NASA L'SPACE TEAM 4 SPRING 2020

Preliminary Design Review

Yielding Evidence of Topographic Ice (YETI)

5/17/2020

Project Managers

Daniel Borden
Samuel Lemma

Table of Contents

1. Introduction and Summary 4
1.1. Team Introduction 4
1.2 Mission Overview 3
1.2.1 Mission Statement 4
1.2.2 Mission Requirements 4
1.2.3 Mission Success Critica 4
1.2.4 Concept of Operations 5
1.2.5 Major Milestones Schedule 5
1.3 Descent and Lander Summary 5
1. 4 Payload and Science Summary 8

2. Evolution of Project 9
2.1 Evolution of Decent and Lander 9
2.2 Evolution of Payload 10
2.3 Evolution of Experiment Implementation Plan 11

3. Descent and Lander Design **Error! Bookmark not defined.**
3.1.1 System Overview 11
3.1.2 System Overview 12
3.1.3 Dimensioned CAD Drawing of Entire Assembly 16
3.1.4 Manufacturing & Testing Plan 18
3.1.6 Validation and Verification Plans 20
Lander Engines 20
TEGA 21
Robotic Arm 21
3.1.7 FMEA and Risk Mitigation 22
3.1.8 Performance Characteristics and Predictions 22
3.2 Confidence and Maturity of Design 23
3.3 Recovery and Redundancy System 24

4. Payload Design & Science Experiments 25
4.1.1. System Overview 25
4.1.2. Subsystem Overview 30
Communications and Data Management 27
Science Instrumentation 27
Navigation 28
4.1.3. Precision of Instrumentation, Repeatability of Measurement, and Recovery System 28
4.1.4. Validation and Verification Plan 30
4.1.5 FMEA and Risk Mitigation 30

4.1.6. Performance Characteristics 32
4.2.1 Science Payload Objectives 33
4.2.3 Payload Success Criteria 34
4.2.5 Describe Testing and Measurements 35
4.2.6 Show Expected Data 38

5. Safety 39
5.1. Personnel Safety 39
5.1.1. Safety Officer 39
5.1.2. List of Personnel Hazards 39
5.1.3. Hazard Mitigation 39
5.2. Lander/Payload Safety 40
5.2.1 Environmental Hazards 40
5.2.2 Hazard Mitigation 40

6. Activity Plan **41**
6.1 Budget 41
6.2 Schedule 42
6.3 Outreach Summary 42
6.4 Program Management Approach 43

7. Conclusion 43**3**

1. Introduction and Summary

1.1. Team Introduction

Project Manager	Daniel Borden

Deputy Project Manager	Samuel Lemma

Chief Financial Officer	Anaily Lorenzo

Safety Officer	John Gambino

Mechanical Design & Validation		**Power Systems & Instrumentation**	
Lead Engineer	Will Harvey	Lead Engineer	Tom S.
Sam Lemma		Benjamin Chevrette	
Daniel Borden		Nick Hurley	
Shawn Cimonetti		Eileen Ong	

Planetary Science	
Lead Scientist	Juan Cabrera
Asma Ali	
Anaily Lorenzo	
Daniel Borden	

1.2. Mission Overview

1.2.1. Mission Statement

L'Space team four's mission is to successfully land on the lunar surface and by using simple robotic technology a heating element and gas chromatography, verify that ice deposits exist in places where water ice signatures have been detected by previous missions.

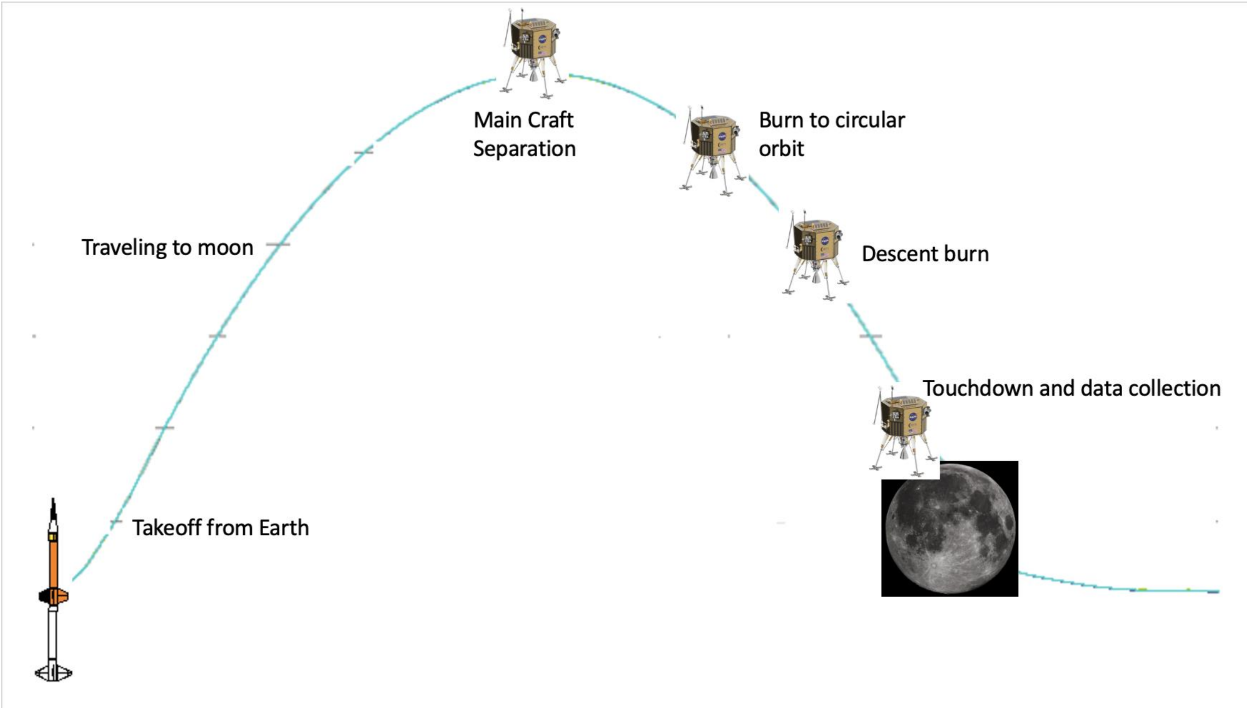
1.2.2. Mission Requirements

- ❏ Must be able to land upright on the lunar surface.
- ❏ Must be able to land in the target area with possible ice.
- ❏ Must be able to extend a robotic arm to the surface to collect surface material.
- ❏ Be able to collect multiple samples of the surrounding area.
- ❏ Must be able heat ice to a liquid to then feed into the science analysis system.
- ❏ Must be able to transmit science data back to earth for analysis.
- ❏ Must be able to power lander for the duration of multiple sample analyses.

1.2.3. Mission Success Criteria

The mission will be considered successful if the YETI lander successfully transmits data from one vaporized sample from the TEGA instrument.

1.2.4. Concept of Operations (Graphic)



1.2.5. Major Milestones Schedule

YETI Major Milestones		
Mission	Start Date	End Date
Begin Research	9/1/2019	Until launch
Critical Design Review	12/1/2019	3/1/2020
Preliminary Design Review	3/2/2020	9/2/2020
Critical Design Review	9/3/2020	3/3/2021
Begin Build	3/4/2021	3/4/2022
Subsystem Testing	3/5/2022	3/5/2023
Full System Testing	3/5/2023	3/5/2024
Launch		10/5/2024

1.3 Descent and Lander Summary

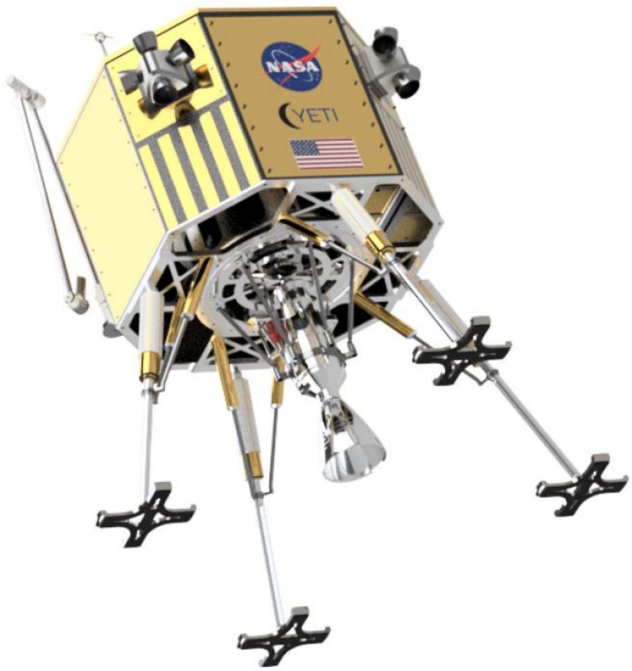


Figure 1. Lander Design

The lander releases from the main ship and will conduct a series of three burns to align the orbit with the target landing zone, reduce orbital height from the surface, and achieve a safe descent. The RCS thrusters module will maintain course and proper alignment determined by the flight computer during the lunar transit using a suite of sensors. Once the lander is 100 meters above the lunar surface. The final burn will be used to achieve the predicted landing velocity of 1.7 m/s.

A single RC-107s hydrazine engine from Aerojet Rocketdyne was selected as the main engine. The MRM-122 rocket engine module will be used for the RCS thrusters. The combination is a fuel efficient system allowing the overall lander to be lighter. The full size of the lander is 0.475 m x 0.475 m x 0.497 m. The mass of the lander is as follows.

Subsystem	**Mass (kg)**
Payload/Instruments	3.00
Structural Mass	2.75
Fuel	4.15
Total Mass	9.90

Table 1. Lander Mass Distribution

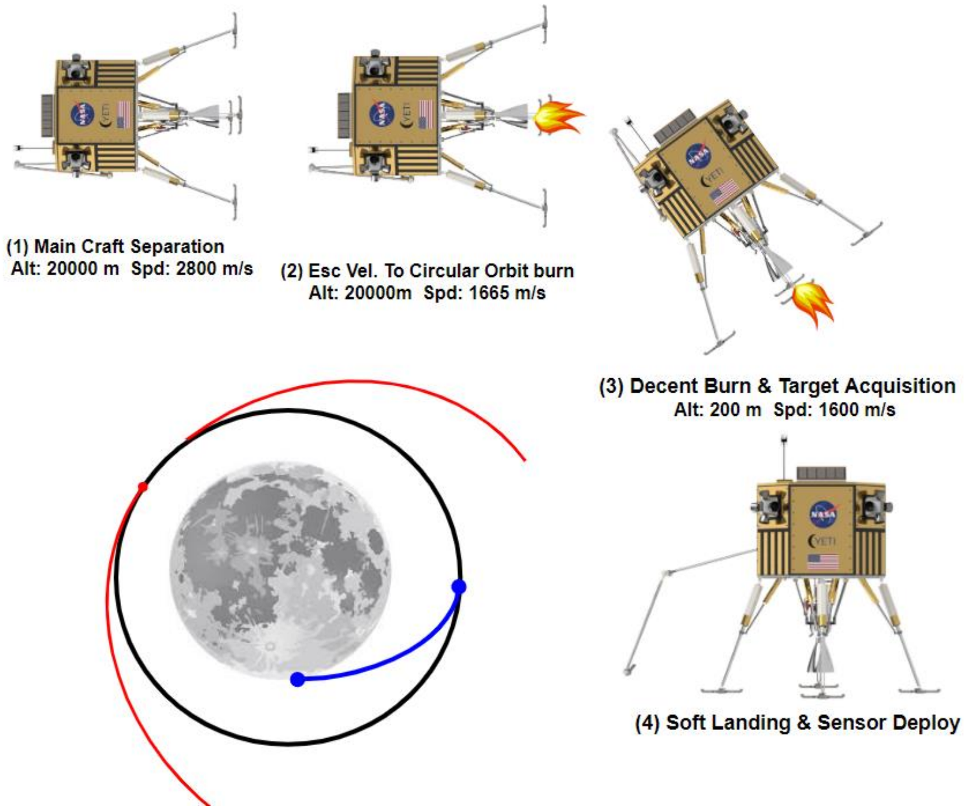


Figure 2. Lunar Transit EDL

1. 4 Payload and Science Summary

The science instrument of the YETI lander will be modelled after the TEGA instrument from the Martian Phoenix mission[1]. The instrument will take lunar regolith samples collected by a robotic arm, and analyze them via scanning calorimetry and mass spectroscopy. The instrument has two one-time use ovens and thus will analyze two lunar samples.Due to the lighting conditions in lunar craters, the lander will utilize stored energy from a lithium-ion battery. All data handling will be performed by a radiation-hardened CPU and delivered to the nearby base-station via a transceiver and low-gain antenna. The lander will navigate to its destination vis-a-vis an inertial mass unit and radio antenna tracking.

