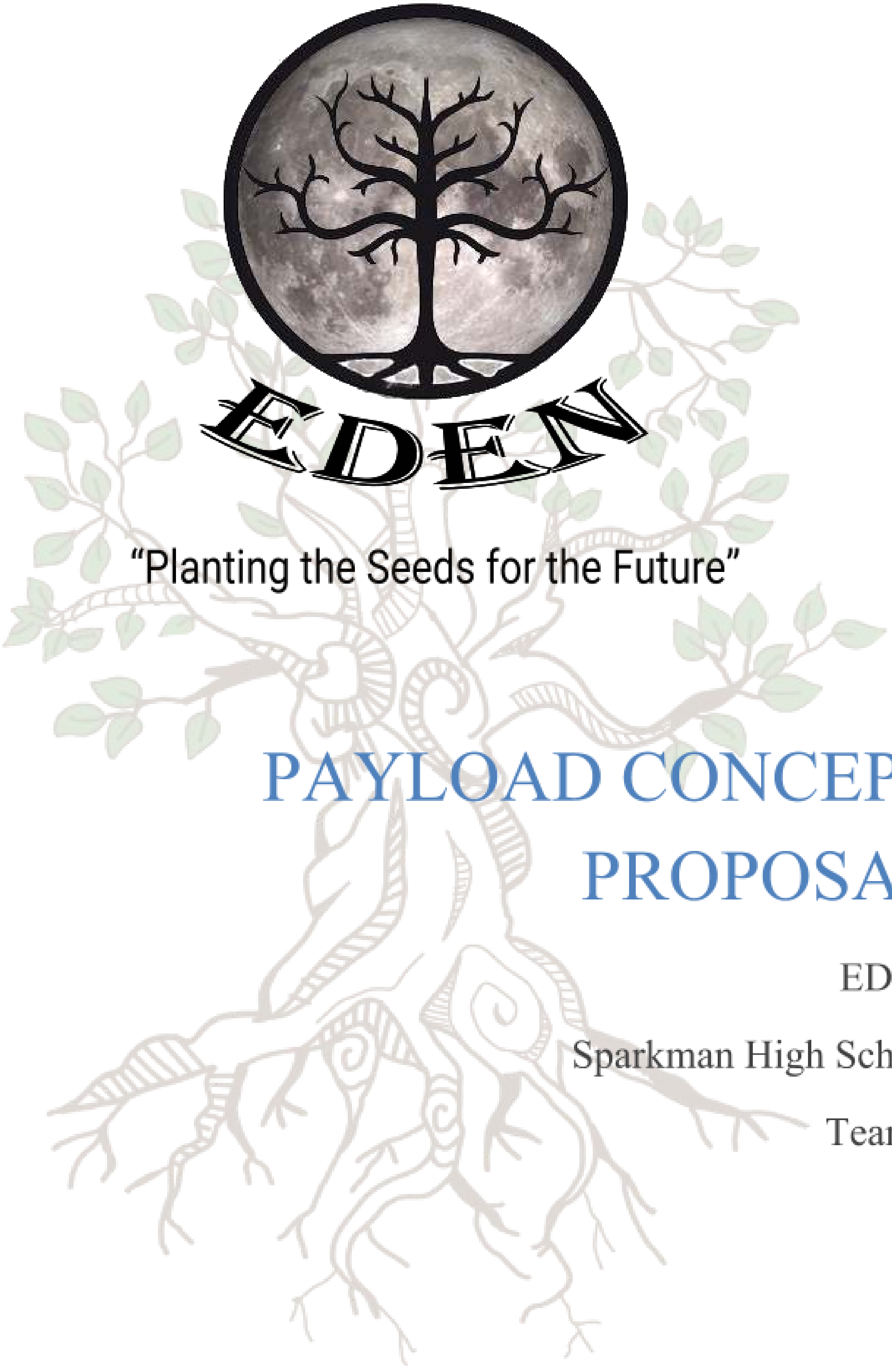


“Planting the Seeds for the Future”

PAYLOAD CONCEPT PROPOSAL

EDEN

Sparkman High School

Team 1

1.0 Introduction

Throughout history, humanity has always yearned for expansion. Against the environment, against the wildlife, against each other, and against the Earth itself, we have trekked onward. Now with our payload, Sprout, we strive to do so beyond the stars. As EDEN(Environmental Development and Extraterrestrial Navigation), we have tasked ourselves with laying the foundation for a future in lunar habitation without a dependence on atmospheric gases from Earth or bulky, unwieldy spacesuits. Our name is a reference to the paradise we hope to have a hand in creating. EDEN was tasked with developing a payload to accompany the LASER mission to the Moon, which focuses on the Shackleton Crater on the South Pole of the Moon. The crater's rim is almost always blanketed in sunlight, while the interior of the crater is shrouded in darkness, a stark contrast to the rest of the Moon's two week cycles of day and night. The created payload, Sprout, the name being a reference to new life, is our companion to the LASER mission, providing soil samples and atmospheric gas tests on the moon. Our slogan, "planting the seeds for the future," directly relates to this, as it is a potential step towards interstellar travel, and may extend the lifetime of manned missions.

