Preliminary Design Review

Hella Impact – Team #8

L'SPACE Mission Concept Academy

Summer 2020

Prepared by: Hella Impact – Team #8

South Florida United States District

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1. Introduction and Summary

1.1. Team Introduction

Enrique Torres, Project Manager • Engineer • Scientist • Administrator

- **Major(s):** Chemical Engineering • Biomedical Engineering Technology • Industrial Engineering Technology
- **University:** Miami Dade College
    - **Location:** Miami, Florida
- **Relevant Hard Skills:** Project Management • SOLIDWORKS • C (Programming Language) • Business and Academic Writing • Financial Modeling.
- **Relevant Experience:**
    - Wrote a 600+ page and a condensed 30 page business plan/proposal in high school as a senior capstone project
    - Writing a textbook about chemistry introductory knowledge in a digital note-taking format

Jack Tanski, Deputy Project Manager • Engineer • Scientist

- **Major(s):** Aerospace Engineering
    - **Minor(s):** Astronomy
- **University:** University of Central Florida
    - **Location:** Orlando, Florida
- **Relevant Hard Skills:** C Programming Language • C# • Microsoft Office • MATLAB
- **Relevant Experience:**
    - Recognized as a LEAD Scholars Academy Alumni
    - Built a maze-navigating robot as well as a boat with pathing
    - Member of both the American Institute of Aeronautics and Astronautics (AIAA) and the Students for the Exploration and Development of Space (SEDS)

Tienna Matthews, Lead Scientist

- **Major(s):** Plant Biology
- **University:** Florida International University
    - **Location:** Miami, Florida
- **Relevant Hard Skills:** Python
- **Relevant Experience:**
    - Participated in the NASA Community College Aerospace Scholars (NCAS) Program
    - Recognized as a Billing And Coding Specialist (CAM)

Ashton Frazier, Lead Engineer • Administrator

- **Major(s):** Mechanical engineering
- **University:** Florida Atlantic University; Florida International University
    - **Location:** Miami, Florida
- **Relevant Hard Skills:** SOLIDWORKS (Associate Certified) • FORTRAN (Programming Language) • CAD Modeling • Graphic Design (Photoshop Certified) • Note-taking • Rapid Prototyping
- **Relevant Experience:**
    - Held a role for 8 months as a Lab Assistant in a Rapid Prototyping Lab
    - Founding Member of FAU’s electric formula racing team (SPEED)

Camila Benavides, Lead Administrator • Engineer

- **Major(s):** Aerospace Engineering • Biomedical Sciences
- **University:** University of Central Florida
    - **Location:** Orlando, Florida
- **Relevant Hard Skills:** xflr5 • C programing language • SOLIDWORKS • MATLAB
- **Relevant Experience:** N/A

Rey Maldonado, Safety Officer • Scientist • Administrator

- **Major(s):** Environmental Engineering
- **University:** University of Central Florida
    - **Location:** Orlando, Florida
- **Relevant Hard Skills:** C Programming Language • Java Programming Language • Excel • Procurement Management
- **Relevant Experience:**
    - Participated in the NASA Community College Aerospace Scholars (NCAS) Program
    - Held a role as a Valencia College Math/Science Learning Assistant and Biology Lab Assistant
    - Held a role as a Credit Union Member Consultant

Thavishka Gamage, Engineer • Scientist

- **Major(s):** Electrical Engineering
- **University:** Broward College
    - **Location:** Fort Lauderdale, Florida
- **Relevant Hard Skills:** Biology • Chemistry • Physics • Microsoft Office • Academic Writing • Scientific research • Laboratory skills • Note-taking
- **Relevant Experience:**
    - Held a role as a Medical Laboratory Technician at a private medical laboratory and trained to perform phlebotomy
    - Wrote an academic level research paper on the topic “Science vs Religion”

Steven Ortiz, Engineer

- **Major(s):** Aerospace Engineering
    - **Minor(s):** Philosophy
- **University:** University of Central Florida
    - **Location:** Orlando, Florida
- **Relevant Hard Skills:** C programming • MATLAB • Mathcad • Microsoft Office • Adobe Suite
- **Relevant Experience:**
    - Minor in philosophy to help guide ethics in engineering projects

Rhaeuz Bathan, Engineer • Scientist

- **Major(s):** Mechanical Engineering
- **University:** Miami Dade College
    - **Location:** Miami, FL
- **Relevant Hard Skills:** AutoCAD • SOLIDWORKS • C Programming Language • Mechanically Inclined • Microsoft Office
- **Relevant Experience:**
    - Built a self-driving car with the Engineering club at MDC Homestead in collaboration with the Tech Society

Aracelis Partida, Scientist • Administrator

- **Major(s):** Physics
- **University:** University of Central Florida
  - **Location:** Orlando, Florida
- **Relevant Hard Skills:** Data Analysis • Coding • Astrophysics
- **Relevant Experience:**
  - Held a role for over a year as a physics laboratory assistant
  - Have assembled two computers successfully
  - Have extensive experience in team collaboration and scientific procedures

Jonathan Castillo, Engineer • Scientist

- **Major(s):** Aerospace Engineering
- **University:** University of Central Florida
  - **Location:** Orlando, Florida
- **Relevant Hard Skills:** SOLIDWORKS • Microsoft Excel • AutoCAD
- **Relevant Experience:**
  - Presented an RC plane design to Lockheed Martin engineers
  - Participated in AIAA projects: rocketry, aviation design, CAD model analysis

1.2. Mission Overview

1.2.1. Mission Statement

The “Unceasing on Mars” (UOM) mission will help prepare for a long term, sustainable, manned mission to Jezero, Mars; this includes the following tasks

Objectives:

The “Unceasing On Mars” (UOM) mission will be caching scientifically compelling data for newer ways to understand human adaptations by distinguishing the geologic history of a site with evidence of an “astro biologically-relevance” and geologic diversity—while evaluating/estimating the nature, ability, and/or quality of the habitability and “potential evidence of past life” in units with “high biosignature preservation potential”, specifically, macroscopic physical structures and textures.

1.2.2. Mission Requirements

Mass Constraints: 180 kg is the Maximum
Volume Constraints: 61cm X 71cm X 96cm (24in X 28in X 38in)
Cost Constraints: $100M is the Maximum

1.2.3. Mission Success Criteria

Mission success will require finding ways of long term, sustainability for future manned missions to Jezero, Mars.

Minimum Mission Success:

- Successful De-orbit landing on Martian surface.
- Determine possible locations for H_2O sources.
- Identify local geography and locate a suitable location for sample.

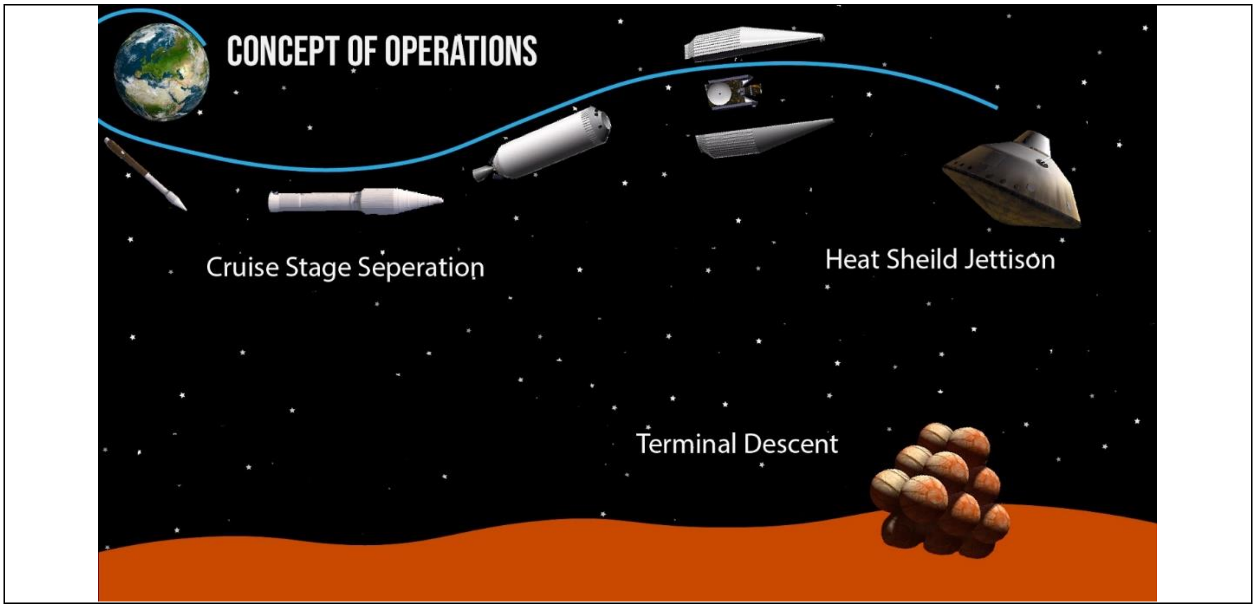
Critical Mission Success:

- Successful De-orbit landing on Jezero Crater.
- Identify local geography of Jezero Crater and determine sample gathering viability.
- Determine possible locations for H_2O sources and categorize geography based on geologic diversity.

Risks, Assumptions, and Constraints:

- Failure to De-orbit to the Martian surface.
- Failure of the Rover to record and or transmit data.
- Data yielded from data analysis yields no usable nor useful results.