[1] http://phoenix.lpl.arizona.edu/science_tega.php

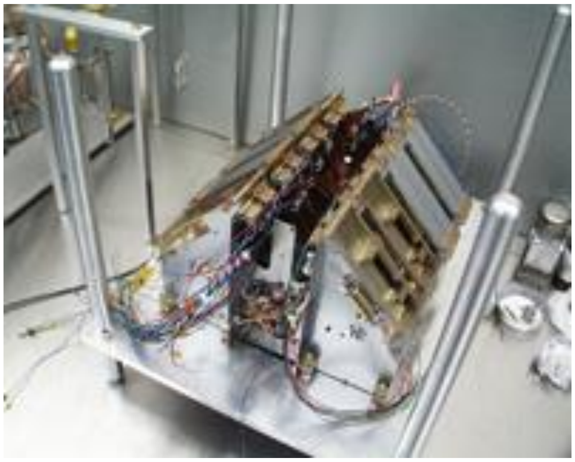


Figure 3. TEGA Instrument

Instrument	Model	Cost	Mass	Volume
Battery[2]	BPS2S4P	$17,300	500g	9.3 x 8.6 x 4.1cm
TEGA[3]	TEGA	$13,140,163	1.425 kg	6 x 5.75 x 4.5 cm
IMU[4]	OEM-STIM300	$20,000	55g	3.9 x 4.5 x 2.2cm
CPU	Rad 750	$200k	549g	10 x 16 x ~1 cm
Total:		$13,377,463	2.529kg	681.778cm^3

2. Evolution of Project

As with any complicated systems engineering process, many compromises needed to be made in order to prioritize the mission objective. The YETI lander evolved as quotes were received and CAD was created and validated, and the final iteration of the lander is much leaner and simpler than was originally conceptualized.

2.1 Evolution of Decent and Lander

From the beginning, the concept of a rover capable of transiting the lunar terrain was explored. While the prospect of gathering samples from various geographical locations yielded surveying information, research into lander and rover design led otherwise. The

[2] https://gomspace.com/shop/subsystems/power/nanopower-bpx.aspx
[3] http://anserver1.eprsl.wustl.edu/phx/solbrowser/documentation/missionDocs/t_tega/inst.cat
[4] https://hexagondownloads.blob.core.windows.net/public/Novatel/assets/Documents/Papers/OEM-STIM300-PS/OEM-STIM300-PS.pdf

basic propulsion needed to decelerate and land a 10kg payload was determined too much to allow for a complex rover with stored energy for transiting the surface. Other evolutionary milestones included the transition from three landing legs to four landing legs, after tipping points were calculated. The internal structure of the lander was originally designed and FEA tested for carrying more instrumentation. However, a lack of affordable instrumentation and mass restrictions led to a lightweight robotic arm in lieu of a 4 DOF articulating arm. The scientific priority of finding water was always placed first and the payload was adapted to become more realistic, lean and reliable instead of attempting to complete multiple mission objectives at once.

2.2 Evolution of Payload

Throughout the design process, YETI underwent several design changes most notably involving the selection of instrumentation. The lander design was chosen early on in the selection process. A rover was first considered as it would allow the team to take multiple measurements at different areas around the landing zone. After discussions, it was decided that this option would not be feasible as the space needed for wheels/motors and the power required to drive the rover would mean a very short mission duration unless there was onboard power generation. Both solar panels and RTG (Radioisotope Thermoelectric Generator) were also considered but found to be too large.

Initially the team considered using LIDAR to steer the lander in its descent. This combined with detailed mapping of the lunar surface, already available, would have meant an accurate way for our lander to find its way to the designated landing zone. As more research was done it was realised that this would not work for our lander as the mass and cost constraints did not allow for such flexibility. This brought us to deciding to use a camera instead. By imaging the lunar surface during descent, YETI would be able to compare those images against known images and pinpoint its location. But similar to the LIDAR option, this proved too massive and voluminous. The final decision was then to use a highly accurate IMU and use a predetermined entry track down to the surface. This allows less flexibility for real time correction but it allowed us to meet the sizer and cost constraints.

There were several design considerations before the TEGA was decided on as our water verification instrument. The main contender was the TECP (thermal electrical conductivity probe) which also flew on the Phoenix lander. This was initially more attractive than the TEGA as it was simpler and smaller but we were unable to find enough information on it (namely cost and volume). This led us to the final decision of using a scaled down version of the TEGA instrument, compromising the number of trials we could run but meeting the mass and volume constraints.

2.3 Evolution of Experiment Implementation Plan

From initial research and discussion with the YETI planetary science teams, it was determined that designing a lander to help characterize the composition of the lunar surface, in the hopes that there would be water or ice, would be the most beneficial to current human exploration. From this decision, the planetary science team was able to dive into researching the optimal landing zone for the lander, in order to maximize the chances of discovering water on the lunar surface. The final selection for the landing site of the YETI is a crater in the lunar south pole, Cabeus A. From previous data of the Cassini mission and LCross, this site is on a perpetually dark side of the moon and therefore more likely to contain ice on the surface. If the lander does detect water on the surface, the main objectives are to determine the purity of the lunar water, and the main contaminants.

3. Descent and Lander Design

3.1.1 System Overview

Figure 4. Lander Design

The navigation and control package is responsible for the successful landing of the mission at the preselected landing site. Once the lander is released from the mothercraft the flight computer will make inertial measurements using a suite of gyroscopes and accelerometers. Data will be cross referenced with RF signal data from the mothercraft which will give information on the crafts speed and distance. During the two orbital burns, RCS thrusters will be used to keep the attitude of the spacecraft fixed in the optimal thrust vector.

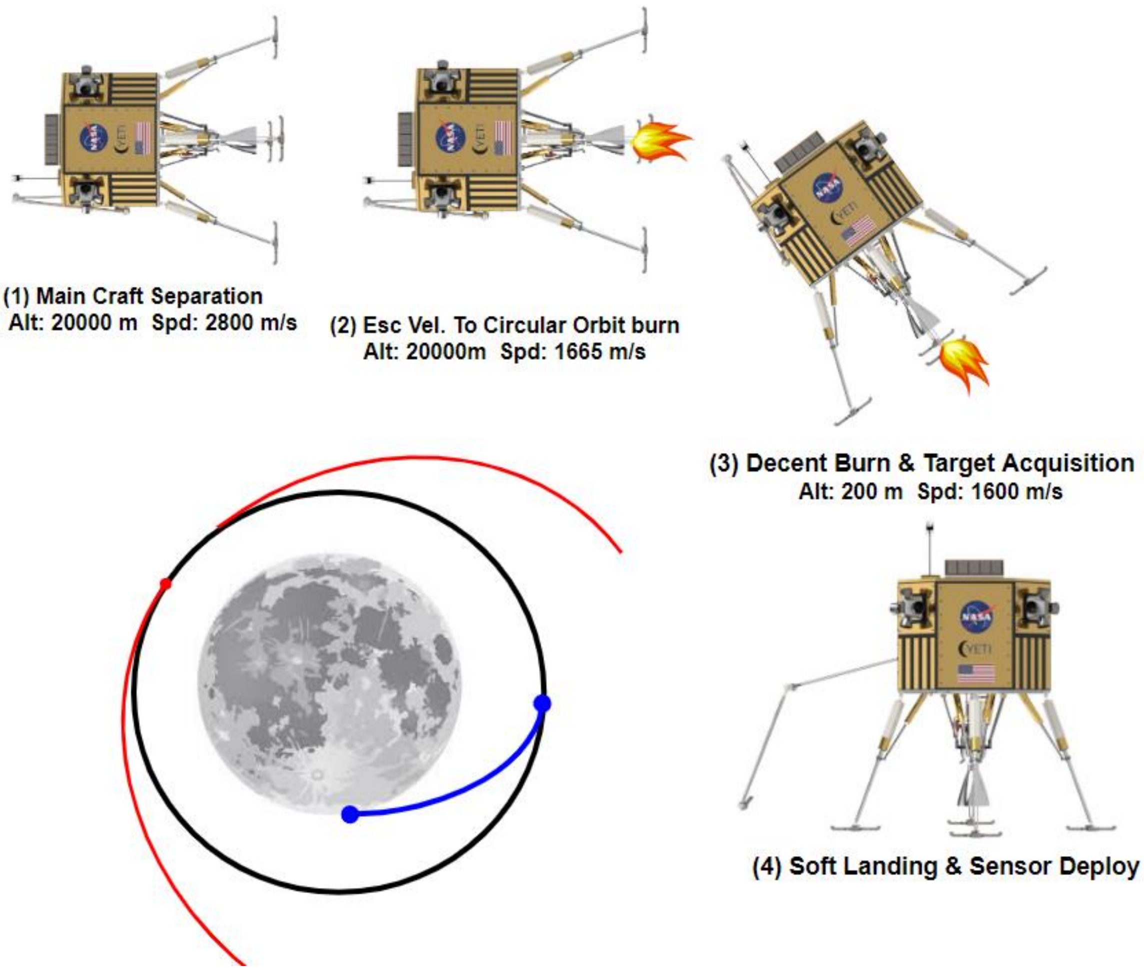


Figure 5. Lunar Transit EDL

Once the lander is on final approach in the descent & target acquisition phase, a wide angle complementary Metal Oxide SemiConductor camera will be used to analyze the lunar surface. Judgments will be made from the flight computer to find the most suitable landing zone within the target crater and flight adjustments will be made to achieve the optimal landing site.

3.1.2 System Overview

Figure 6. Full Propulsion Sub Assembly CAD

The propulsion assembly consists of several steel struts giving the general structure for the fuel tanks. The main engine holds in place my struts and it is also bolted to the main interface plate. The main combustion chamber and control valves are located below the interface plate. The propulsion tanks are made from a carbon fiber graphite composite which will be able to handle the high tank pressures needed to increase the total mass of fuel onboard. The composite also has an extremely low thermic response, which will ensure the tanks don't expand under thermal loading.

The lander release from the main ship was calculated to be in a hyperbolic escape orbit. Upon release of the lander, the lander will start its first burn to maintain a circular orbit around the moon at the same altitude as its release. Inertial tracking will be done with a forward integration method with measurements made from the onboard sensor package including accelerometers, gyroscopes, and a ground radar. Once the lander's flight path is aligned laterally with the landing site on the south pole, a second burn will place the spacecraft on an elliptical orbit where the minor radius (apalapse) of the orbit is 100 meters above the lunar surface. The final burn will be used to eliminate the horizontal velocity of the craft starting the final descent. The predicted landing velocity will be about 1.7 m/s.

A single MR-107S hydrazine engine from Aerojet Rocketdyne was selected as the main engine for its highly efficient light weight design. The MRM-122 rocket engine module will be used for the RCS thrusters, which has a high level of thrust controllability and force for accurate control which will lead to fuel savings. The entire propulsion subsystem measures .45 m in height and has max diameter of .152 m leaving adequate room for the rest of the onboard sensors and the robotic arm.