2.0 Science Objective and Instrumentation

EDEN was provided with eight weighted Figures of Merit (FOMs) from The University of Alabama in Huntsville (UAH) to determine the viability of EDEN's three potential science objectives: Atmospheric Generation, Subsurface Mapping, and Atmospheric Trend Analysis. The objectives were rated based on importance, either receiving a 1, 3, or 9 in each category. This number system was also applied to FOMs in their weights. After calculations, Atmospheric Generation received the highest score, prompting us to move forward with it as our focus. We felt confident that Atmospheric Generation would be a successful candidate as breathable air has continued to be a major factor in the high weight and space requirements on manned extraterrestrial missions. In order to generate an atmosphere, bacteria would be genetically modified to produce the desired gases. The bacteria's effect would be measured using a gas sensor, oxygen sensor, and pressure transducer, to measure the volumes of gases outputted. Additionally, a thermocouple will measure temperature to see if it affects the amount of gas produced. The Sprout payload would be a vital asset to the extension of mission lifetimes, the expansion of off-world infrastructure into that of a more permanent variety, and drastically decrease the amount of space, money, and equipment necessary to do so.

Table 1. Science Objective Trade Study

Figure of Merit	Weight	Atmospheric Generation		Subsurface Mapping		Atmospheric Trends	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Interest of Team	9	9	81	1	9	1	9
Applicability to other science fields (broadness)	1	9	9	1	1	1	1
Mission Enhancement	1	9	9	1	1	1	1
Measurement Method	9	1	9	9	81	3	27
Understood by the Public	9	3	27	9	81	1	9
Creates excitement in the public ("wow factor")	3	9	27	3	9	1	3
Ramification of the answer	3	9	27	1	3	9	27
Justifiability (nice, neat package), (self-consistent	1	9	9	1	1	3	3
Sum			192		184		80

Table 2. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Atmospheric Generation	Observe bacterial growth of extremophiles	Deposit bacterial samples and measure their growth rate	O_2 Sensor
			Gas Sensor
	Measure gas output and composition	Observe the increase of atmospheric gases	Pressure Transducer

Table 3. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (months)	Frequency (hours)	Duration (minutes)
O_2 Sensor	0.016	0.050	12.5	0.020 x 0.017	6.00	24.00	0.25
Gas Sensor	0.020	0.050	13.7	4.00 x 2.10	6.00	24.00	0.25
Pressure Transducer	0.130	0.040	1.00	2.20 x 8.60	6.00	24.00	0.25
Thermocouple	0.005	Negligible	0.001	20 AWG wire	6.00	6.00	0.25
SUM	0.216	0.175	28.2	33.57 cm^3	6.00	24.00	0.25

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Dimensions	Other Technical Specifications
Electromagnet	0.053	1.00	N/A	18.2 x 25.4mm	Adamsmagnetic.com electromagnetic assemblies
Antenna	0.100	0.020	Up to 3.4 mbps downlink	98 mm	Cubesatshop.com Deployable antenna system
On-Board Computer	0.094	0.400	2 x 2 GB onboard storage	96 x 90 x 12.4 mm	Cubesatshop.com ISIS on board computer, 4 MHz, ARM9 processor
Transmitter/ Receiver	0.1	5	2 Mbps	96 x 90 x 15 mm	CPUT S-Band CubeSat Transmitter
Battery	0.10 kg	400 Whr/kg	N/A	Size Varies	Based on power requirements

3.0 Payload Design Requirements

UAH provided six payload design requirements: deployment from the UAH mission vehicles, taking measurements, collection and relaying of data, and self sufficiency in power and payload housing. The payload itself was also constrained to a maximum of 10 kilograms of mass, maximum volume of 44 cm by 24 cm by 28 cm. The payload could not cause harm to the UAH vehicle and be able to survive the lunar environment. The lunar environment posed a significant challenge with temperature ranging from 396K to 120K and pressure at 2.971x10^{-15} atm. In addition, the extremely thin lunar atmosphere compounds the danger of cosmic rays and solar flares. The remarkably low gravity, harsh radiation, and wide temperature ranges significantly influenced the development of alternative payload concepts. The types of usable materials was drastically decreased and the methods of mission execution were difficult to design around. However, these complexities were addressed and solutions were developed, resulting in our payload alternatives and, finally, our final payload.