1.2.4. Concept of Operations (Graphic)



The EDL sequence consists of the standard cruise stage separation after leaving Earth's atmosphere. After the spacecraft reaches the Martian atmosphere, the rover will be ejected out of the space craft. The parachute will be unleashed and then the airbags will be inflated. The rover will "bounce" on the mars surface until it has lost all of its kinetic energy. The airbags will be deflated and the rover will undergo a system verification system to ensure all of its components and instruments are functioning properly. Then the rover, assuming it landed successfully and is capable of moving, will carry out the mission objectives in Jezero crater.

1.2.5. Major Milestones Schedule

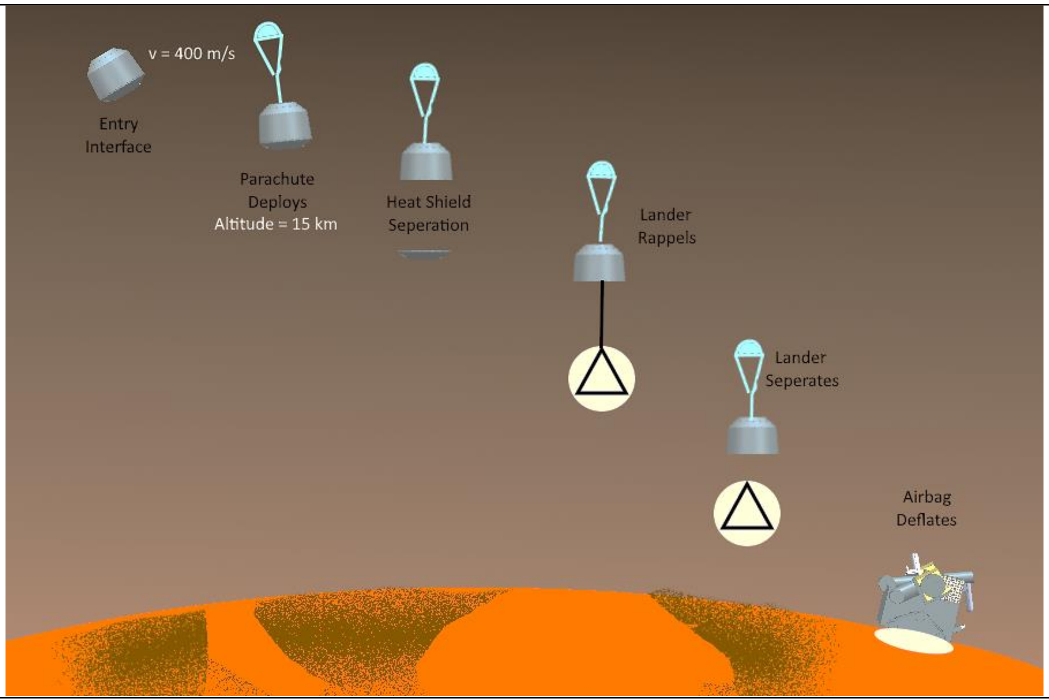
- **May 19, 2020:** Pre-Phase A - Conceptual Study
    - **Duration:** One (1) Day
    - Includes the theoretical rover mission assignment regarding sending a team designed rover to a mars landing site for a series of scientific objectives.
- **May 20 - June 21, 2020:** Phase A - Preliminary Analysis
    - **Duration:** Forty (40) Days
    - Includes determining the mission timeline, space path (EDL), destination, and purpose. It also consists of determining purpose driven rover instruments, and ground data system capabilities.
- **June 22 - July 12, 2020:** Phase B - Definition
    - **Duration:** Twenty-one (21) Days
    - Includes detailed technical solutions that embodies the mission's purpose with defined requirements, schedules, and specifications to initiate the system design and development phase. The experimenters are also divided into teams around a designated set of hardware.

- **July 13 - July 22, 2020:** Phase C - Design
    - **Duration:** Ten (10) Days
    - Includes detailing a manufacturing schedule, determining which components of the rover and spacecraft will be outsourced, the engineering and scientist hardware research is conducted, and designing the final rover and spacecraft.
- **July 23, 2020 - July 22, 2021:** Phase D - Development
    - **Duration:** One (1) Year
    - Includes the ATLO (Assembly, Test, and Launch Operations) process; the hands on assembly of all the fabrication of the designed components and procurement of outsourced instruments and parts. This phase also includes, the simulated interplanetary space environment tests the rovers and computer requirements and testing the ground systems that support the mission prior to launch.
- **July 23, 2021:** Launch Date
- **July 23, 2021 - February 23, 2022:** Spacecraft Conveyance
    - **Duration:** Seven (7) Months
    - It takes around seven months after the launch date for the rover to land on mars. This stage also includes the flight monitoring step.
- **February 24 - March 23, 2022:** Phase E - Verification
    - **Duration:** One (1) Month
    - After the launch, ground and rover connectivity and systems are checked and reviews to ensure proper communication and satisfied requirements to properly conduct the mission.
- **February 24, 2022 - February 24, 2025:** Phase E - Operations Phase
    - **Duration:** Three (3) Years
    - Includes the mission purpose driven instrument usage of the rover in the specified landing site. The rover is expected to operate for three years at Mars, but this phase can be extended far after the predicted lifeline of the rover.

1.3. Descent and Lander Summary

Hella Impact intends to be a large rover with constraints in volume (61cm x 71cm x 96cm), mass (180kg) and budget ($100M). In addition to the mass constraint awarded, an extra 72kg will be allocated to the entry, descent, and landing (EDL) phase of the project. This phase will include a heat shield, a parachute, and airbags.

The heat shield—serving as the main protection for the payload's entry to the Martian atmosphere— is made of ceramic ablator with a 0.35m diameter and 0.25m height and it is estimated to weigh 1.2kg. Its release will start at a 400km distance from Mars' surface with an entry angle of 11.5 degrees and a speed of 3,362m/s. The heat shield's contact with Mars' atmosphere will create enough friction to slow down most of the payload's initial velocity (around 90%), 4 minutes after atmospheric entry a parachute (located in the backshell) made out of polyester and nylon with a disk-bag-band configuration system will take place to further slowdown the payload to 7 percent its original speed. Lastly, an airbag strong enough to cushion the rover— made of Vectran (synthetic material)— will inflate seconds before being released and it's expected to bounce around 15 to 30 times before coming to a complete stop where the airbag will deflate at a one kilometer distance from its original release with destination Jezero. A total of four bags with 6 lobes each, these will be held together with a rope to give the bags shape and make inflation easier (3 gas generators are used for inflation).



- **Entry Angle:** 11.5 to mars surface
- **Height:** 400 km
- **Entry Speed:** 2.38 km/sec
- **Landing System:** Airbags

EDL Items	Mass (kg)	Prices
Heat Shield	1.2	3,000,000
Supersonic Parachute	8	3,000,000
Airbag	4	2,000,000
Transmitter package	.075	50,000
Total	**13.275**	**9,050,000**

- *Heat shield mass does not count towards EDL mass and budget cost*
- *EDL prices will be included in total budget.*
- *EDL allotted mass: 40% buffer to payload mass (in addition to awarded 180kg)*

Once the EDL system has been completed, the egress of the rover will begin. Deployment of the cameras will initiate the process by taking a visual survey of the surroundings— these visuals will provide information such as the presence of debris, airbag material, height of the rover with respect to the terrain and the viable paths the rover could take. Once the information is gathered, the high antenna is deployed to communicate to earth via X-band.

The PANCAM camera will then determine the sun's position (to serve as orientation). Soon after, the rover will stand up and perform the calibration of science instruments and be ready to drive on the Martian surface.

The rover is composed of a "warm electronic box" (WEB)—in charge of protecting the rover's electronics and computer as well as keeping them at a controlled temperature. Two Rover Compute Elements (RCEs) are placed in the rover's body (one serves a spare set) to communicate with the instruments in the rover to obtain data and commands. Mobilization will happen by means of a track system, this transportation style was chosen for its lower mass as well as its lower use in power.

1.4. Payload and Science Summary

Instruments:

To fulfill the objectives laid out within the mission overview (Section 1.2), the rover will be outfitted with several state-of-the-art science instruments. Given the procedural evolutionary nature of science instrument creation, those that would fit onto the rover would be ‘descendants’ of the following instruments, if not the instruments themselves.

- Panoramic Camera (PANCAM)
    - Pancam is a high-resolution color stereo pair of CCD cameras used to image the surface and sky of Mars.
- Subsurface Radar (RIMFAX)
    - The RIMFAX (**R**adar **I**mager for **M**ars' subsur**FA**ce e**X**periment) is a ground-penetrating radar designed to produce high resolution stratigraphic data about the Martian subsurface, whilst atop the surface of Mars.
- Rover Environmental Monitoring Station (REMS)
    - The Rover Environmental Monitoring Station (REMS) is an atmosphere/wind sensor data gathering instrument that will collect data about wind speed, wind direction, air temperature, and pressure.
- Radiation Assessment Detector (RAD)
    - The Radiation Assessment Detector (RAD) is a radiation sensor data gathering instrument will show how much radiation the surface of Mars is currently exposed to.

2. Evolution of Project

2.1. Evolution of Descent and Lander

- The team decided on implementing a supersonic parachute and a sky crane due to its functionality, but because the sky crane cost 40 million dollars, according to Astrobiobound, the team decided on a cheaper alternative which is a supersonic parachute and airbags as for the EDL sequence.
    - The Supersonic Parachute: The parachute price of $5,000,000 was meant for the opportunity rover, but because the mission rover is a lot lighter, there was a 40% cut in cost.
    - Airbags: The airbags price of $10,000,000 was meant for the opportunity rover, but because the mission rover is a lot lighter, there was a 80% cut in cost.