Figure 7. MR-107S Engine(left) MRM-122 Engine Module (right)

Figure 8. Internal Structure CAD

The inner structure has several mass cuts and has mounting points for different decks for mounting electronics and the internal power plant.The propulsion assembly is bolted to the main structure at the top plate and the base plate providing a secure hold. The internal structure composed of Al will be manufactured out of one solid block. This will minimize the induced internal structural stress from thermal expansion during the thermal profile the structure will face over the entire flight envelope. Al provides a better weight to strength ratio, so it was preferred over steel. In areas where extra strength was needed, titanium was used. Titanium was used in the landing gear and in the base plate that connects to the landing gear where most of the landing shock will be concentrated. To reduce weight and maintain stiffness. The base plate of the structure is using an aluminum sandwich design, where the internal structure is honeycombed. This is important because the plate acts as an interface between the landing gear and the rest of the structure and this design allows for better shock absorption and dissipation. The mass was roughly reduced by roughly 80%.

Figure 9. Aluminum Honeycomb Base Plate

To further reduce the shock from landing, the landing gear will have shock absorbers in all four landing legs. Since the use of hydraulic fluid or springs are impractical under extreme temperatures, aluminum foam will be used. The general structure is a crushable honeycomb that compresses longitudinally and absorbs the impact forces. This allows for the landing gear to reduce in length, which reduces mass and launch costs.

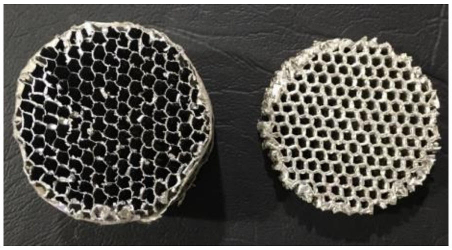


Figure 10. Aluminum Absorption Foam

At the base of each landing leg, the landing pads are allowed to pivot along a point joint, this will allow the landing legs to adjust and provide more survivability at larger landing angles to prevent tipping.

Figure 11. Landing Leg

As the YETI mission will explore into the exosphere, intense solar radiation will be contacting the payload during both the orbital transit and it's brief operation on the moon. To combat this ultraviolet and infrared radiation, MLI multi layer mylar insulation will be used to line an external carbon fiber payload fairing. This specific Mylar is mission proven on previous lunar missions[5] and will cover a carbon fiber fairing. The carbon fiber fairing is constructed to shield the vital internal components from radiation.

[5] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19990047691.pdf

3.1.3 Dimensioned CAD Drawing of Entire Assembly

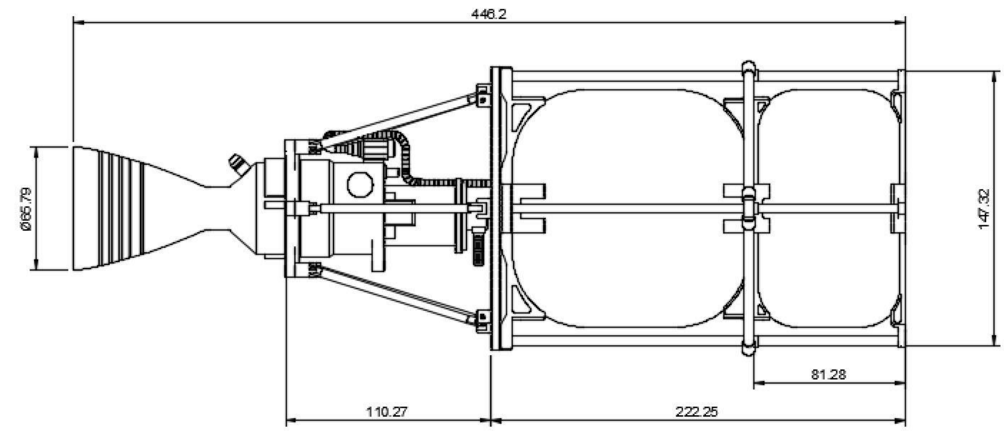


Figure 12. MR-107SEngine Assembly

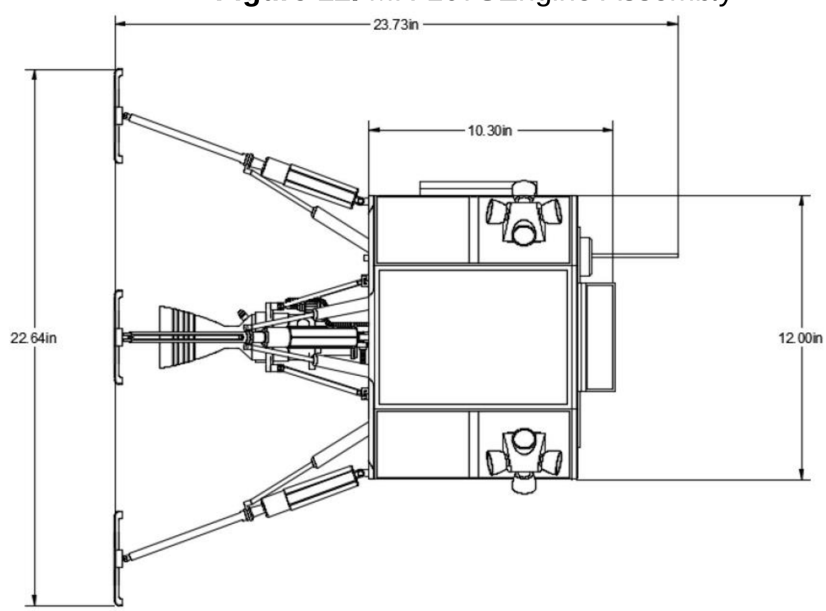


Figure 13. YETI Lander

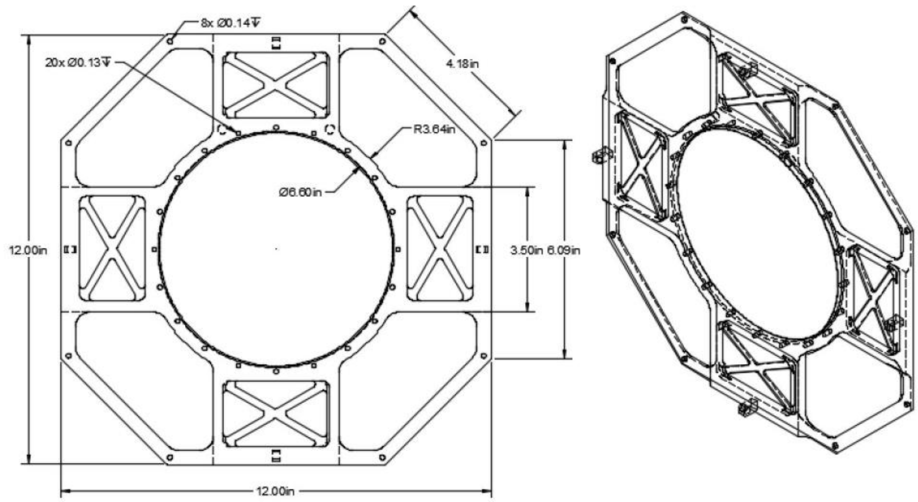


Figure 14. Structural Base Plate

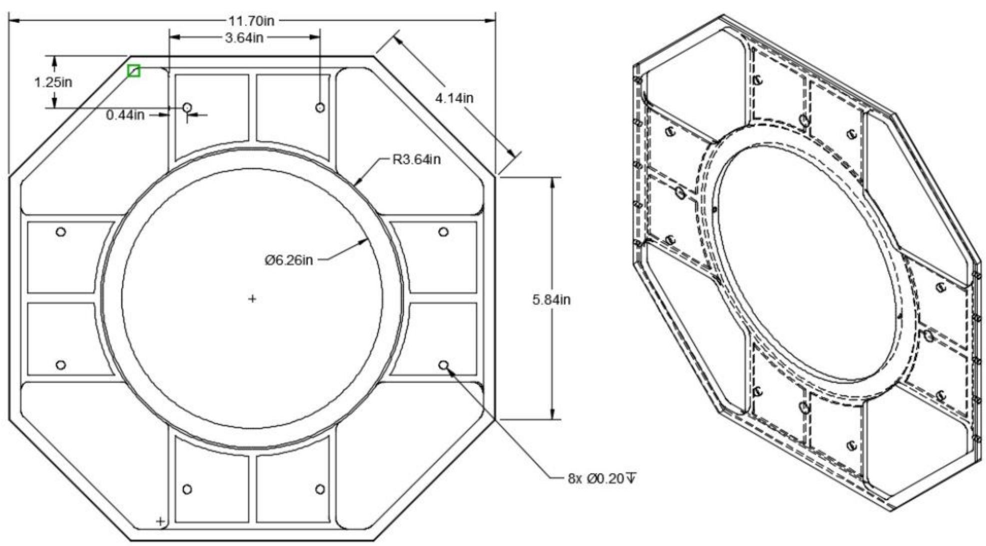


Figure 15. Internal Payload Plate

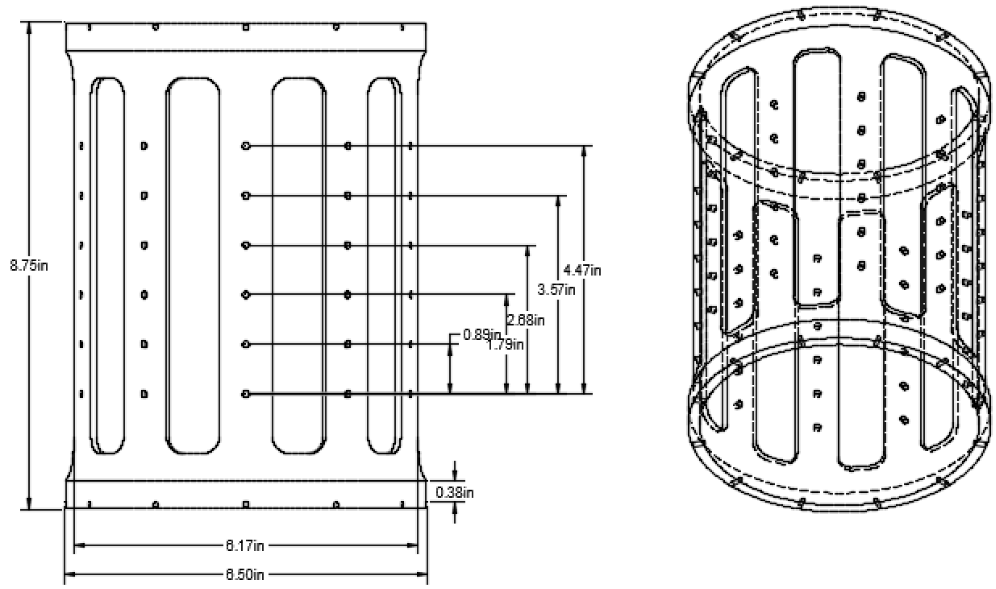


Figure 16. Inner core propulsion housing

3.1.4 Manufacturing & Testing Plan

The internal structure composed of Al will be manufactured by a large 3 Axis CNC. This will minimize the induced internal structural stress from thermal expansion during the thermal profile the structure will face over the entire flight envelope. Al provides a better weight to strength ratio, so it was preferred over aluminum.

The team will initially utilize heavily Finite Element Analysis to predict the structural performance of the lander in a variety of loading conditions. These would be the modal response of the structure to random vibrations that can be experienced in the launch vehicle. Thermic cycling will be another large portion of testing, ensuring that the induced stresses are within a reasonable safety factor. Impact testing would be the last.