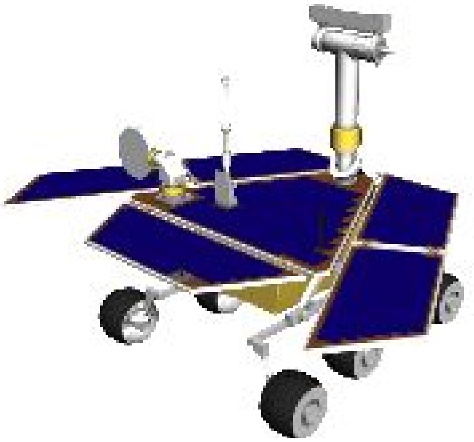
A more unique challenge was on the biological front, an area few other missions confront. EDEN has elected to introduce several constraints to the proposed bacterial component to ensure the protection of the lunar environment: containment of the bacteria, and the post-mission decommissioning of the bacteria in use.

4.0 Payload Alternatives

Upon selecting our objective, EDEN sought to determine the viability of certain bacterial strains for the mission. The prevention of biological contamination was given the utmost importance, and high tractability and competency for genetic transformation were the highest- valued traits, along with virility in extreme conditions. EDEN moved forward with the species *Deinococcus radiodurans* and the genus Carnobacteria for study before selecting the former. *D. radiodurans* was selected for its high resistance to radiation, self-reviving capability, and competency for genetic transformation.

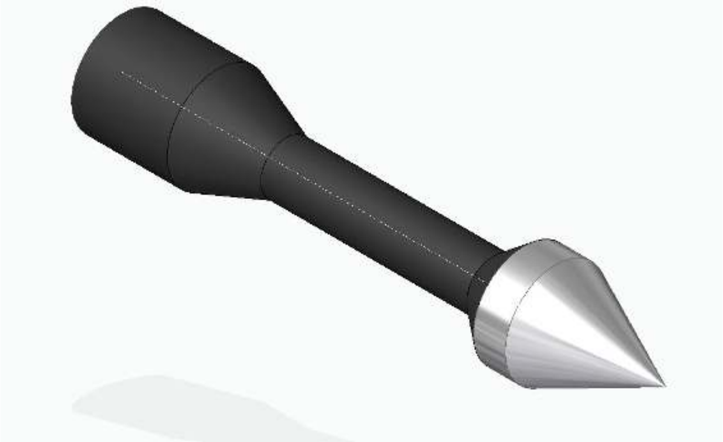
EDEN then divided into two design teams to develop mission payload designs. The first of the teams designed the Hermes Rover, which featured movement independent from the LASER vehicle. Deployed from the UAH lander, it would have collected soil samples, housed on board for a safer environment for the bacteria. It would also aid the LASER mission by recording additional navigational data.

Figure 1. Hermes rover



The second team developed the Orbital Gas Released Excavator (OGRE) payload, a probe deployed from the LASER orbiter, similar in concept to the Japanese Lunar-A. Its propulsion would be derived from the orbiter's on-board helium reserves. The payload would launch from the orbiter and bury itself into the moon's crust, insulating and protecting OGRE from radiation. Following soil sample collection, the pod would close via an integrated motor system, sealing the contents inside. The pod would then release the bacteria onto the collected soil, once all security parameters are met. The remaining wattage would be solely dedicated to its set of scientific instruments, allowing for a larger data set.

Figure 2. OGRE Probe



The ideas and advantages of the two aforementioned concepts were taken into consideration when we designed our third concept — Sprout. This payload design combined the best features of the preceding payloads and developed them further. The pre-impact velocity would be far less than that of the OGRE, maintaining a higher degree of safety, while still penetrating the lunar surface. The separation of samples necessitated multiple sensor units, which provides a redundancy that would insulate the mission from failure in the event of instrument malfunction. The pods would follow the general OGRE mission- bury themselves into the lunar surface, collect and isolate soil, and release the bacteria onto the samples. However, the pod would close using a combination of magnets and springs, creating a stronger seal. Another key difference between the concepts is the housing apparatus — whereas the OGRE is housed on the LASER orbiter, the Sprout payload is housed on the LASER rover, from which it releases its pods.