2.2. Evolution of Payload

- There were no design iterations as the rover was designed only to satisfy requirements for the mission.
    - After finding the main components that are required for the mission to be a success, cheaper alternatives were chosen to satisfy the budget limitations so there was no room for creativity.
    - The Hella Impact team members were also incapable of allocating a satisfactory amount of time for scientific and engineering research so only the minimum was achieved.
- Originally there was a 70% cut in quality and therefore costs in all instruments and components of the rover to meet the $100 million mission project budget, but more research was done as the component and instrument prices that were being used were for the curiosity and opportunity rover which had many more working components and a much larger mass. As a result, a select few did specific instrument and component based research to find instruments that can be bought by third parties or made space ready. These prices were attained through quotes and search engines.

2.3. Evolution of Mission Experiment Implementation Plan

- The mission statement started with an objective similar to all of the Mars 2020 Perseverance rover, but because of the budget constraints, the team focused on generally tackling a few based on the instruments that were affordable.
- There was very little debate on the landing site. The team chose Jezero crater because of how close it is to neighboring sites that can possibly be explored if the life of the rover were to be extended.

3. Descent and Lander Design

3.1. Selection, Design, and Verification

3.1.1. System Overview

The Hella Impact rover is comprised of powered instrument systems consisting of a solar power array system, environmental monitors, cameras, liquid heating, radiation monitor, and a subterranean radar. These packages are all attached to a 17 cm x 27cm x 30 cm, 20 mm thick Aluminum shell, which is steered by a caterpillar track tread system. Similar to the typical wheel architecture, the continuous track of the Hella Impact Rover is a series of interconnected coils with a rubber overlay. All the powered systems in combination with the shell and treads give the rover a total weight of 21.8 kg. The heat shield of the aeroshell is assembled of PICA tiles, like those used on the Heat Shield of the Curiosity rover. Based on relative size, the heat shield of the Hella Impact rover is expected to weigh 79.95 kg. The airbag structure and accompanying airbag envelopes have a combined weight of 8 kg. The backshell is composed of 25 mm thick honeycomb aluminum panels encased between two solid 6.35 mm thick aluminum sheets. This gives the backshell the necessary stability while maintaining the low weight necessary for the constraints. Mounted underneath the backshell is a mortar packed with a supersonic parachute similar to that of the Opportunity rover. The weight of the total backshell structure is 85 kg.

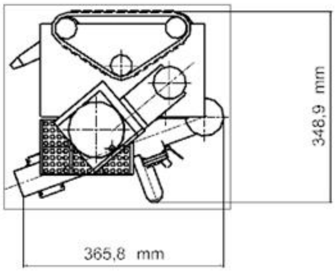
The rover is mounted inside the airbag structure using zip ties located at the bottom airbag panel. As the payload enters the Martian atmosphere, friction decelerates the payload to a velocity of 400 m/s. At an altitude of 15 km, on-board accelerometers trigger the parachute mortar, firing it off at Mach 1.7. The deployed parachute slows the rover down to 45 m/s. 20 seconds after parachute deployment, micro explosives separate the heat shield from the backshell. This causes the lander to hang from the de-escalating backshell. The airbags inflate, and the lander’s altimeters send a signal for spring-loaded scissors to sever the rappel tape at an altitude of 300 m. The inflated lander impacts with the surface of mars at a velocity of 13 m/s. Once the airbag comes to a standstill, the system deflates and unfolds, exposing the rover to the surface of mars. The ties around the tracks are set to cut when the airbag’s computer board receives the signal to force deflation, assuming the airbags have not already deflated upon impact.

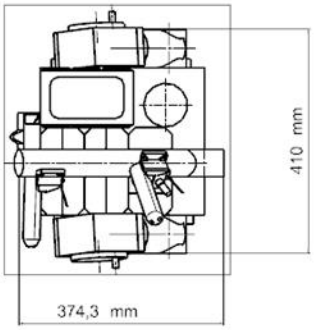
3.1.2. Subsystem Overview

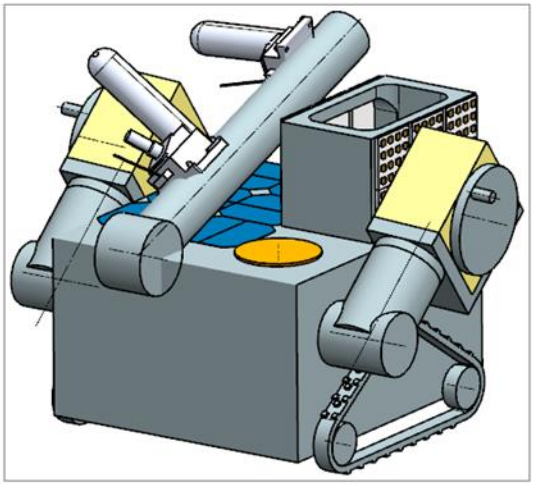
The rover’s Solar Power Array system consists of twelve 40 mm x 80 mm solar cell assemblies that weigh 4 grams each on average. The Cells provide power to the powered instruments of the rover, as well as to 3 Li-Ion batteries to store power when energy is not demanded from the solar cells. The environmental monitors, known as the REMS, consists of two separate booms each weighing around 150 grams each. Each boom is outfitted with a wind sensor, but only one has either a temperature sensor or humidity sensor. The booms have a height difference of 5 centimeters. The camera system is an adjustment of the PANCAM system, constant of two lenses attached to swiveling arms on either side of the rover. Given the shorter width of the rover compared to the Curiosity, the focal length of the cameras’ stereoscopic imaging is shorter. The liquid heating system consists of a powered pump moving liquid through plastic piping inside the rover, in order to maintain a consistent operating temperature among the instruments. The radiation monitor, known as the MSL RAD, is a large cylinder-like object atop a large block, altogether weighing 1.5 kg. The subterranean radar, known as the RIMFAX, consists of two modules, the radar itself mounted outside the rover’s shell, and the electronics which are housed within the shell. The low-gain x-band antennae is a 1U platform manufactured by enduroSAT. The rad-hardened main processor is a BAE RAD6000 microprocessor. The flash memory and DRAM are both manufactured by the New York-based computer manufacturer, DDC. All instruments connect through the VMEBus backplane to interact with the rover’s main computer board.