FEA Tests			
Vibration	**Heat Transfer**	**Dynamic Loading**	**Topology Optimization**
Modal Analysis - Find the frequencies (natural frequencies) in which structure will violently vibrate anc cause large deformations.	**Launch -** Temperature drop from sea level temp to space conditions (will cause compression). HT: conduction/convection	**Impact Load-** Stress induced from the impact on the lunar surface.Will have to determine the impact velocity using orbital mechanics and fuel	**Use Generative Design & Topology Optimization** to create a mass efficient design for 3-axis machining or

		burn.	5 axis milling.
Random Vibration Analysis - Apply random vibration and specific vibration payload vibration from launch. **Acoustic Testing Waves** - Sound wave induced stress with acoustic modeling.	**Orbit/Moon -** Extreme fluctuations will cause constant heat induced stress. HT: Radiation	**Full Thrust -** Stress on structure during full thrust produced. **Launch** - Stress due to the launch acceleration 3-5 G's.	[redacted]

Table 3. FEA Loading Cases

Once these tests are done, empirical validation would be needed. Vacuum tests, thermal cycling, vibration, and drop tests will all have to be done. The electronics on the navigation package will also have to be radiation hardened and ensure they will survive for the duration of the mission.

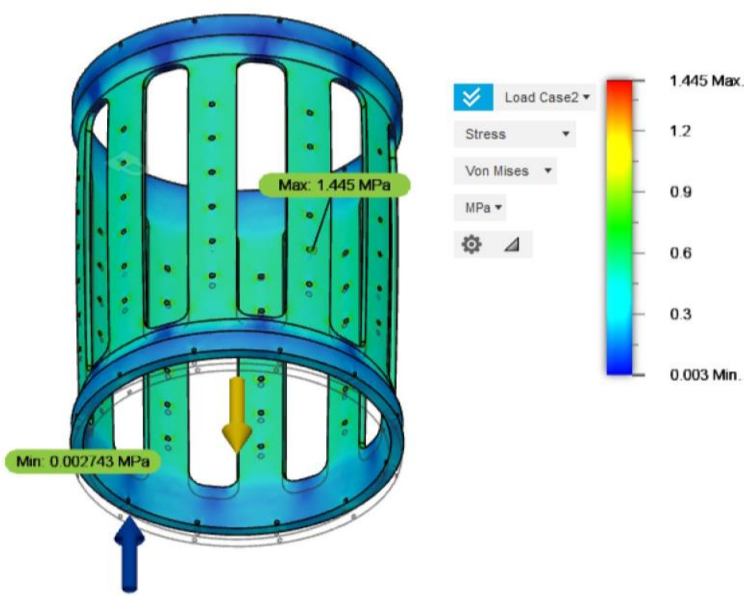


Figure 17. Inner Core Under Landing Load

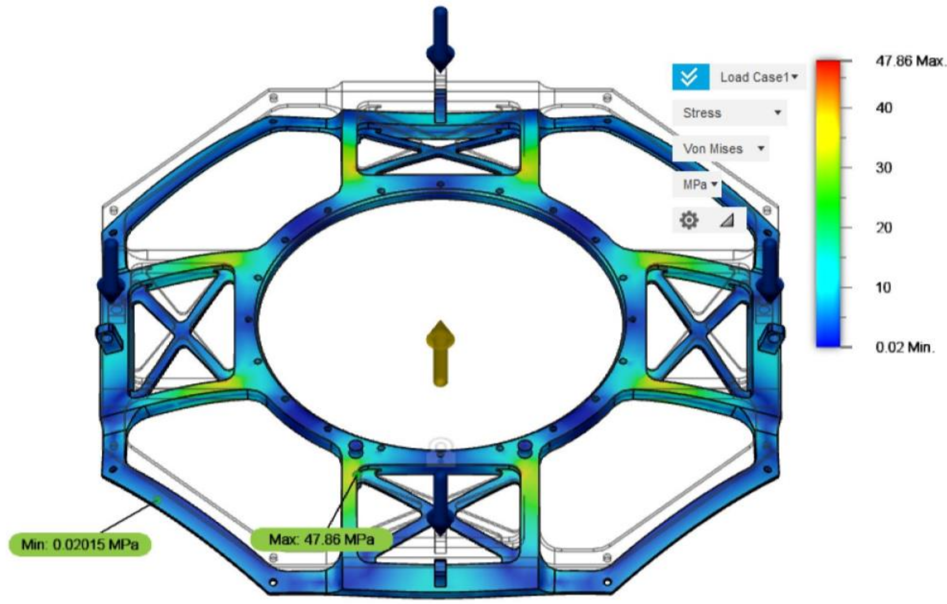


Figure 18. Base Plate Under Landing Load

3.1.6 Validation and Verification Plans

The lander will undergo significant testing validation and verification to ensure that each component is working as needed. The main components in this design are the TEGA, robotic arm, and the MR-107S engines. In order to verify that each component is working as specified, individual, on earth tests will be performed.

Lander Engines

The MR-107S rocket engines are a key component to this mission's success. There are a series of tests that the rocket engines will undergo, the ignition system test, turbomachinery test, and transient tests will be discussed (note that there are hundreds of actual tests done to verify rocket engines). The ignition system confirms that sufficient energy will be produced in order to ignite all the combustion devices, in both normal conditions and worst case scenarios. The worst case scenario involves poor mixing ratio, a lower pressure environment (testing in a vacuum will occur to mitigate this concern), and leaking in the fuel cells. The YETI lander engines will undergo a series of burns, given both worst case, and normal conditions, verifying that all hardware, electrical systems, mixing ratios, each yield an adequate flame, that provides enough thrust for the lander's flight pattern. The turbomachinery tests focus on the overall performance of the engines. This test is a single burn the duration of what the YETI will actually need to complete its flight pattern. This test will verify that all turbines, and pumps are working properly for flight. Finally, the transient engine tests will be performed. The transient tests are done in order to examine hardware durability and more importantly, how each subsystem works with each other. Many hot fire tests are done to test flow interactions, thermal conditions, valve timing, propellant slosh, and shutdown control and procedures. These tests will provide significant verification in all subsystems within the engine working properly.

TEGA

The TEGA or Thermal and Evolved Gas Analyzer is the main instrument for the YETI lander analysis of the lunar surface. This instrument will take samples collected from the robotic arm and vaporize them, providing calorimetric data to determine the chemical makeup of the samples. Just like the engines, the TEGA is a critical component to the mission's success, so it will undergo significant on earth testing. Isolated oven tests will be done to first calibrate and ensure they are working to a sufficient level. Isolated vacuum tests will also be done to simulate how they will function on the lunar surface. Significant subsystem testing will also be done in conjunction with the robotic arm, to ensure that the arm has the correct range and mobility to scoop samples and place them into the TEGA. These tests will allow the YETI design team to verify that each oven is working to specification and validate that this subsystem works in conjunction with the robotic arm.

Robotic Arm

Figure 19. Robotic Arm

The robotic arm is mounted to the outside of the lander structure, and is used to collect the samples from the lunar surface and deliver them to the TEGA. For this design the YETI team decided to go with a simple 4 degrees of freedom arm with a scoop on the end to allow for lunar surface samples to be collected. This system will also undergo significant on earth testing. Early stage tests will include electrical interface tests, making sure the wiring does not cause the mounting plate to be charged, and isolated tests of running each series of motors. These earlier tests will allow the YETI team to verify that the smaller electronics in the arm are working properly. Final stage tests will include a full system integration with the lander. Vibration tests will be done to ensure that the arm mount will be able to withstand the launch. Additionally as described in the TEGA validation plan, field testing will be done to ensure that the arm can grab a soil sample, and place it in the oven. These tests will also be performed in cold conditions to simulate the lunar environment. The tests will validate the robotic arm and ensure that it will work during the mission.

3.1.7 FMEA and Risk Mitigation

*See section 4.1.5 for FMEA regarding lander, payload, and science.

3.1.8 Performance Characteristics and Predictions

$$V_{esc} = \sqrt{\frac{2GM}{R}} = 2800\ m/s$$

Initially, once the lander is released it is on a hyperbolic escape orbit. Therefore, a burn needs to be executed to reduce the velocity to produce a desired lunar transit. The first burn will produce an elliptical orbit where its apogee is at its current altitude and its smallest height perigee will be 100 meters above the target sight. Below is the required velocity to produce this orbit at the release position of the lander from the mothership.

$$V_{ellip} = \sqrt{\frac{2GM}{R + \frac{R^2}{R_m + H}}} = 1665\ m/s$$

Taking this result and subtracting it from the lander speed gives the delta v required.

$$\Delta v_1 = V_{esc} - V_{Ellip}$$

One the lander is near the perigee (minor radius of the elliptical orbit) a second burn will be used to deorbit the craft for final descent. The velocity at the minor orbit is as follows:

$$a = (R + R_m + H)/2$$

$$b = \sqrt{R(R_m H)}$$

$$e = \frac{\sqrt{a^2 + b^2}}{a}$$

$$V_{ellip_{minor}} = \sqrt{\frac{(1 + e)gR_m^2}{R_m + H}} = \Delta v_2 = 1682\ m/s$$

Therefore, the total delta v needed for the maneuver is:

$$\Delta v = \Delta v_1 + \Delta v_2$$

Using the general rocket equation with a full weight of 10kg, the fuel required is given as the following:

$$m_{fuel} = 10 - 10e^{\frac{\Delta v}{Ig}} = 4.15\ kg$$

The speed along the orbit can be found simply by the relation that RV = constant by the law of conservation of momentum.

3.2 Confidence and Maturity of Design

Initial designs of the YETI lander included discussion about the possibility of a rover. The rover would be able move around to different parts of the lunar surface, and drill to collect samples of the surface for analyzing. While in theory, this rover would be ideal for the mission goals, the reality of it was short lived due to size, cost, and feasibility. The YETI team then moved on to the idea of a lander that would be able to use a simple robotic arm to scoop up soil samples, and deliver them to a device within the lander to analyze and determine the composition of the samples. Choosing the instrument that will analyze the samples went through multiple design options.

Initial considerations for scientific instrumentation were chosen with historical precedence as a top priority. Since no lunar water ice landers have been developed before, the next closest precedent was found in martian landers. The Phoenix lander was a perfect case study as one of its main science objectives was analyzing water ice contents of martian soil. Among the instruments used in the Phoenix mission, the TEGA was most applicable to our main objectives of determining the presence of water ice. The TECP instrument of the Phoenix lander was also considered, but due to lack of information, it was uncertain whether the instrument would be suitable for our mission objectives.

The navigational and ambient sensors went through multiple iterations. The initial sensor considerations included a camera, light based radar system (LiDAR), thermometer, radiation sensor, and inertial measurement unit. Due to mass constraints, the camera, radar, and radiation sensor were eliminated from our design. The thermometer was eliminated due to added complexity and irrelevance to mission objectives. The IMU was kept considering its low mass and significant navigational value.

Redundancy systems also matured throughout the duration of the mission planning process. As mentioned, navigational redundancy was compromised for the sake of fulfilling mass constraints. Computational redundancy was also reduced due to the large weight of the RAD750 processors. This compromise was partially curtailed by implementing redundancy in software instead of hardware. Redundant batteries were also rendered unachievable due to their high mass.

The final design of the YETI lander utilizes all size and mass given in order to pack in all instrumentation that will allow for a successful mission. The YETI is equipped with the TEGA, a robotic arm, an IMU, communication systems, and navigation systems. With all these instruments working together, the YETI team is very confident that the mission to analyze the composition of the lunar surface will be successful, and provide insightful data for future science and missions to the moon.