Figure 3. Sprout Launcher

5.0 Decision Analysis

To determine which payload should be selected, UAH provided 7 FOMs to measure the payloads against. EDEN created 3 additional FOMs, sample variety, redundancy, and environmental protection. Environmental protection was specifically chosen by EDEN to emphasize our preparation and concern for potential biological contamination. Sample variety allows for comparison between soils in different areas to determine its effect, and redundancy ensures that the mission does not immediately fail in the unlikely event of an equipment malfunction. The FOMs were weighted by EDEN similarly to the Science Traceability Matrix: weights of 9 were considered the most important, followed in importance by 3, and 1. The team came together, assigned raw scores for each FOM, and calculated the final weighted scores. These weighted scores were added together, with the Hermes concept receiving a sum of 204, OGRE with 148, and Sprout with 246. Table 5 reflects this process, and highlights the design process EDEN underwent, with Sprout achieving the highest scores in eight out of the ten FOMs.

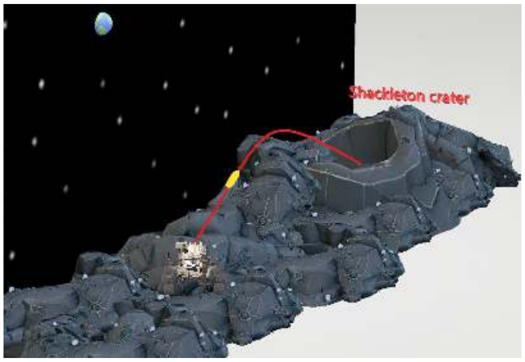
Table 5. Payload Decision Analysis

Figure of Merit	Weight	Hermes		OGRE		Sprout	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score
Science Objective	1	3	3	3	3	9	9
Likelihood Project Requirement	3	1	3	9	27	9	27
Science Mass Ratio	3	1	3	9	27	9	27
Design Complexity	9	1	9	3	27	3	27
ConOps Complexity	1	9	9	1	1	3	3
Likelihood Mission Success	9	9	81	1	9	3	27
Manufacturability	3	1	3	3	9	3	9
Sample Variety	3	3	9	1	3	3	9
Redundancy	3	1	3	3	9	9	27
Environmental Protection	9	9	81	1	9	9	81
SUM			204		124		246

6.0 Payload Concept of Operations

The Sprout mission begins on the LASER rover, where its pods remain open with the use of electromagnets, powered by the LASER vehicle. At a distance of 10.5 km from the rim of the Shackleton Crater, the Sprout launcher will fire a probe on to the rim, utilizing the helium reserves of the LASER vehicle. Upon reaching the crater, Sprout will fire three additional probes, at distances of 2.5 km, 5 km, and 10.5 km. From launch, the Sprout battery will power the electromagnets. Upon surface impact, the pod will collect soil in its first airlock, burying itself 0.29 meters into the lunar crust. Once 6 minutes have elapsed from deployment, the electromagnets will disengage, triggering the springs and magnets to close the airlock, creating an airtight seal. Following the seal, the bacteria and limited resources will be released onto the collected soil. The onboard gas sensor, oxygen sensor, and pressure transducer will activate for fifteen seconds daily to take measurements for a period of six months. Upon the conclusion of the mission, the bacteria will enter dormancy and eventual death due to starvation, facilitated by genetic termination failsafes.

Figure 4. Sprout Concept of Operations



7.0 Engineering Analysis

To ensure that the mission would be completed as described, EDEN made several calculations to verify that the payload complies with the UAH requirements, deploys out of the barrel, travels the desired distance, survives impact, and has enough battery life to power its instruments.