3.1.3. Dimensioned CAD Drawing of Entire Assembly

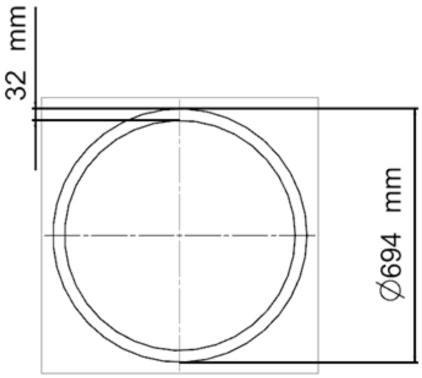
Rover

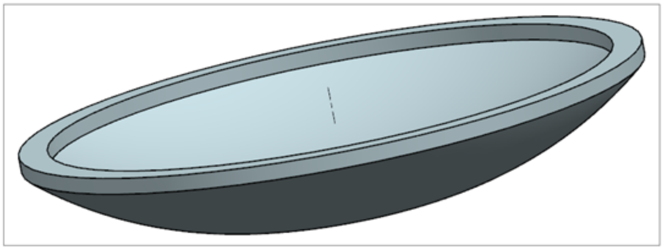


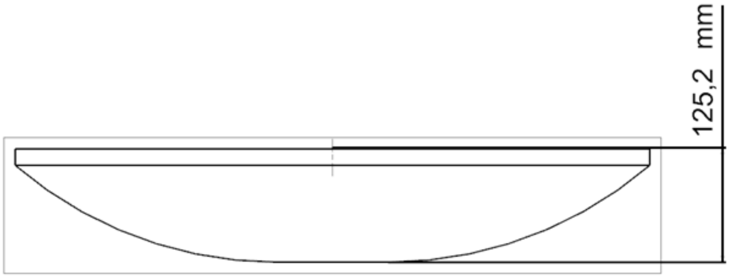




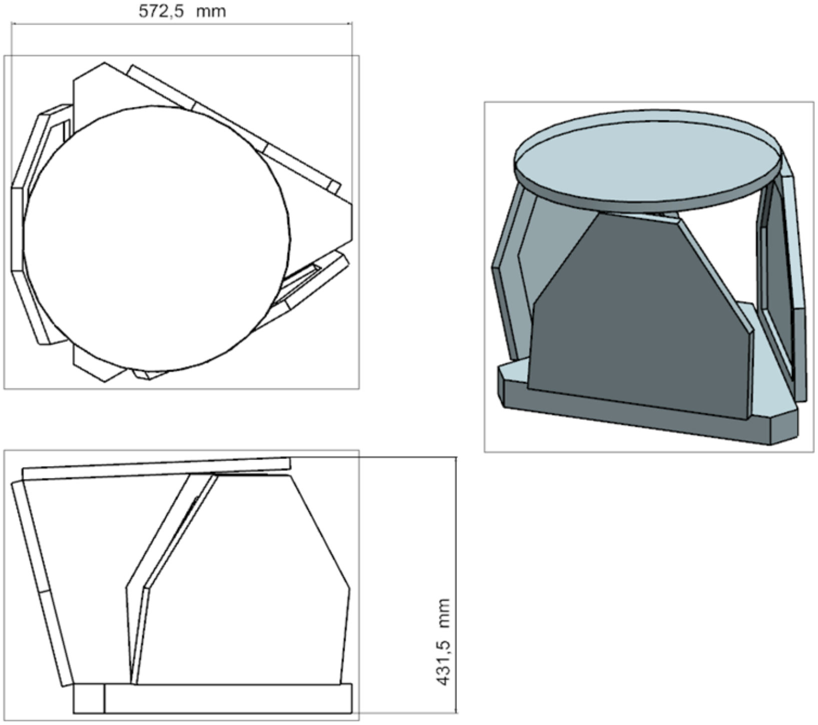
Heat Shield



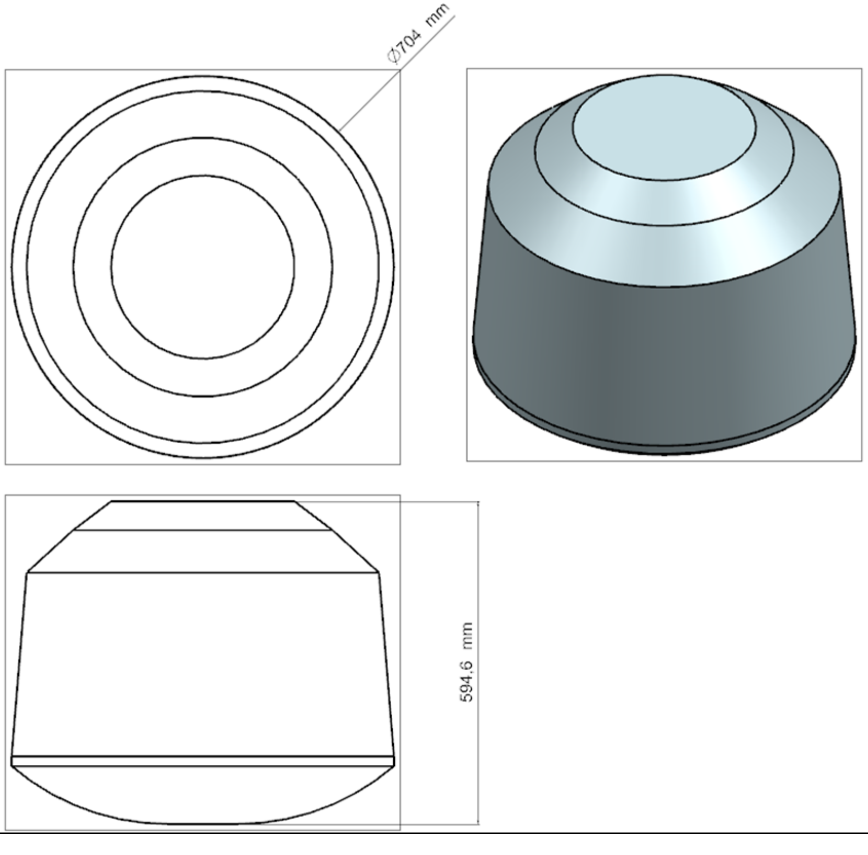




Airbag “Petal” Structure



Aeroshell



3.1.4. Manufacturing and Testing Plans

The antennae, solar cells, and VMEBus Backplane, and memory systems are all COTS parts. As the associated manufacturers are all veterans of the aerospace industry, testing of these parts is primarily to ensure compatibility among all systems. All scientific instruments already have documented use within the Mars Exploration Rover projects, and would again be tested for compatibility. Work to assemble the aeroshell, airbag structure, and main chassis would have to be outsourced to an outside manufacturing shop. Multiple drop tests would be necessary to ensure the airbag is weighed properly to land upright on the Martian surface. The micro-explosives in place between the backshell and heat shield would be tested by forcing the heat shield to reach atmospheric entry temperatures in a controlled environment, before the pyrotechnics at the connector's pins are set off. The parachute would have to be exposed to launch and deceleration testing to ensure no rips or significant bouncing occurs during descent. Assembly for a rack on the VMEBus would be performed in-house, demanding a short number of man-hours. Assembly of the complete lander would take up to 6 months, once all parts are received.

3.1.5. Validation and Verification Plans

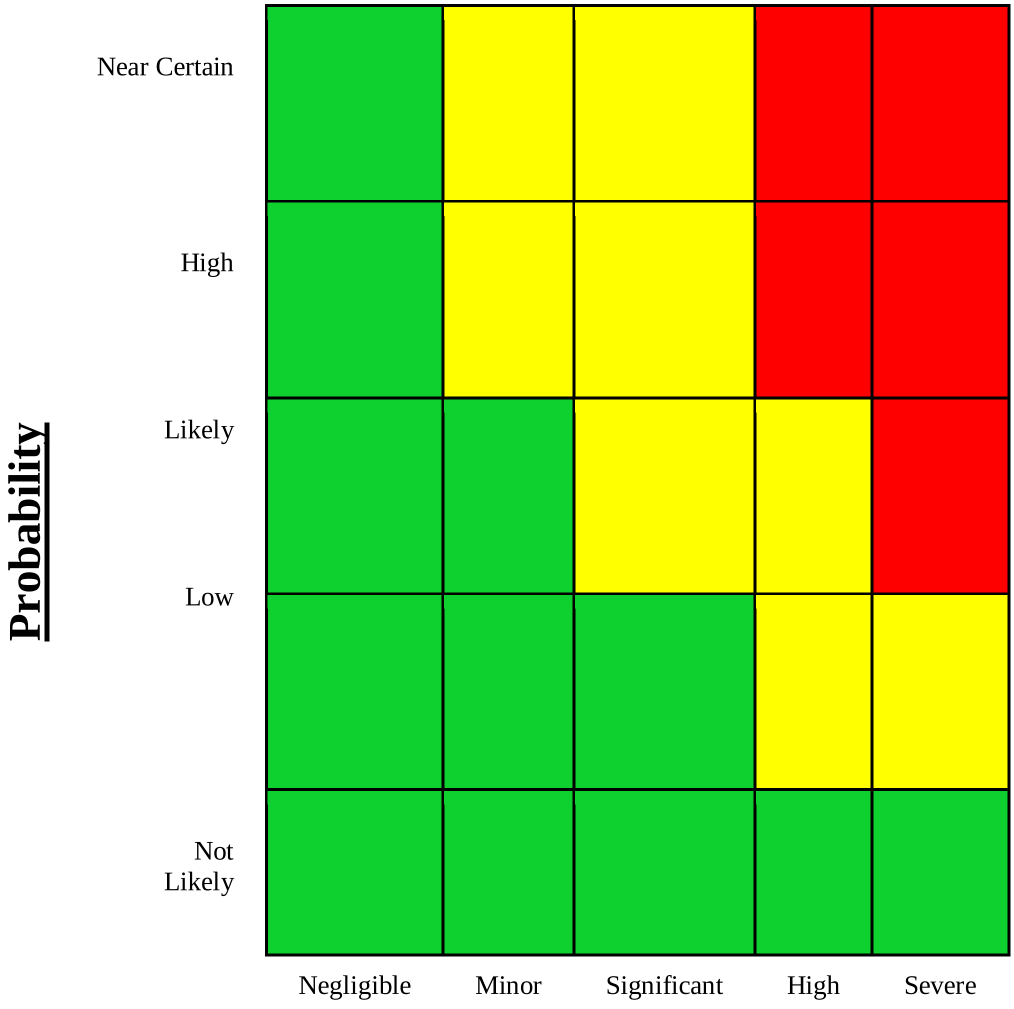
The validation and verification plans analyze how the rover and its components accomplish the outlined objective. This analysis includes a rigorous amount of testing before the final launch in preparation for the first mission. This testing will be broken up into three phases. In Phase 1, each rover component will be tested independently of the rover: this includes the Triple Junction Gallium Arsenides Solar Array, the Rover Environmental Monitoring Station (REMS), the Radiation Assessment Detector (RAD), two fully charged lithium-ion batteries, a standard microprocessor, the RIMFAX (Radar Imager for Mars' Subsurface Experiment), SSD and RAM memory cards, a low-gain antenna, and one medium-resolution camera. For more detailed explanations of each item, refer to sections 3.1.1 and 3.1.2.

Phase 2 is similar to Phase 1 and will occur after all subsystems have been properly integrated within the rover prior to the mission. More details regarding these steps can be found in section 4.2.5. There will be a one-month interim in which post-landing testing can be conducted during Phase 3 once the status of the rover can be confirmed and verified. The most crucial subsystem for accomplishing outlined objectives will be the RIMFAX, although peak conditions of all subsystems are inherently optimal. The RIMFAX will be the primary method of evaluating the rover's condition once it makes contact with the Martian surface.

It is through these evaluations of each component of the rover's primary systems and subsystems that potential failure modes can be uncovered. If said failure modes arise, swift design modifications will be made to avoid the rover becoming compromised during the mission. Through these tests, the objectives of the mission can be accomplished.

3.1.6. FMEA and Risk Mitigation

The following provides an analysis of possible failures that may occur throughout the descent and landing process of this mission, categorized by the likelihood of occurring and the severity of the impact on the mission. The figure below establishes a guide in determining what course of action to take with a given risk or failure.



Probability	Negligible	Minor	Significant	High	Severe
Near Certain	🟩	🟨	🟨	🟥	🟥
High	🟩	🟨	🟨	🟥	🟥
Likely	🟩	🟩	🟨	🟨	🟥
Low	🟩	🟩	🟩	🟨	🟨
Not Likely	🟩	🟩	🟩	🟩	🟩

Impact

Legend

- 🟢 Monitor for new developments
- 🟡 Manage and/or consider alternative plans
- 🔴 Change baseline plans

Using the risk matrix above as a reference, the following list of possible failure areas was established as well as methods of prevention.