3.3 Recovery and Redundancy System

The YETI lander will land on the lunar surface and carry out its mission (estimated mission duration is about 8 hours) and then the battery will run out of power and the YETI will be stuck on the moon. In this case, due to cost, and sizing constraints, there is no plan to recover the YETI lander. However, the data collected from the TEGA will be transmitted back to earth for further analysis, not requiring a manual pickup of the YETI lander, or a return flight. The main redundancy system focuses on the electrical components of the lander. As previously discussed, the main goal for the YETI is to use the TEGA to vaporize and provide calorimetric data of the composition of the lunar surface. The TEGA comes with two ovens for heating the samples. This provides a set of redundancy of the most critical part of the mission, if one oven goes down there is a backup and the mission is not compromised. Another set of redundancy within the electrical system is with the battery system. The electrical team has chosen a battery that will allow for the lander to grab three samples, leaving room for error in collecting a sample.

4. Payload Design & Science Experiments

4.1.1. System Overview

This N^2 chart shows the basic interfaces between YETI's main systems. YETI is designed to operate remotely and independent of human intervention so it's only output (red arrow) is the information relayed back to NASA containing the data collected by the TEGA. During entry onto the lunar surface, the IMU will send information of the main computer system (RAD 750 CPU) which will determine what adjustments need to be made. These instructions are then sent to the motors and the course corrected. After landing the data collection will begin with the TEGA collecting information from the regolith samples and then sending the data to the computer system for storage. AFter completion of each sample trial, the information is sent to the communications systems so that it can be sent back to earth for analysis.

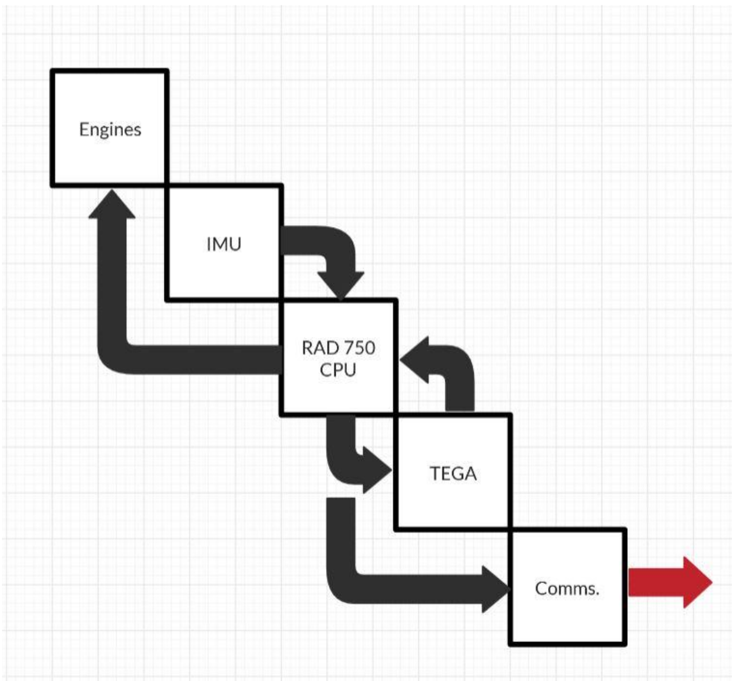


Figure 20. N2 Chart

4.1.2. Subsystem Overview

Power Distribution

The lander will have no onboard power generation**.** Solar power is unfeasible due to the darkness of icy craters. Radioisotope thermoelectric generators are also unattainable due to size constraints and governmental overhead required for approval. Therefore, power will be sourced from a battery on-board the lander, and operations will cease when the battery is depleted.

With such limited energy, the chosen battery must have high energy density. The BPS

2S-4P[6] is a fitting example of a battery that fits our constraints. At a nominal voltage of 7.4V and a capacity of 10.4Ah, this battery has a total energy capacity of 76.96 Wh. With a mass of 500g, this is an energy density of 153.92 WH/kg, which is sufficient for our mass constraints. The battery has a volume of 93 x 86 x 41mm, which fits within our volume constraints.

To ensure that this battery would fit our power needs, the power draw of the major components onboard the lander, as well as the time spent active for each device, must be considered. Persistently active instruments, such as onboard computers and transceivers, were considered active for some maximum mission duration T.

These power values were determined through online-sourced documentation, as well as from educated approximations. The motor was assumed to draw 2A at 24V. Radiation-proof redundancy for the RAD750 processor was not possible due to mass constraints.

Component	Quantity	Power (W)	Duration of Operation (Hours)
Rad 750 Processor[7]	1	5	T
UHF Transceiver (Rx)[8]	1	.0825	T
UHF Transceiver (Tx)[2]	1	1	.1T
Motor	3	48	.167 (10 minutes)
TEGA[9]	1	13	.0833 (5 minutes)
UHF Antenna[10]	1	3.5	.1T
OEM STIM300[11]	1	3.6	.1T

We now find the maximum duration T that would exhaust our battery's resources:

$$1*5*T + 1*.0825*T + 1*1*.1T + 3*48*.167 + 1*13*.0833 + 1*3.5*.1T + 1*3.6*.1T = 76.96Wh$$

6 https://gomspace.com/shop/subsystems/power/nanopower-bpx.aspx
7 https://www.petervis.com/Vintage%20Chips/PowerPC%20750/RAD750.html
8 https://www.endurosat.com/cubesat-store/cubesat-communication-modules/uhf-transceiver-ii/
9 https://pubs.acs.org/doi/pdf/10.1021/jasms.8b03058
10 https://www.endurosat.com/cubesat-store/all-cubesat-modules/uhf-antenna/
11 https://hexagondownloads.blob.core.windows.net/public/Novatel/assets/Documents/Papers/OEM-STIM300-PS/OEM-STIM300-PS.pdf

Solving for T, we get a maximum mission duration of 8.80 hours. This is sufficient time to collect and analyze two samples. Note that the values and components listed are not final, but instead approximations used to determine the viability of our power management.

Components require varying voltage, so voltage conversions need to be made. Since energy is such a vital resource on this mission, we will not use dissipative voltage regulation, but instead opt for boost and buck converters.

Communications and Data Management

Since the comms package will handle the task of tracking the orbiter, the lander will be fitted with a non-tracking, low-gain antenna to transmit data to the local comms package. There will be a two-way coherent link between the lander and mission control. This coherency will allow for Doppler tracking of the lander during descent. Due to the irregular time intervals between spectrographic measurements, data transmission will be organized by packets, instead of time-division multiplexing. These packets will adhere to the OSI ISO protocol suite. Each of these packets will include header information such as the identification number and time of the measurement.

The uplink will issue commands to the robotic arm, science instruments, and propulsion systems. The downlink will transmit science data when available, and lander health data at regular intervals. Data will be stored in RAM until the lander receives a signal from mission control, confirming that the signal path is unobstructed and ready for transmission.

The system will utilize a UHF Transceiver II[3] and the UHF Antenna[5], both from EnduroSat. Both of these products are featured on NASA's State of the Art Report and have flight heritage. They are also extremely lightweight, summing to 179g total. It will be configured to GMSK, which is a phase modulation scheme similar to the one used by Cassini[12].

Science Instrumentation

The YETI sample analysis instruments will be modelled after the Phoenix lander's Thermal and Evolved Gas Analyzer (TEGA)[13]. This mission utilized a robotic arm to collect 50mg samples of the Martian soil. Each of these samples would be placed in one of eight single-use ovens, which would vaporize the sample. The energy required to heat these samples would provide useful calorimetric data, the analysis of which would help identify the chemical makeup of the sample. The vaporized samples would then be analyzed in a mass spectrometer, yielding even more data revealing the elemental composition of the

[12] https://solarsystem.nasa.gov/basics/chapter10-1/
[13] http://phoenix.lpl.arizona.edu/science_tega.php

sample.The YETI scientific instrumentation will be similar to TEGA. A two-jointed robotic arm will be used to collect lunar samples. Due to mass, size, and power constraints, two samples will be collected, as opposed to the eight samples collected in the Phoenix mission.

Navigation

The Deep Space Network (DSN) will track the location and velocity of the lander using the lander's downlink RF signal. Using the length of time between signal transmission and signal receipt, one can calculate the receiving DSN site's distance to the lander. Using the difference between the received carrier frequency and the lander's transmitted carrier frequency, the lander's velocity can be calculated via knowledge of Doppler red-shifting.An Inertial Measurement Unit (IMU) will be used to determine the attitude and the acceleration of the descending lander, which will give us information on its trajectory.

Measurements from the IMU and lander downlink, as well as expected impulse from thruster burns, will allow for accurate lander trajectory simulations. Limited visual feedback was unachievable due to mass constraints, so the desired landing zone will have to be targeted through simulation and calculation of the lander's trajectory, rather than direct imaging. This may limit the landing zone precision for the lander and thus is considered when selecting the landing zone.

4.1.3. Precision of Instrumentation, Repeatability of Measurement, and Recovery System

The YETI's sample analysis instrument includes high-temperature furnaces and a mass spectrometer. The ovens are heated up to 1000℃ to vaporize the samples into evolved gases. The mass spectrometer then measures the masses and concentration levels of atoms and molecules in the gases, including that of hydrogen and oxygen. With abilities to analyze such measurements down to 10 parts per billion, the instrument can detect the presence of ice water. For repeatability, there are two single-use ovens for two samples of the regolith.

The inertial measurement unit (IMU) will be used to help navigate the YETI as it descends onto its designated location. The instrument consists of microelectrical mechanical systems based (MEMS) gyroscopes and accelerometers. They will help the IMU track the lander's changes in velocity and altitude. For repeatability, the instrument has three gyroscopes and three accelerometers This allows the IMU to take the multiple measurements and use the averages.

The gyroscopes will measure the rotation and rotation rate. It can determine the speed of rotation with an input range of up to 400 degrees per second. Its in-run bias stability, which measures how stable the gyroscope is over a period of time based on its deviation from the mean value of its output, is 0.5 degrees per hour. Its angular random walk is 0.15 degree per square root hour. This describes the average deviation in the signal when the angular rate is integrated over time to find angle as a function of time due to noise in the rate signal.

The accelerometers will measure the velocity and acceleration. It has an input range of 10 g, with g defined as Earth’s standard surface gravitational acceleration of 9.80665 meters per second per second. Its in-run bias stability is 0.05 mg. Its velocity random walk is 0.06 meters per second per square root hour. Using the transmitter on the payload, it will transmit data to a separate communication package near the lander. The comm package will send data to the orbiter, which will then relay that information back to Earth.

4.1.4. Validation and Verification Plan

The instruments selected have all been manufactured to operate within the cold vacuum of space. The TEGA has been specifically chosen as it was flown previously on the Phoenix lander (MARS) so it has been mission tested in full. However, it is still important to test as if it were a new device. The downsizing may have effects not previously considered (on the original TEGA) and the lunar environment that it will be operating in is not the same as the martian environment the TEGA was originally designed for. Every component will be tested in mission simulated conditions to ensure that operating conditions during the mission are known ahead of time. This ensures that we are prepared for the challenges of operating on the lunar surface.

TEGA

<u>Requirements:</u>

- Accurately detect or reject the presence of water in the lunar regolith (accuracy of 10 parts per billion)

<u>Testing Plan:</u>

- Test TEGA device within simulated mission conditions to ensure reliability and accuracy (cold vacuum, fine dust-like terrain etc..)
- Test mass spectrometer with known elements to ensure accuracy

Battery

<u>Requirements:</u>

- Battery should be able to supply entire payload with adequate power (76.96 Wh) for mission duration (Approx. 8 hours)

<u>Testing Plan:</u>

- Run payload within simulated mission conditions to ensure power supply is adequate and reliable
- Run full system operation until battery dies to determine when the YETI can no longer run due to power loss
- Determine the power losses when the system is idle (Quiescent steady state power loss)

IMU

Requirements:

- Accurately determine the payload's acceleration and orientation to ensure touchdown within designated landing zone (.5km radial margin of error).