Table 6. Engineering Analysis Calculations

	Assumptions	Equation	Solution
Initial Conditions	Rover stationary when firing, payload secure, constant inclination angle when flying	$SA = 2\pi r^2 + 2\pi rh$ $V = SA \times d$ $m_{frame} = D \times V$ $m = m_{cannon} + m_{pod}$	SA = 1883.95 cm^2 V = 3767.91cm^3 m_{frame} = 1.098 kg m = 9.98 kg
Deployment	Pod fits perfectly into barrel, pressure is constant, constant angle of inclination	$A = \pi r^2$ $a = PA/m$ $v_f^2 = v_i^2 + 2ad$	A=0.0855m^2 $v_{exit\ max}$ = 130.4 m/s, 90.0 m/s, 63.6 m/s P_{max}= 64.8 kPa, 30.9 kPa, 15.4 kPa
Trajectory	No air friction, horizontal velocity is constant	$s = v_i^2 sin(2\theta)/g$ $t = v_i sin\theta/g$ $TOF = 2t$	t_{flight} = 114s, 78.6s, 55.5s x=10.5km, 5.00km, 2.50km
Ending Conditions	Constant gravity, appropriate ground conditions, oriented correctly, pod contact	$v_f^2 = v_i^2 + 2ad$ $A = \pi r^2$ $D = 1.8 \times 10^{-5} \times S \times N \times (m/A)$ $(v_i - 30.5)$ $a = v_i^2/2D$ $g - load = a/g$ $F = ma$	V_f = 152.7m/s A = 1.13 x 10-2 m^2 D = 0.29m $F_{impact\ max}$ = 1.3 x 10^4 N G-$load_{max}$ = 795.1 V_{final} = 0 m/s
Battery Mass	Thermocouple power negligible	$Whr * t = W$ $400 Whr/kg / W = Mbattery$	W_{pod} = 52.8 W $M_{battery}$ = 0.336 kg

8.0 Final Design

EDEN's final payload, Sprout, combines the most successful attributes of its two predecessors, while also adhering to the constraints presented by UAH. The pre-impact velocity was decreased by firing the pods from the rover, while the potential for mission failure was mitigated by firing multiple probes away from the main payload. With a total mass of 9.980 kg and a design created so as to pose no threat to the LASER mission or vehicle, EDEN has developed a mission that completely follows the guidelines set forth. We are aware that our science objective involves bringing biological material into contact with the moon, and have taken the risks and benefits into account. We believe our failsafes are more than sufficient to provide a safe and successful basis for new research, and that the definite benefits far outweigh the potential detriments.

Figure 3. EDEN's Mission

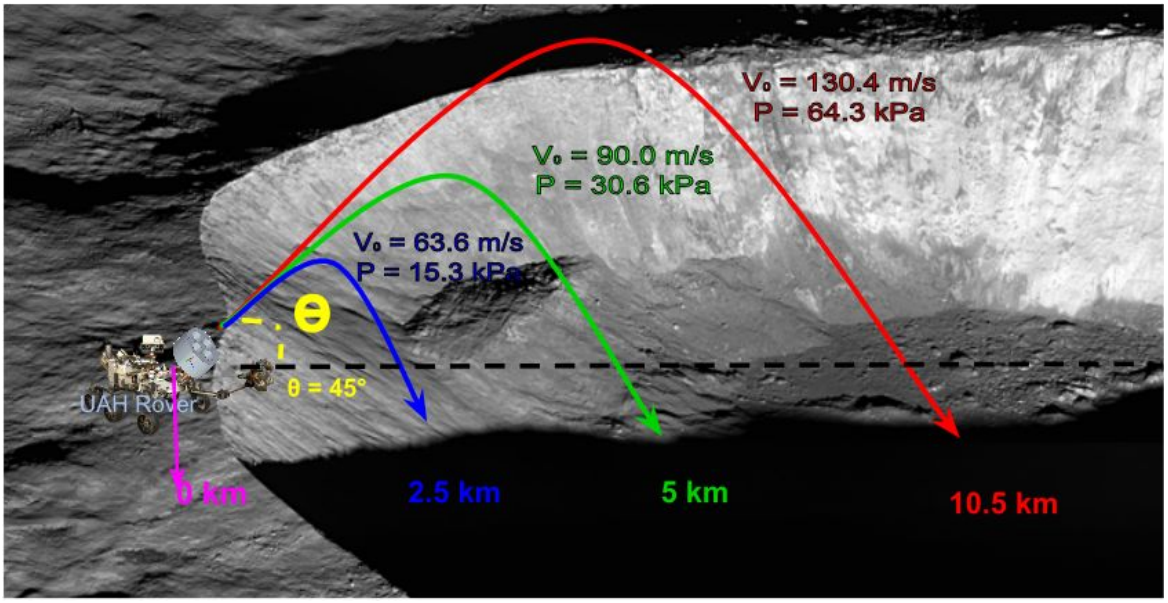


Table 6. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Cannon	3.200
Measure	Pressure Transducer	0.130
Measure	O_2 Sensor	0.016
Measure	Gas Sensor	0.013
Collect Data	Computer	
Provide Power	Battery	0.084
Send Data	Antenna/Transmitter	0.200
House/Contain Payload	Carbon Fiber Frame	1.098
House/Contain Payload	Electromagnet	0.053
Mass per Probe		1.695
Total Mass of Payload		9.980