Failure Event	**Effect**	**Likelihood**	**Prevention**
Failure of required parachute deployment	Ballistic landing; immediate mission failure	Low	Testing of parachute deployment reliability and performance
Failure of airbag function	Significant damage to rover; immediate mission failure	Low	Testing of airbag material strength and deployment
Rover does not land upright	Possible instrument damage	High	Airbag configuration maintains equilibrium
Communications system failure	Breach in data collection	Likely	Vigorous testing between rover and communications package
Power source malfunction	Collapse of rover systems	Low	Verification of power system reliability
Instrument malfunction	Impairment of data collection; possible mission failure	Likely	Thorough examination of instrument and communication connectivity

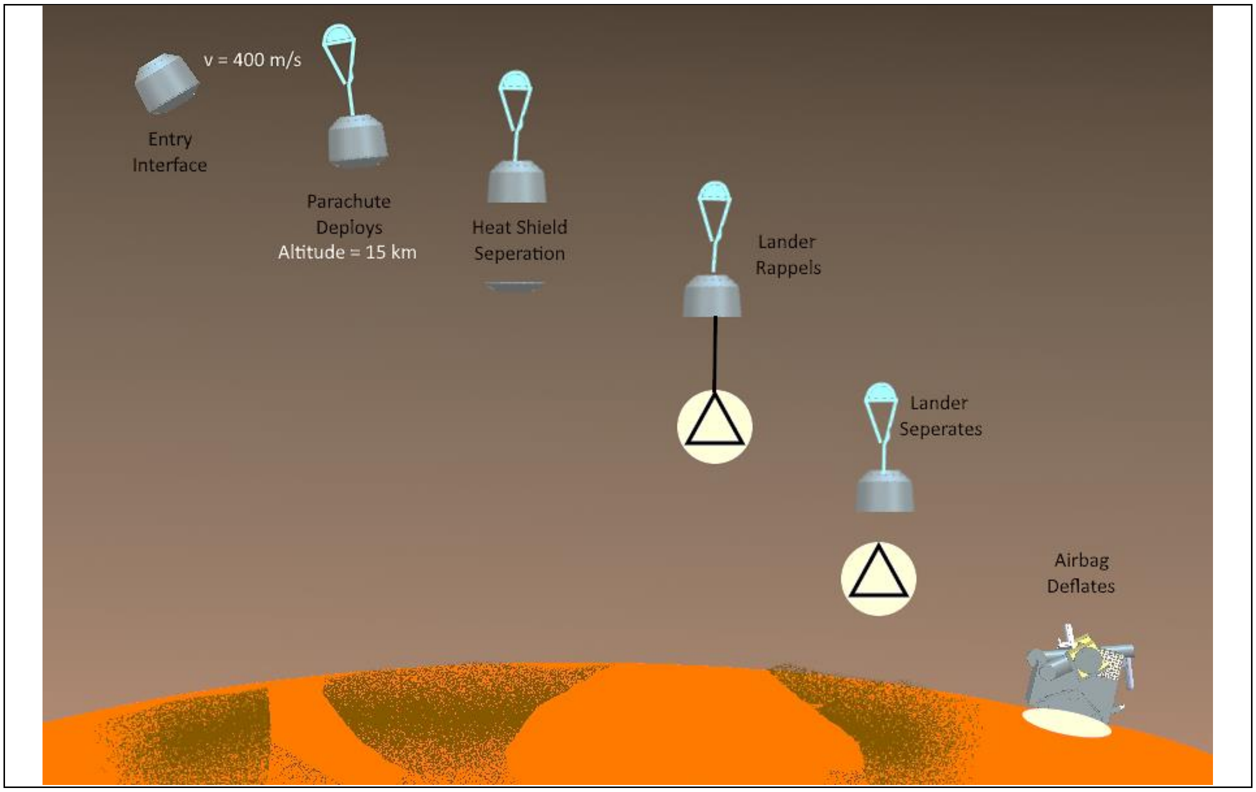
3.1.7. Performance Characteristics and Predictions

The payload's performing characteristics were decided based on several factors to ensure its success.

Geological and Climate Factors: The payload will land in Jezero crater (on the northern half of mars) during wintertime. The rover is expected to land in the afternoon while Earth is still in view, this to ensure earth receives a landing signal.

Overcoming Obstacles: The payload will enter Mars' terrain at a speed of 3,362 meters per second. During the first few minutes of descent, Mars' atmosphere in combination with the high drag heat shield will reduce the payload's kinetic energy. It is expected that the heat shield's drag in combination with the atmosphere's friction will reduce the kinetic energy by more than 90 percent (reducing the payload's speed to approximately 445 meters per second).

The addition of a parachute will further reduce the speed an extra 1 percent. In order to remove the remaining kinetic energy and ensure safe landing, an appropriate system was chosen to best fit landing obstacles while remaining in project's constraints—airbag landing system.



Entry, Descent and Landing System:

- **Aeroshell:** The entry vehicle, in charge of protecting the payload from heat. First in contact with the Martian atmosphere: it goes through a heating and deceleration stage. Its high drag in combination with the atmosphere's friction serve as the initial deceleration structure.
- **Parachute:** Its deployment further decelerates the payload to approximately 45 meters per second. Heat shield separation occurs at this stage.
- **Retro-rockets:** Soon after heat shield separation occurs, the landing system is put in place. Retro rockets decelerate the payload to about 13 meters per second and an airbag system descends prior to being dropped.
- **Airbag:** The airbag is dropped at 13 meters per second near Jezero—where it will bounce until coming to a stop. This system is used to further aid with cushioning, and was chosen based on the relatively small structure of the project.

3.1.8. Confidence and Maturity of Design

Designing a mission that not only meets mission criteria, but works, is of high priority. Several steps have been taken to improve the confidence of success. When analyzing potential risks, attributes such as likelihood and consequences are taken into effect. Risks will be prevented and limited as follows. Malfunctions in both the onboard instruments and power sources have been mitigated by comprehensive inspections. These systems have been properly examined to have exceptional reliability. To even better the success of the mission and meet the budget criteria. An airbag maneuver has replaced the original one of a skycrane. This significantly reduces the complexity of the landing process, which can be considered the most crucial. The airbags which will be used have been carefully tested to ensure their performance is up to par. In addition, the technology behind airbag deployment is undoubtedly proven to generate consistent results. Maneuvers such as landing facing earth for better signal transmission will be done to mitigate risk of signal loss. Other factors such as a small rover size will work hand in hand with the airbag landing. This weight advantage will help lower the stresses upon impact in comparison with a larger rover.

3.2. Recovery/Redundancy System

Debris Damaging Instruments:

- **RIMFAX:** If this instrument fails then the rover will still have three other capabilities. This includes the Medium-Resolution Camera, Radiation Assessment Detector (RAD), and Rover Environmental Monitoring Station (REMS).

- **Damaged Rover Environmental Monitoring Station (REMS)**: If this instrument fails then the rover will still have three other capabilities. This includes the RIMFAX, Medium-Resolution Camera, and Damaged Radiation Assessment Detector (RAD).

- **Damaged Radiation Assessment Detector (RAD):** If this instrument fails then the rover will still have three other capabilities. This includes the RIMFAX, Medium-Resolution Camera, and Rover Environmental Monitoring Station (REMS).

- **Damaged Medium-Power Solar Panel:** If the solar panels fail and the rover is incapable of recharging its batteries, then the mission will continue till the rover runs out of battery. Then the rover will be considered “dead” and the mission will come to a close.

- **Damaged Batteries:** If the batteries fail and the batteries are incapable of being recharged, then the mission will continue till the rover runs out of battery. Then the rover will be considered “dead” and the mission will come to a close.

- **Damaged Microprocessor:** If the microprocessor fails and is therefore incapable of performing roles such as command and control, payload processing, and other roles, then the rover will be incapable of using any of its instruments or components and will therefore, be considered “dead” and the mission will come to a close.

- **Damaged Main Bus:** If the communication interface (Main Bus) that enables the main computer to exchange data with the rover´s instruments and sensors fails, then the rover will be incapable of using any of its instruments or components and will therefore, be considered “dead” and the mission will come to a close.

- **Damaged Low-gain Antenna:** If the form of communication between the rover and satellite is cut, then the rover will be considered “dead” and the mission will come to a close.

- **Damaged Main Memory Cards:** If the rover cannot store data with the Main Memory Cards, then the rover will only operate during times it can immediately send collected data to home base, without storing the information.

- **Damaged Tracks:** If the tracks are damaged then the team will attempt to continue the mission, assuming it can partially move. If one side of the rover's tracks stops operating, then the rover will be incapable of moving. If that is the case then the team will collect as much data as they can of the specific region till the rover can no longer communicate with home base. Then the rover will be considered “dead” and the mission will come to a close.

- **Damaged Medium-Resolution Camera:** If this instrument fails then the team will be incapable of seeing where the rover is going, but they can still communicate with the rover if the Low-gain Antenna is still operating. If the Low-gain Antenna is still operating then the team will continue to roughly calculate where the rover is and is going to mission planned trajectory, using the instruments to collect data of an area rather than a specific location that needs to be viewed with the camera.

EDL Malfunctions:

- **Airbags:** If the airbags do not inflate before contacting the ground at Mars, then the rover will hit the ground at such a high speed that it will destroy the rover. If that happens then the mission will come to a close. If the airbags do inflate, but come into contact with a sharp meteorite or rock, then the airbags will continue to soften the landing of the rover until it loses all of its kinetic energy. As soon as it comes to a halt, the airbags will deflate, and the team will check for any damages in the rover from the puncture. If an instrument no longer operates, please refer to the "Plan B" for that specific instrument.
- **Parachute Deployment:** If the parachute deployment fails and cannot be used in the EDL process, then the rover will follow the next EDL mechanism, the Airbags.