Testing Plan:

- Mount IMU is a testing device similar to payload (same mass and volume) and drop from high altitude balloon to ensure accuracy when at high speed.
- Test accuracy in a cold vacuum environment

Communications System

Requirements:

- Ensure communication link between lander and satellite orbiter during mission duration (Approx. 8 hours)

Testing Plan:

- This instrument will be tested in mission simulated conditions to ensure it can survive the lunar environment (low temperature and vacuum)

4.1.5 FMEA and Risk Mitigation

Due to the nature of this mission, it is imperative to account for all potential risks and determine a course of action to avoid these potential risks. Presented below are all the key components of the YETI lander, the potential risks, and plans to mitigate them.

YETI

Failure Mode and Effects Analysis

Failure Mode Number	Identification of Item or Function	a. Failure Mode b. Failure cause	Failure Effects a. Local or Subsystem b Next Higher Level - System c. End Effect - Mission	Severity Category	Remarks a. Failure Detection Method b. Compensating Features/Action c. Other	1.__ = Mission Science Instrument 2.__ = Mission Support Payload 3.__ = External Lander
1.1	TEGA Heating Implement	a. No/underheating b. Short-circuiting, radiation damage	a. TEGA Instrument failure b. Mission Failure	HIGH	a. In situ thermocouples sensing oven temperature b. Redundant circuit paths to TEGA heating implement	
1.2	Evolved Gas Analyzer	a. Electrical failure b. Radiation/Stress from impact	a. Failure of mass spectrometer b. Critical mission objective compromised	MED	a. Monitor voltage and current b. Redundant circuitry	
1.3	Pneumatic Subsystem	a.Gas leakage b. Stress from impact	a. TEGA Instrument failure b. Mission Failure	HIGH	a. Pressure monitoring b. Pneumatic stress tests/Redundant systems	
2.1.1	Battery	a. Combustion b. Extreme Temperature	a. Battery unable to discharge b. Mission Failure	HIGH	a. Temperature monitoring b. Temperature regulator for battery	
2.1.2	Battery	a. Combustion b. Vibrational stress	a. Battery unable to discharge b. Mission Failure	HIGH	a. IMU measurements b. Absorbant Padding	
2. 2	Antenna	a. Structural Damage b. Stress from impact, debris	a. Failure of communications subsystem b. Mission Failure	HIGH	a. No Signal b. Increase sensitivity/ modulate scanning spectrum of nearby base station	
2.3	IMU	a. Inaccurate data b. Vibrational stress from launch	a. Navigational accuracy compromised b. Inaccurate/failed landing	MED	a. Readings inconsistant with doppler measurements or thruster maneuvers b. Attempt recalibration; If fails, navigate solely from doppler tracking	
2.4	RAD750 CPU	a. Bit-errors b. Radiation damage	a. Failure of data handling b. Total lander failure	MED	a. Establish redundant multithreading and check for consistancy between processes b. Close and restart erroneous processes	
3.1	Lander Leg	a. Force of impact causes failure in legs b. Large dynamic loading from lander impact	a.Landing failiure b.Failed Landing/Mission might not be jeopordized	MED	a.Honeycomb like structure on landing pads to cushion landing	
3.2	Engine Nozzle	a. Failure to produce sufficent thrust. b. Failure in turbomachinery or flow rates	a.Failure to perform flight pattern b. Failed landing	HIGH	a. Significant on earth testing to mitigate failure b. Redundant systems for engine failure	
3.3	Robotic Sampler	a. Cannot scoop regolith b. Encounters hard substrate	a. Robotic arm sample failure b. TEGA instrument cannot obtain sample	LOW	a. Internal feedback from motor b. Retrieve arm from regolith without scooping	

YETI

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Battery Volatility	1	5	New	M	Given that: Lithium-ion batteries can combust if placed under 1) extreme temperatures or 2) vibrational stress. There is a possibility that: the battery can explode, suspending all power onboard the spacecraft.	1) Battery system includes autonomous heating which can monitor and maintain battery temperature. 2) Battery enclosed in isolation padding. IMU informs battery to mitigate power output and thrusters to reduce intensity.
2	Overcurrent	3	3	New	M	Given that: Short circuits and ground faults can result in overcurrent, There is a possibility that: the battery is depleted and the spacecraft is overheated.	Current limiter circuit protects against unexpected surges in the circuit. Each device can be disconnected from the main power bus via circuit breaker should malfunction occur.
3	Coronal Mass Ejections	1	4	New	W	Given that: Solar storms and associated coronal mass ejections emit high energy protons with inclement electromagnetic consequences, There is a possibility that: bits in computer memory are flipped.	Plan mission for predicted periods of relative solar inactivity. Command system shut-down and reset if coronal mass ejection is detected during the mission. Use radiation-hardened RAD750 processor.
4	Instrument Availability	3	3	New	R	Given that: The TEGA instrument was custom-developed for the Phoenix-lander mission, There is a possibility that: the instrument may not be readily or cheaply made by the Univeristy of Arizona.	Request schematics and documentation from the University of Arizona and hire independent contractor to assemble instrument.
5	Instrument Applicability	3	4	New	R	Given that: The TEGA instrument was designed for the Martian environment, There is a possibility that: The instrument may be unfit for the conditions on the moon.	Test TEGA replica in a vaccum chamber with a simulated lunar regolith on earth.
6	Measurement Viability	3	3	New	A	Given that: The lander is immobile and can only take two samples, There is a possibility that: the robotic arm might collect samples in regions without water ice.	Select landing zones with high probability of containing ice water.
7	Uneven Landing Terrain	2	3	New	R	Given that: The lander will be landing in polar craters, There is a possibility that: The lander may encounter excessively uneven terrain.	Perform simulations testing the lander under various reglith inclinations and courseness levels. Research eligible regions whose size is consistant with landing zone precision.
8	Empty Sample	2	4	New	M	Given that: The lander has no visual confirmation of its surrounding terrain, There is a possibility that: The sample collection device collects no/insubstantial sample and wastes one of the one-time thermal heating units.	Use feedback from the motor to determine whether the sample collection device is encountering the lunar regolith. Use the motor feedback to determine how much regolith is collected.

4.1.6. Performance Characteristics

The lander's primary scientific instrument is the Thermal and Evolved Gas Analyzer (TEGA). The TEGA had been used in previous space missions, particularly that of the Phoenix Mars Lander and the Mars Polar Lander.The Mars Polar Lander utilized the Mars Volatiles and Climate Surveyor, which was a suite of five instruments focused on searching for water vapor and ground ice in the south polar region of Mars. Of those five instruments was the TEGA. Although the Mars Polar Lander did not complete its mission, it shows that its TEGA was designed with the ability to detect water on celestial objects. This aligns directly with YETI's mission objective: to characterize the polar water ice on the moon and verify the location of ice deposits.

The Phoenix Mars Lander later used a very similar design of the Polar's TEGA. Its objective was the same; the lander was ultimately able to identify and confirm the presence of water in Martian soil using the TEGA. This presents a precedent for the instrument to be able to work in the expected environment on Mars. It is important to take into account the environmental differences between Mars and the moon and how they can affect the performance of the instrument. In doing so, the TEGA is determined to be able to function accordingly as part of the YETI mission.

4.2.1 Science Payload Objectives

1. Main Objective:

    a. Verifying the presence of water ice in the crater Cabeus A (Coordinates:) in the lunar south pole. Data from Cassini's lunar mapping in 1999 and LCROSS Centaur's impact in 2009 heavily suggest the presence of water in the form of ice in this perpetually dark section of the moon.

2. Secondary Objectives:

    a. If water ice is found, the priority is to determine the purity of the sample through the Thermal and Evolved Gas Analyzer's (TEGA) mass spectrometer. This process is explained in detail in section 4.2.3. This test can aid in determining the viability of water ice extraction as a resource for future manned missions to this region of the Moon.

    b. Determining the main contaminants of the water ice that is found. Other gases are suspected to be trapped in the ice alongside the water (mainly Carbon compounds: CO, CO_2 and CH_4) and verifying their presence could help in determining if they can be extracted as a resource. This again is done through the mass spectrometer which will analyze the gases caught in TEGA's heat chamber.

4.2.2 Creativity/Originality & Uniqueness/Significance

The design is original in the sense that the Thermal and Evolved Gas Analyzer (TEGA), an instrument used to analyze Martian ice and soil samples, will have two scanning calorimeters instead of eight. It will also be calibrated for the vacuum of space instead of the Martian atmosphere.

The landing site of the mission will be Cabeus A, a lunar impact crater. It is located about 100 km from the Moon's south pole, and is an almost perpetually shadowed region. The Lunar Prospector spacecraft detected a hydrogen signature around this area of the Moon. The perpetual shadow is significant since this allows the temperature of the region to be low enough, below 100 K, to allow water ice to exist on the surface without undergoing sublimation.

4.2.3 Payload Success Criteria

The Thermal and Evolved Gas Analyzer (TEGA) that will constitute the payload is composed of two types of subparts: Scanning Calorimeters and a Mass Spectrometer. There are in total 8 Scanning Calorimeters on the instrument[14], each capable of holding 1 sample collected from the vicinity of the lander. After all the samples are collected, the calorimeters will function as ovens and proceed to gradually increase their temperatures. Each oven will increase its temperature at a rate independent of the others, depending on the gases that will be continuously released from the samples. Since the main goals of the payload are to determine the purity of the water ice and the presence of other gases trapped in the ice, the ovens are programmed to reach a max temperature of 1000 C degrees.

As the samples are being heated, the calorimeters will detect any change of chemical state i.e. from solid to liquid or from liquid to gas. The temperatures at which these changes happen is recorded and it will serve as one of the first signals of water purity. If the water is 100% pure (unlikely) the ice should change from solid to liquid at 0 C degrees. If the change happens at a different temperature, it is a first indication of how pure the water ice is. The rate of transformation between the chemical phases also indicates the chemical composition of the sample.

As the samples are heated and gases are released, they will ascend to the upper part of the chambers where a constant supply of N_2 will serve as a carrier gas to take the gas samples to the mass spectrometer. The mass spectrometer is divided into 4 sections, each generating magnetic fields of different intensities to create charged ions. The spectrometer is highly sensitive to different masses of particles and its sections (called “channels”) can detect particles from the range of 0.7 Da to 140 Da.

The channels are set for the following ranges:

Channel 1	0.7-4 Da
Channel 2	7-35 Da
Channel 3	14-70 Da
Channel 4	28-140 Da

[14] http://anserver1.eprsl.wustl.edu/phx/solbrowser/documentation/missionDocs/t_tega/tega_tutorial.pdf

The mass spectrometer measures the mass-to-charge ratio of ions, effectively finding composition of the gas in the chamber and the isotopic ratios of these different types of gases. This last step will determine the purity of the water ice samples and the composition of the contaminants, which will aid in determining the viability of water collection from Cabeus A. The data collected from these samples can then be extrapolated statistically to infer presence of water from southern craters with similar compositions to Cabeus A.

4.2.4 Exp. Logic, Approach, & Method of Investigation

The payload's Thermal and Evolved Gas Analyzer (TEGA) will be responsible for analyzing ice and soil samples. Scanning calorimeters will be utilized to detect changes of chemical state, and the rate of transformation and the temperature at which the transformation occurs will be recorded. Water ice purity will thus be deduced as well. The mass spectrometer will aid in determining the elemental composition of a gas. Data that will be collected from both the scanning calorimeters and mass spectrometer on the TEGA will yield a mass spectroscopy graph and a graph showing the temperature vs. power draw of the scanning calorimetry oven. The former will display relative concentrations of different masses. The scanning calorimetry graph will show the specific heat of the contents of the regolith.

4.2.5 Describe Testing and Measurements

TEGA possesses 7 different types of sensors[15] in order to perform its tests:

1. **AD590 Temperature Sensors:** These are analog sensors (the "AD" represents "Analog Devices",) and work by passing a current that is proportional to the temperature registered. They operate with an accuracy of 1.7K in the range of 218K to 423K, making them very reliable.
2. **PRT Temperature Sensors:** These are digital sensors and they operate outside of the range 218K to 423K, when the AD590 is less reliable.
3. **T-Heater Temperature Sensors:** As they're name suggests, these sensors are located in the plumbing junction between the manifold heater and each oven, and help regulate temperature above 65 degrees Celsius.
4. **The Manifold Pressure Sensor:** There are 2 of these pressure sensors. One located between the carrier gas tank and the TA inlet valve (valve to the ovens) and one between the calibration gas and the TA inlet valve. These pressure sensors help regulate the amount of gas being let into the ovens.
5. **The Outlet Pressure Sensor:** There are 8 outlet pressure sensors located between each oven and the Evolved Gas Analyzer. These regulate the entry of the sample gas mixed with the carrier gas into the chamber in which they will be analyzed.
6. **TA Full Detect Optical Sensors:** There is 1 optical sensor per oven in TEGA. Each sensor is located in the bottom of each oven. The sensor captures the amount of light

[15]http://anserver1.eprsl.wustl.edu/phx/solbrowser/documentation/missionDocs/t_tega/tega_calibration_report.pdf

in each oven, and as the sample soil is deposited in the oven the sensors are covered and the light captured by the sensor drops to 0. When the optical sensors don't capture any more light, the oven is assumed to be at maximum capacity.

7. **Voltage and Current Sensors:** For each temperature, pressure, and optical sensor, there is a voltage and current sensor that collects measurements and transforms it into data to be sent back.

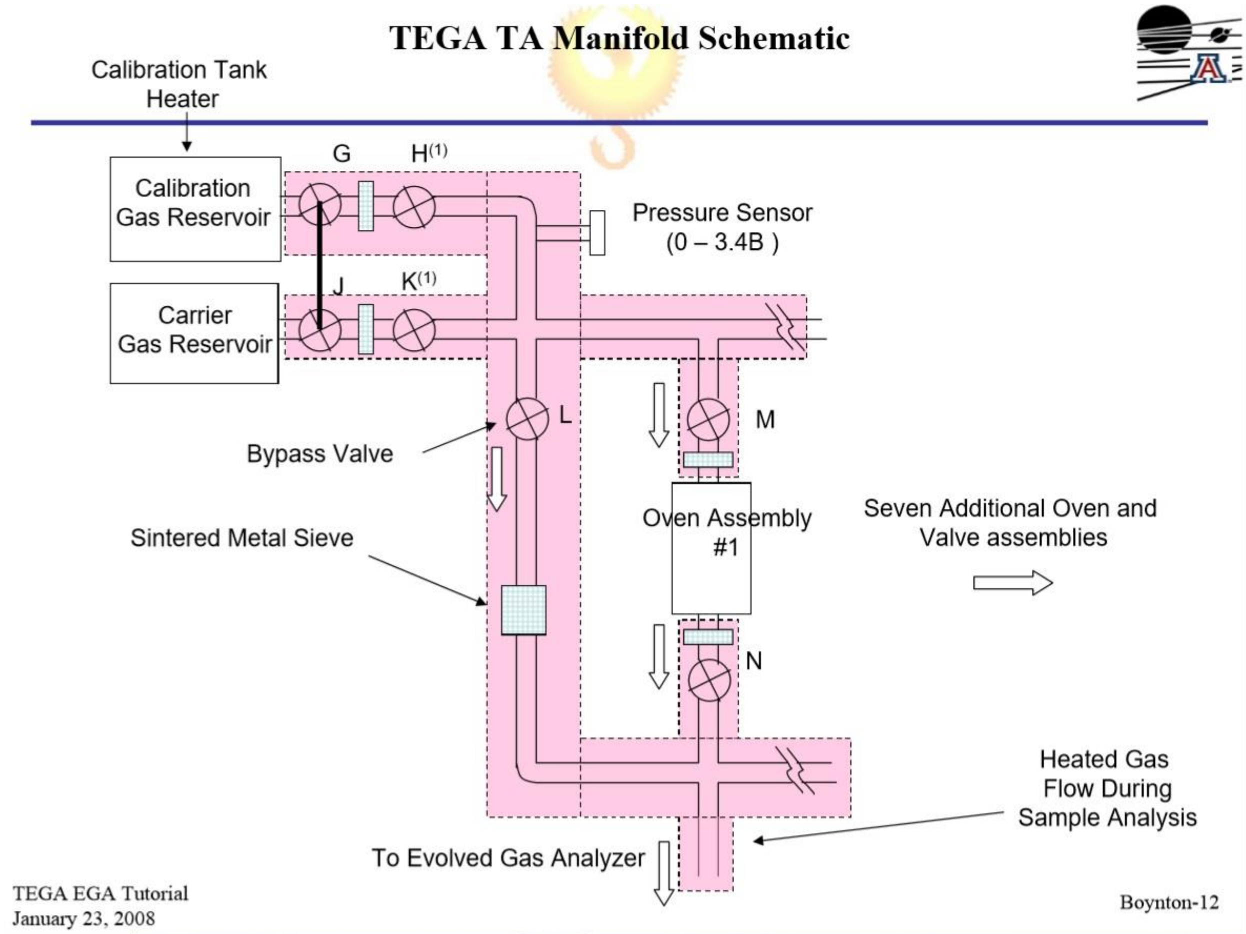


Figure 21. Schematic Showing Several of the Main Sensors. Taken from the TEGA Manual.

The calibration process for TEGA works by running one full sweep of the system with the gas in the Calibration Gas Reservoir. This gas is a mixture of 60% N_2 and 40% CO_2 (minor traces of O_2, H_2O and Kr.) Releasing the gas from the calibration tank, mixing it with the carrier gas, passing it on to the ovens, heating the ovens, moving the gas to EGA and measuring the Voltage-to-Mass in the channels is considered a full sweep. Through this process, all of the sensors will be tested for optimal performance.

Using the Igor software package we can calibrate the sensors and tools, if there is an offset of the results:

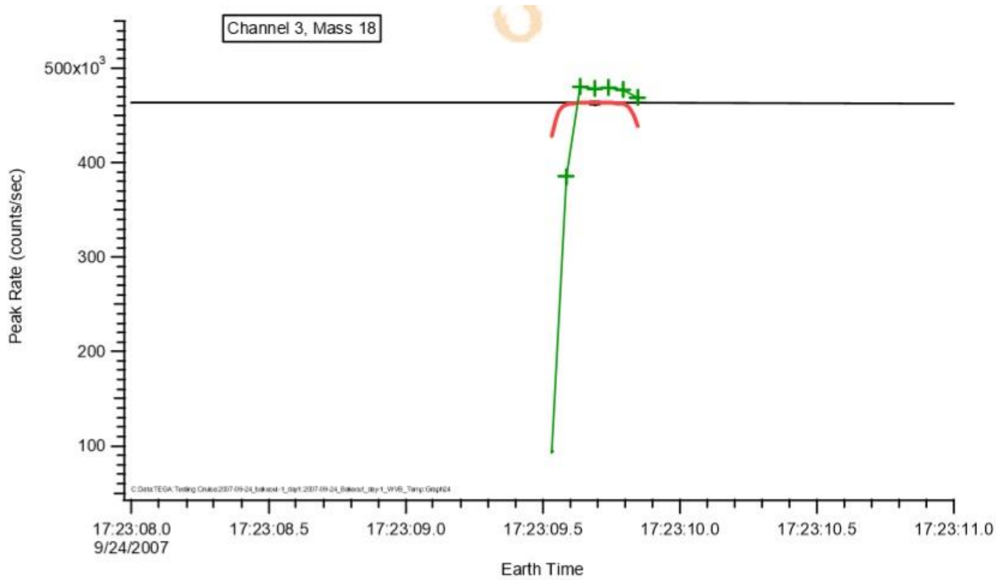


Figure 22. Uncalibrated Sample. Taken from TEGA Manual.

In this image, the red line is the expected output, and each cross belongs to one sample taken. The Voltage-to-Mass output is off for the samples in channel 3. Correcting with Igor, we obtain the following image:

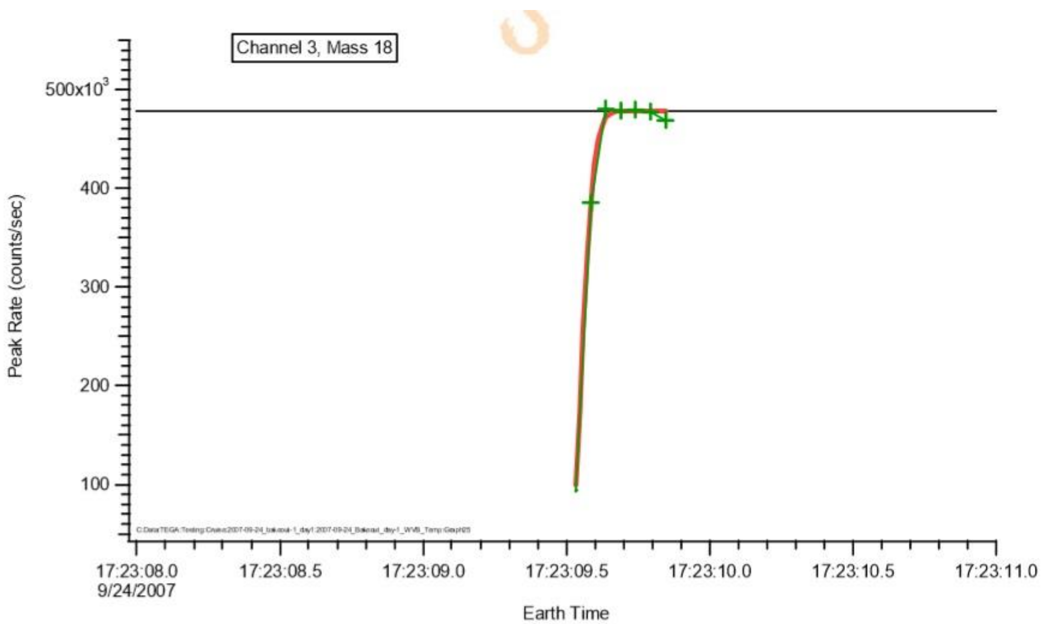


Figure 23: Calibrated Sample. Taken from TEGA Manual.