3.3. Payload Integration

All of the rover instruments will work independently. These sensors will generate data from its environment, store the information in the rover, and then send the data to home base through the rover antenna.

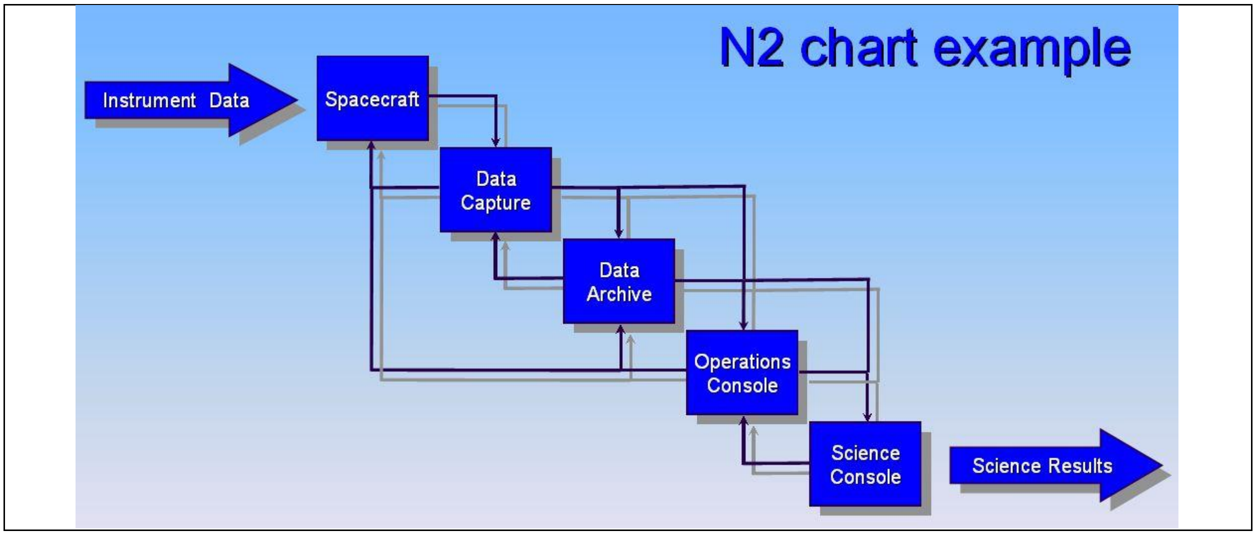
All of the components and instruments will be powered by the rover batteries which will be charged by the rover solar panels that satisfy the power demand from all instruments and components working simultaneously.

In summary, all components and instruments need to be charged and all instruments use the components needed to send the collected information to home base.

4. Payload Design and Science Experiments

4.1. Selection, Design, and Verification

4.1.1. System Overview - N^2 Chart



Medium-Power Solar Panel (Triple Junction Gallium Arsenides Solar Array)

- **Purpose:** Power
- Acceptance Values
    - **Voltage:** 2350 mV
    - **Min. average current Iop avg @ V:** 444 mA
    - **Min. individual current Iop min @ V:** 417 mA
- **Description:** The specific Triple Junction Solar Cell is called the GaAs Junction Solar Cell 3G30C. It will be the only power source of the rover. The panel will consist of 20 cells. It is a solar cell that will be attached to the rover and satisfy all requirements in powering instruments and rover components.

Low-gain Antenna (Endurosat X-Band Patch Antenna)

- **Purpose:** Communication
- **Description:** The Low-gain Antenna is the only method of sending data to Earth from the rover.

4.1.2. Subsystem Overview

Atmosphere/Wind Sensor (Rover Environmental Monitoring Station (REMS))

- **Purpose:** Data Gathering Instrument - Atmosphere/Wind Sensors
- **Description:** The Rover Environmental Monitoring Station (REMS) will collect data about wind speed, wind direction, air temperature, and pressure.

Radiation Sensor (Radiation Assessment Detector (RAD))

- **Purpose:** Data Gathering Instrument - Radiation Sensor
- **Description:** The Radiation Assessment Detector (RAD) will show how much radiation the surface of Mars is currently exposed to.

Radar Imager for Mars' subsurFAce eXperiment (RIMFAX)

- **Purpose:** Data Gathering Instrument - Ground Sensor
- **Description:** The RIMFAX is a ground-penetrating radar that uses radar waves to see geologic features under the surface.

Medium-Resolution Camera (PANCAM)

- **Purpose:** Photography Instrument
- **Description:** The Medium Resolution Camera will provide the team operating the rover with visuals of the terrain in Mars and the Path of the Rover.

2 GB of flash memory (SSD)

- **Purpose:** Hardware/Functionality - Main Memory Card
- **Description:** The 2 GB of flash memory (SSD) will be the method of storing data during times where the Antenna cannot send collected data to the Space Probe that sends it to Earth.

256 MB of dynamic random access memory (RAM)

- **Purpose:** Hardware/Functionality - Main Memory Card
- **Description:** The 256 MB of dynamic random access memory (RAM) will perform calculations on the data retrieved from the 2 GB of flash memory (SSD).

Standard Microprocessor (RAD6000)

- **Purpose:** Hardware/Functionality - Standard Microprocessor
- **Description:** The IBM RAD6000 Microprocessor provides the necessary functions needed to receive commands and send data.

Main Bus (VMEbus)

- **Purpose:** Hardware/Functionality
- **Description:** The Main Bus is a communication interface that enables the main computer to exchange data with the rover´s instruments and sensors.

On-board Battery (Two Lithium-Ion Batteries with a charge of 42 Ah)

- **Purpose:** On-board Battery Array
- **Description:** The Two Lithium-Ion Batteries will store excess power from the solar panels and power the rover when under hibernation.

GROVER Tracks (Greenland Rover and Goddard Remotely Operated Vehicle for Exploration and Research Tracks)

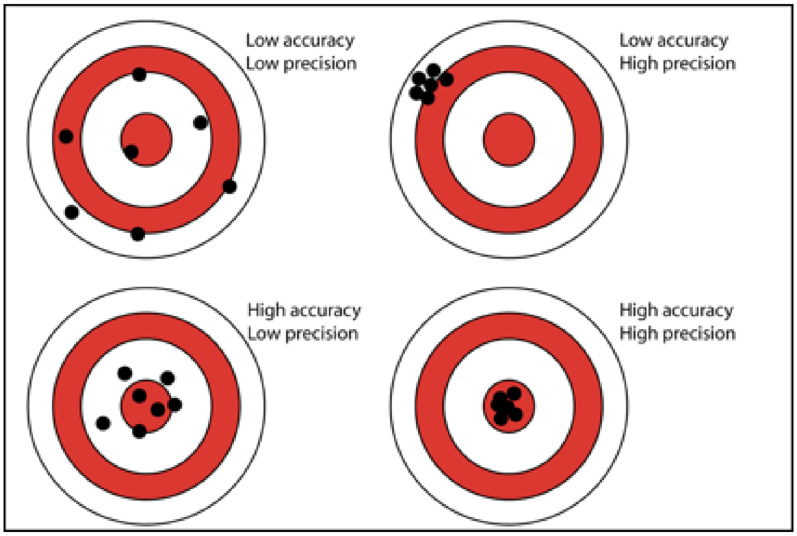
- **Purpose:** Motion
- **Description:** The Tracks will be the method of movement for the rover.

4.1.3. Precision of Instrumentation, Repeatability of Measurement, and recovery system

Accuracy and Precision

Accuracy is how close a measurement is to the correct value for that measurement. The precision of a measurement system refers to how close the agreement is between repeated measurements (which are repeated under the same conditions). Measurements can be both accurate and precise, accurate but not precise, precise but not accurate, or neither.

Low accuracy, high precision



High accuracy, low precision: The hits are all close to the center, but none are close to each other; this is an example of accuracy without precision.

Low accuracy, high precision: The hits are all close to each other, but not near the center of the bullseye; this is an example of precision without accuracy.

Precision is sometimes separated into:

- Repeatability — The variation arising when all efforts are made to keep conditions constant by using the same instrument and operator, and repeating the measurements during a short time period.
- Reproducibility — The variation arising using the same measurement process among different instruments and operators, and over longer time periods.

Accuracy and Precision This is an easy to understand introduction to accuracy and precision.

Error

All measurements are subject to error, which contributes to the uncertainty of the result. Errors can be classified as human error or technical error. Perhaps you are transferring a small volume from one tube to another and you don't quite get the full amount into the second tube because you spilled it: this is human error.

Technical error can be broken down into two categories: random error and systematic error. Random error, as the name implies, occurs periodically, with no recognizable pattern. Systematic error occurs when there is a problem with the instrument. For example, a scale could be improperly calibrated and read 0.5 g with nothing on it. All measurements would therefore be overestimated by 0.5 g. Unless you account for this in your measurement, your measurement will contain some error.

How do accuracy, precision, and error relate to each other

The random error will be smaller with a more accurate instrument (measurements are made in finer increments) and with more repeatability or reproducibility (precision). Consider a common laboratory experiment in which you must determine the percentage of acid in a sample of vinegar by observing the volume of sodium hydroxide solution required to neutralize a given volume of the vinegar. You carry out the experiment and obtain a value. Just to be on the safe side, you repeat the procedure on another identical sample from the same bottle of vinegar. If you have actually done this in the laboratory, you will know it is highly unlikely that the second trial will yield the same result as the first. In fact, if you run a number of replicate (that is, identical in every way) trials, you will probably obtain scattered results.