4.2.6 Show Expected Data

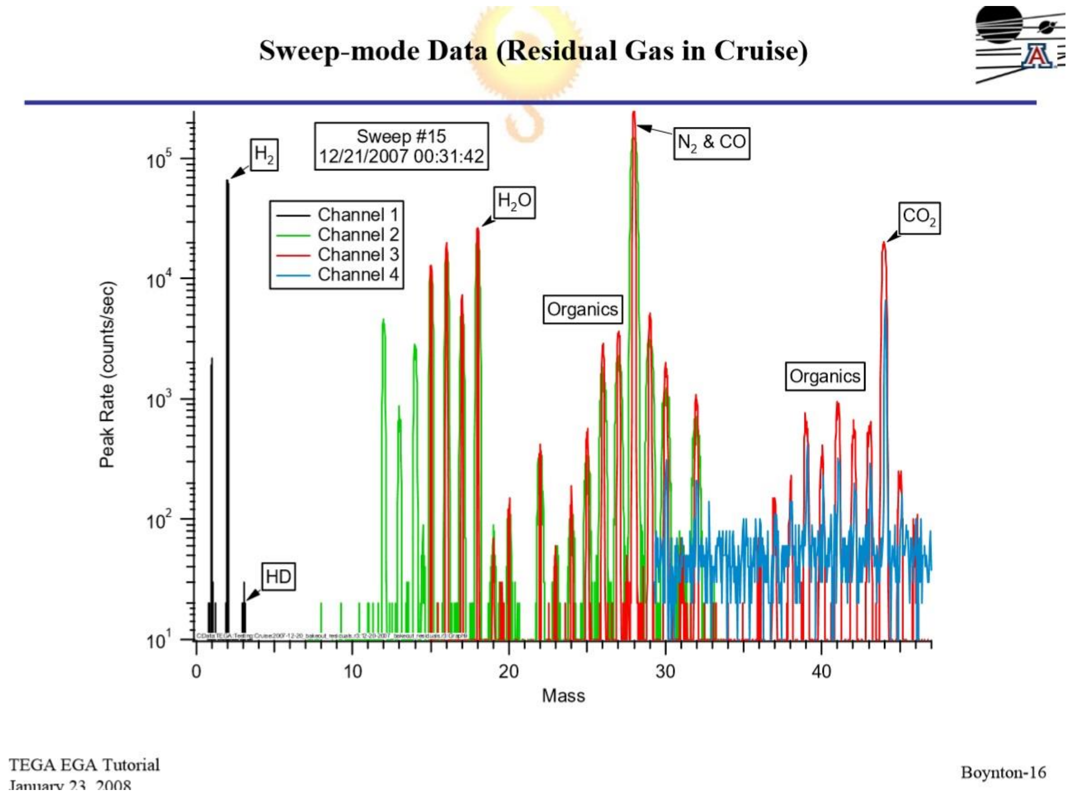


Figure 24: Real Data from the Evolved Gas Analyzer, Several Particles Can Be Distinguished. Taken from the TEGA Manual*.*

The previous image presents real data from the EGA (Evolved Gas Analyzer,)[16] which is the final step in the process. Here we can see a sample that has been broken into parts and whose parts have been charged. The mass spectrometer measures the mass-to-charge ratio of these ions, and counts the amount of each mass/charge present in each sample. Once a sample is completely analyzed we can begin to draw conclusions from the spectrometry. Since particles will have the same spectrometry reading regardless of where the sample comes from, we can safely confirm the presence of each element.

As can be seen in the graph, this spectrometry will tell us 3 things from the samples we collect:

1. Is there a presence of water?
2. Is there presence of contaminants?
3. What is the ratio of contaminants to water?

[16] http://anserver1.eprsl.wustl.edu/phx/solbrowser/documentation/missionDocs/mission.cat

Since the channels in the EGA overlap in the ranges of mass they can detect, we can observe that there are certain molecules that are measured several times in the graph. Namely H_2O, N_2, and CO are measured by channel 2 and 3, and CO_2 is measured by channel 3 and 4. Since we expect these to be the main molecules that we will find in our samples, it helps that they are measured several times since this decreases the possibility of misguided results.

5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

Our safety officer of the team is John Gambino. He oversees any safety related issues with the mechanical, power systems, and science teams. After doing research, we feel that we will take the approach of NASA’s Safety Culture Program. Here, their mission is to help make everyone feel safe and comfortable reporting safety issues, learn from mistakes, and keep safety as a frontrunner when it comes to the work environment. We feel that taking this approach and having these ideals will ensure that our team can complete the work needed for our project. Our team will give constant feedback to our safety officer which will then be communicated with the necessary personnel to ensure our team is in a safe working environment.

5.1.2. List of Personnel Hazards

The hazards we face are mainly from the mechanical and power systems side of the project. Operating heavy machinery can be a dangerous task and can sometimes pose a life threatening injury. Working with electrical equipment or any exposed wires may also pose the same threat to our team working in various facilities. A hazard that is often overlooked is the maintenance of the facilities. Work cannot be done in a safe manner without this being ensured.

5.1.3. Hazard Mitigation

To ensure our team is safe, we will require that each employee who works with heavy machinery will have to wear the necessary PPE (Personal Protective Equipment) such as safety glasses, protective shoes, face shields, respirators, and gloves. Machine guarding will be of utmost importance to our team and will be taken seriously. While working with any electrical systems, our team will be required to wear the necessary PPE such as safety glasses, face shields, hard hats, safety shoes, insulating gloves and sleeves as well as flame-resistant clothing. Lastly, to combat poor maintenance in facilities, our safety officer will be in constant contact with leaders at these various facilities to assure they are up to code and safe for the team to work in.

5.2. Lander/Payload Safety

5.2.1 Environmental Hazards

As we plan for our mission to the moon, we have to outline some expected hazards that await us on the moon's surface. For one, the lunar surface does not have the same protectiveness the Earth has with its atmosphere. Without having an atmosphere, this exposes the lunar surface directly to repeated hypervelocity impacts. The moon has the possibility of being bombarded with meteorites at any given moment. The range in which the size and speed of these meteorites are can vary. Observations are conducted at NASA Marshall Space Flight Center in Huntsville, Alabama at the Automated Lunar and Meteor Observatory (ALaMO) by aiming at the dark portions of the moon. When a meteoroid strikes the Moon, a large portion of the impact energy goes into heat and produces a crater. A small portion goes into generating visible light, which results in a large flash at the point of impact.

5.2.2 Hazard Mitigation

To combat the hazard of hypervelocity impacts, our team plans to collect and analyze previous data of space object collisions on the lunar surface from the Automated Lunar and Meteor Observatory (ALaMO) located in Huntsville, Alabama. Here, they use low light level video cameras, which records continuously at rates of 1/30th of a second. Hours of this data can be stored on a video tape or computer hard disk for later analysis. A Watec Ultimate H2 camera to each of their telescopes and route the camera output into a Sony tape deck or Canopus video digitizer. This converts the video signal into a digital format that is stored on a hard disk. Flashes in the data can later be observed. Two telescopes with similar characteristics are used in case. Sometimes flashes are caused by cosmic rays however, a given cosmic ray can only strike one camera. Any flash observed simultaneously with both telescopes being in use cannot be a cosmic ray.

6. Activity Plan

6.1 Budget

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Cumulative Total
PERSONNEL						
12 members on the team						
Total Salaries	$ 960,000.00	$ 960,000.00	$ 960,000.00	$ 960,000.00	$ 960,000.00	**$ 4,800,000.00**
Total ERE	$ 268,800.00	$ 268,800.00	$ 268,800.00	$ 268,800.00	$ 268,800.00	**$ 1,344,000.00**
Total Personnel	$ 1,228,800.00	$ 1,228,800.00	$ 1,228,800.00	$ 1,228,800.00	$ 1,228,800.00	**$ 6,144,000.00**
OTHER DIRECT COSTS						
Total Materials and Supplies	$0.00	$ 15,559,585.00	$0.00	$0.00	$0.00	**$ 23,339,377.50**
Publications	$ 50,000.00	$ 50,000.00	$0.00	$0.00	$0.00	**$ 130,000.00**
Plane tickets	$0.00	$0.00	$0.00	$0.00	$ 3,610.40	**$ 4,693.52**
Hotel	$0.00	$0.00	$0.00	$0.00	$ 7,947.24	**$ 10,331.41**
Per diem (meals)	$0.00	$0.00	$0.00	$0.00	$ 3,195.00	**$ 4,153.50**
Total Services	$0.00	$ 10,000.00	$ 10,000.00	$ 125,000.00	$ 125,000.00	**$ 351,000.00**
Total Equipment	$0.00	$ 25,000.00	$ 150,000.00	$ 100,000.00	$ 25,000.00	**$ 450,000.00**
Total Subcontracts	$0.00	$0.00	$0.00	$ 150,000.00	$ 150,000.00	**$ 390,000.00**
Total Direct Costs	$ 65,000.00	$ 23,454,877.50	$ 238,000.00	$ 507,500.00	$ 414,178.43	**$ 24,679,555.93**
Total MTDC	$ 71,500.00	$ 25,800,365.25	$ 261,800.00	$ 558,250.00	$ 455,596.27	**$ 27,147,511.52**
Total Subcontract F&A	$0.00	$ 100,000.00	$ 225,000.00	$ 300,000.00	$ 100,000.00	**$ 797,500.00**
Facilities	$50,000.00	$ 75,000.00	$ 125,000.00	$ 200,000.00	$ 50,000.00	**$ 550,000.00**
Total F&A	$55,000.00	$ 192,500.00	$ 385,000.00	$ 550,000.00	$ 165,000.00	**$ 1,347,500.00**
Total Project Cost	$ 1,355,300.00	$ 27,221,665.25	$ 1,875,600.00	$ 2,337,050.00	$ 1,849,396.27	**$ 34,639,011.52**

Figure 25. YETI mission budget

6.2 Schedule

YETI Testing, Prototyping, and Building Schedule			Begin Date	Launch Date
			9/1/2019	10/5/2024
Phase One-Research				
Mission Objective	Begin Date	End Date		
Lunar Environment research	9/1/19	2/1/20		
Lander Design	2/1/20	1/1/21		
Phase Two- Subsystem Builds/Testing				
Mission Objective	Begin Date	End Date		
Robotic Arm Subsystem Build	1/1/21	4/1/22		
Propulsion sourcing and assembly	2/1/21	6/1/22		
MR-107S rocket engine subsystem tests	2/1/21	2/1/22		
TEGA subsystem tests	2/1/21	2/1/22		
Controls system build	6/1/21	9/1/22		
Isolated Lander Leg Build/Tests	2/1/21	6/1/22		
Isolated Lander Structure Build/Tests	2/1/21	10/1/22		
Battery System and harnessing	3/1/21	6/1/22		
Phase Three- System Level assembly/testing				
Lander Assembly	1/1/23	6/1/23		
Lander Day in the life testing	6/1/23	6/1/24		
Full System Electronic and Battery Test	1/1/23	6/1/23		
Testing simulating arm delivering dirt to TEGA	1/1/23	6/1/23		
Simulated Lunar Environment Sampling and benchmarking	6/1/23	6/1/24		
Launch		10/5/24		

6.3 Outreach Summary

The YETI Mission will have multiple educational outreach programs tailored to different levels of K-12, higher education and the general public. The YETI Mission will have four levels of YETI Mission Ambassadors. Each type of ambassador will host outreach events in their respective demographic from K-4, 5-8, 9-12, and the general public to bring awareness to The YETI Mission at the appropriate educational level. Outreach with K-4 will involve the identification of different objects in the Solar System and what we plan to look for in a small classroom workshop setting. Outreach with 5-8 will involve having students perform experiments like what the lander will be performing in a small classroom setting. Outreach with 9-12 will involve a career day in the space industry for networking purposes along with how what they are learning in their STEM courses are applicable in industry. Outreach with the general public will include working together with various science museums and amateur astronomy societies to host networking and panel events.

6.4 Program Management Approach

The team became organized with the need of identifying mission objectives based on science, mechanical engineering, and electrical engineering needs. We held weekly general team meetings to discuss different solutions on the best way of making team objectives. Each sub team held weekly meetings in addition to address updates, and problems arising in their sub team. When a problem arose during development, the team readdressed the science behind current engineering models to ensure all models are following the limitations the science team presented.

7. Conclusion

The overall goal for the YETI lander is to touchdown on the lunar surface, and using a robotic arm, scoop up samples of the lunar surface, and then deliver them to the Thermal and Evolved Gas Analyzer (TEGA) for them to be vaporized. This will allow for the YETI team to extract calorimetric data from the TEGA and help characterize the composition of the lunar surface. In addition to the TEGA, the YETI lander is equipped with an inertial measurement unit, and microelectronics such as gyroscopes and accelerometers. This instrumentation will help to guide the lander to its target landing zone. From extensive research into the ideal landing spot, the YETI planetary science team has decided to land and analyze the surface composition of a crater called Cabeus A, in the lunar south pole. This location was chosen based on previous data collected suggesting that there is water or ice on this area of the moon. The YETI lander has been designed so that a return flight to the orbiting satellite will not be necessary, all data collected from the TEGA and other sensors will be transmitted back to the mothership. The duration of this mission will be approximately nine hours. This will allow the YETI lander to perform at least two sample collections, and ensure a successful mission.