As stated above, the more measurements that are taken, the closer to knowing a quantity's true value. With multiple measurements (replicates), the precision of the results can be judged, and then apply simple statistics to estimate how close the mean value would be to the true value if there was no systematic error in the system. The mean deviates from the "true value" less as the number of measurements increases.

4.1.4. Validation and Verification Plan

- Identification and preparation:
    - Budgeting and instrument selection:
        - Budgeting issues were the primary concern throughout the project regarding the selection of scientific instruments for the rover.
        - With a maximum budget of $100 million, the most important instrument to be included onto the rover was the RIMFAX (Radar Imager for Mars' Subsurface Experiment), subsystems were otherwise relatively inexpensive.
        - Supplementary systems are also listed in Section 3.1.5 and specific details about the budget can be found in Section 6.1.

- Planning and Development:
    - Scientific Instrument Testing:
        - RIMFAX (Radar Imager for Mars' Subsurface Experiment)
            - Testable through measuring both the average frequency range of 150 to 1200 megahertz, as well as measuring the average data return of 5 to 10 kilobytes per sound location. Returning both these averages ensures a working RIMFAX.
        - RAD (Radiation Assessment Detector)
            - The Radiation Assessment Detector can be tested by passing through various particles, both neutral and radioactive in nature, and characterizing them. If the RAD properly determines the qualities of the particle that are passed through it, then the RAD is deemed operational and can be used at launch.
        - REMS (Rover Environmental Monitoring Station)
            - The Rover Environmental Monitoring Station will primarily be used to measure ambient weather such as temperature and wind speeds. Dust storms created within the Martian atmosphere pose a significant-enough threat to warrant testing the REMS.
                - The REMS itself can be placed in a sterile environment to gather ambient weather data to determine functionality. If the values appear irregular, then it will not be added to the rover until it is properly fixed and approved for launch.

- Execution:
    - Additional Pre-launch Testing:
        - Testing each of the instruments will increase the confidence level that they will be operational and the time of the rover landing.
        - The tests listed above can be duplicated as many times as necessary, but as long as enough tests are complete with little outliers, an abundance of redundancy is ultimately unnecessary.

- Reporting:
    - Reporting each scientific instrument:
        - Individual reports will be created for each of the primary scientific instruments.
            - This will ensure that every instrument is working at peak performance at the time of the rover launch.
            - These reports will include testing details relevant to each specific scientific device. This report will be used as a reference in the event that any instrument cannot pass the testing phase before the rover is launched.

4.1.5. FMEA and Risk Mitigation

This section focuses on developing a (FEMA) and risk mitigation plan using hazard identification and risk assessment.

The four basic components used within the risk matrix found in section 3.1.6 includes:

- Hazard identification (identify)
- Hazard profiling (access)
- Control measures
- Review

Please refer to section 3.1.6 (FEMA and Risk Mitigation) for evidence that sufficient analysis has been performed to show the most likely points of failure and how the following risks shall be addressed using the Validation and Verification Plan found in section 4.1.4.

4.1.6. Performance Characteristics

This section will focus on the performance characteristics of the Rovers internal and external systems.

Power:

Using the Triple Junction GaAs Junction Solar Cell 3G30C energy of light will be converted into electricity using a physical and chemical phenomenon. The maximum radiance of sunlight on Mars is about 44% than on Earth. The measure of the solar energy that is incident upon Mars is only about 590 W/m2 compared to about 1370 W/m2 at the Earth's surface.

Communication:

The low-gain antenna will be used in order to send data to earth. Using the orbiter with much longer antennas it can take about 5 to 20 minutes before a signal can be sent back to earth depending on the Rovers position on the Martians surface.

Radar Imagery:

The RIMFAX will be used as a ground penetrating radar. Radar waves will be used to see geologic features under the surface. Penetration depth will be greater than 30 feet (10 meters) depending on materials. Frequency range will be 150 to 1200 megahertz. The following data return will be 5 to 10 kilobytes per sounding location.

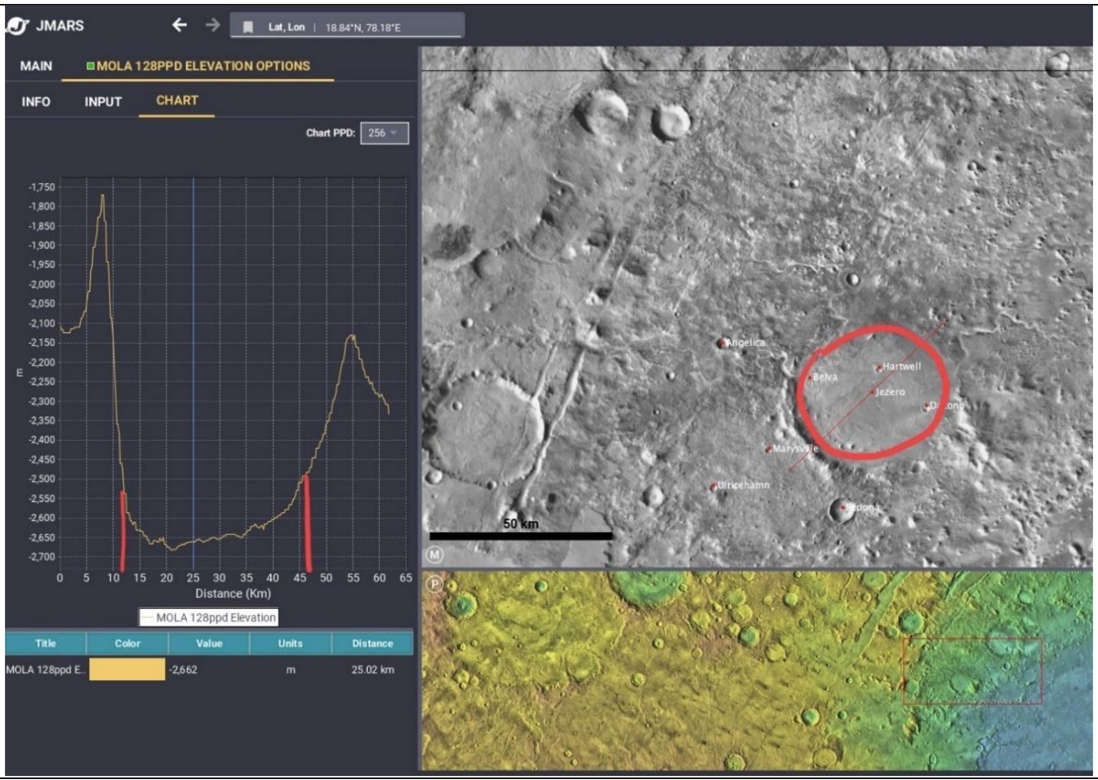
4.2. Science Value

4.2.1. Science Payload Objectives

The aim of the UOM mission is to cache data in order to understand Mars Martian surface for future human exploration. Radar imagery for Mars will be used to see geologic features under the surface with ground penetrating radars by producing high-resolution stratigraphic information.

4.2.2. Creativity/Originality and Uniqueness/Significance

Jezero crater is an ideal choice for this mission because there is so much to study there. First of all, it’s a large, rather flat and low landing site that is not too close to the poles, which is ideal for human presence. Also, there is plenty of potential scientific data to be further collected and studied by humans since it was believed to be an ancient Mars river delta. Below are images of the landing site provided by JMARS. There is a scientific research area of about 1250 square kilometers. The chart below shows exactly how relatively flat and low the crater is compared to the surrounding area.



Lat, Lon | 18.84°N, 78.18°E

Chart PPD: 256

Title	Color	Value	Units	Distance
MOLA 128ppd E..	🟨	-2,662	m	25.02 km

4.2.3. Payload Success Criteria

UOM will be a success if the following occurs:

- Successful de-orbit landing.
- The collection of data and/or transmit of data.
- Mechanism by which power is transmitted from the engine to the wheels of the Rover.

4.2.4. Describe Experimental Logic, approach, and method of investigation

Due to the smaller size of the mission, the team have made the most out of the instruments that were chosen and the planned objectives. REMS and RAD have the specific objective of collecting data to see what types of hazards humans may encounter in a future mission to Mars in order to plan accordingly. The goal of it is to know the kinds of atmospheric conditions and possible radiation humans might be exposed to when there. The purpose of RIMFAX is to survey the ground for a potential permanent presence on Mars. This instrument would allow us to plan how these structures could be built from a civil engineering perspective. The goal of it is to know the composition of the ground not only at the surface, but deep within the planet.

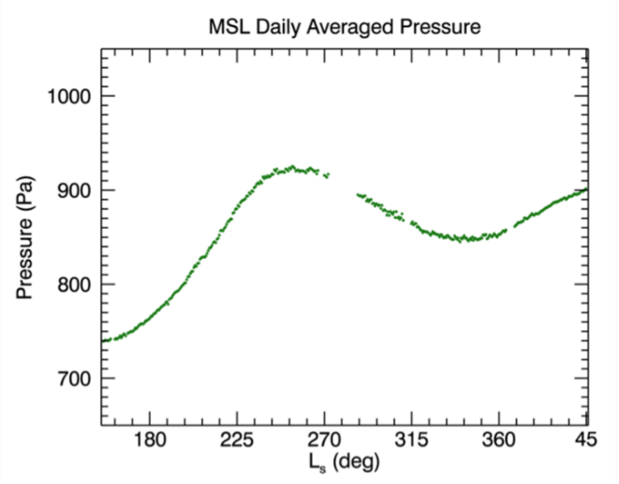
4.2.5. Describe Testing and Measurements, including variables and controls

Testing the rover will involve testing the ability of the sensor instruments to accurately read and analyze the environment. The only way for the instruments to be tested for accuracy and precision is to make measurements of the environment in the environment after landing. All components of the rover will be stress tested before the mission, but after landing, the team can only predict what the values should be based on predictions backed by science and previous missions. With these predictions, the team can determine whether or not the data is accurate.

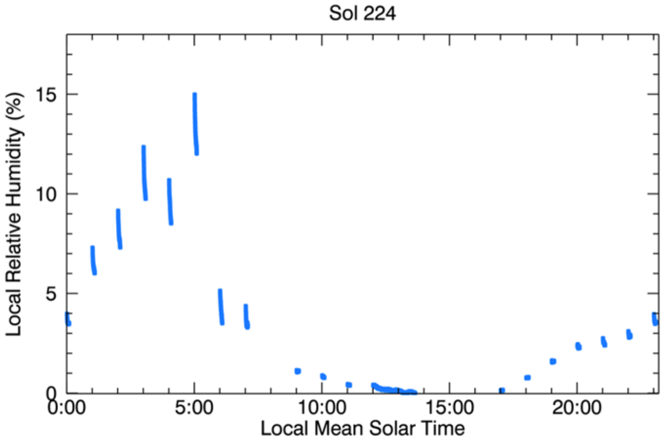
4.2.6. Show expected data & analyze (error/accuracy, data analysis)

The REMS' six sensors are expected to output raw data which can be analyzed to generate charts regarding five properties of the Mars environment: Temperature, Humidity, UV Flux, Pressure, and Wind Data. In the cases of Temperature, Humidity, UV Flux, and Wind Data, the sensors inside the Booms are calibrated to record responses as well as the timing of said responses. The standout, Pressure, records pressure responses from beneath the rover alongside the solar latitude of said responses occurring. These would look similar to the following charts gathered from the Curiosity.

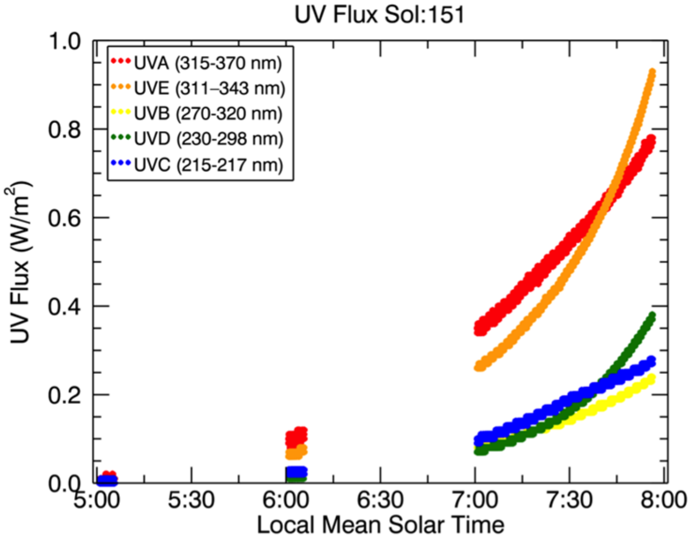
Pressure (Accuracy of 20 Pa)



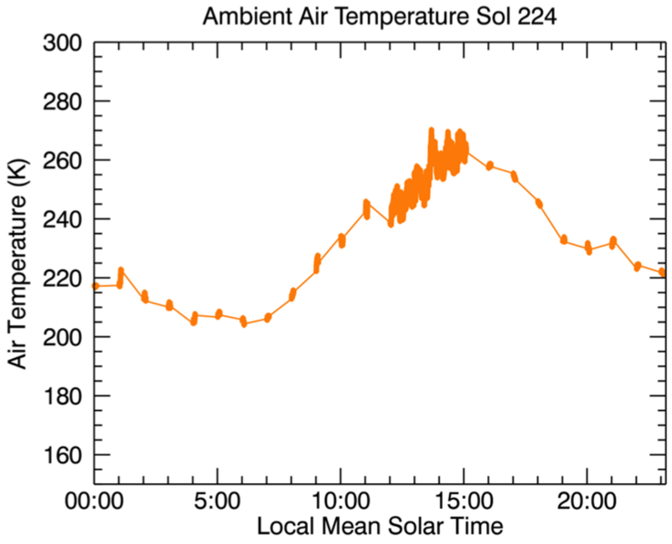
Humidity (Accuracy of 10%)



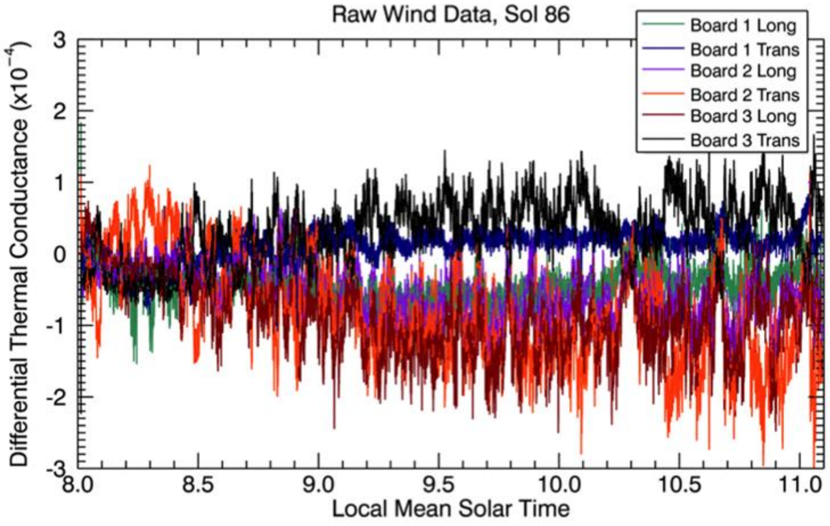
UV Flux (Accuracy of 8%)



Air Temperature (Accuracy of 5 K)

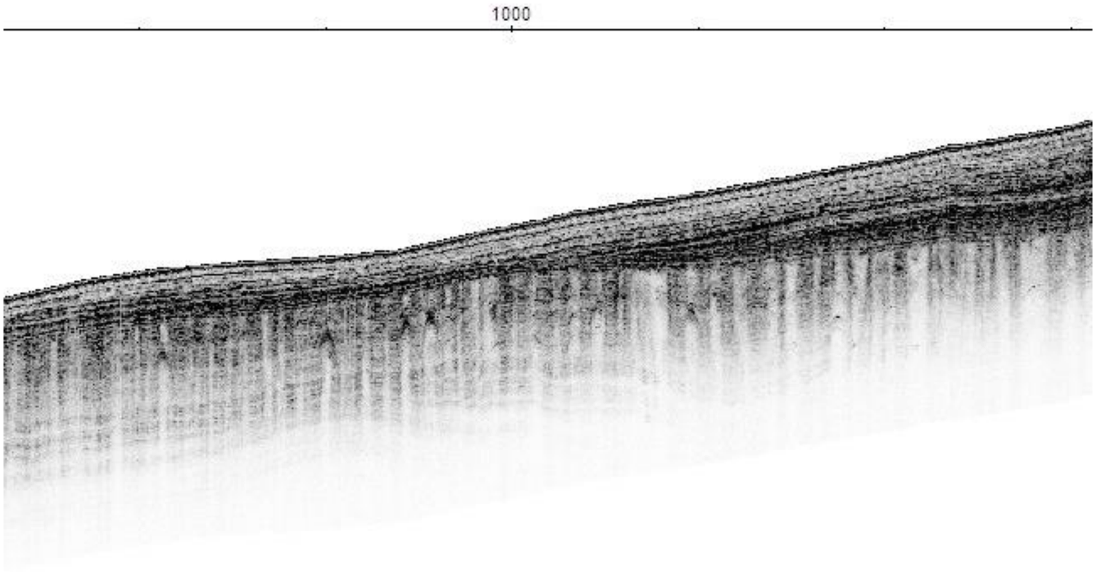


Wind Speed and Direction (Accuracy of 70 m/s in speed and 30-deg in direction)

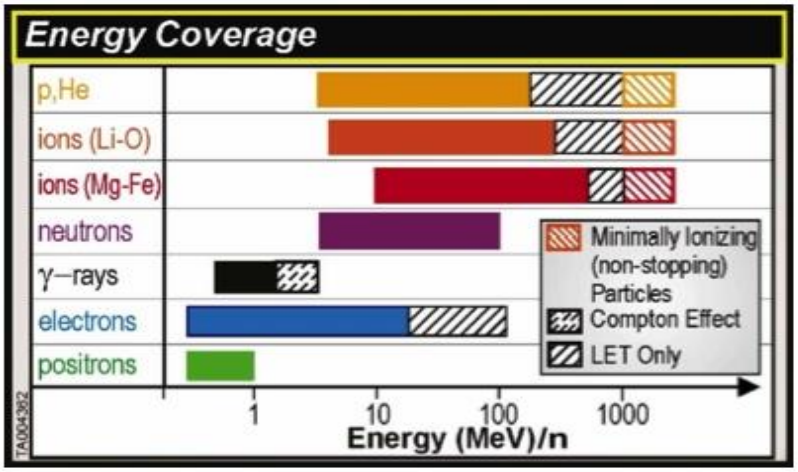


The RIMFAX is tuned to record the stratigraphic data of the regolith as the rover crosses the area. Thus, it outputs an image that could be observed as the cross-section of the Martian surface beneath the radar. Comparing the layered image to the images given off by GPRs used on Ice, Water, or dirt, reveals what the composition of the regolith is at these points.

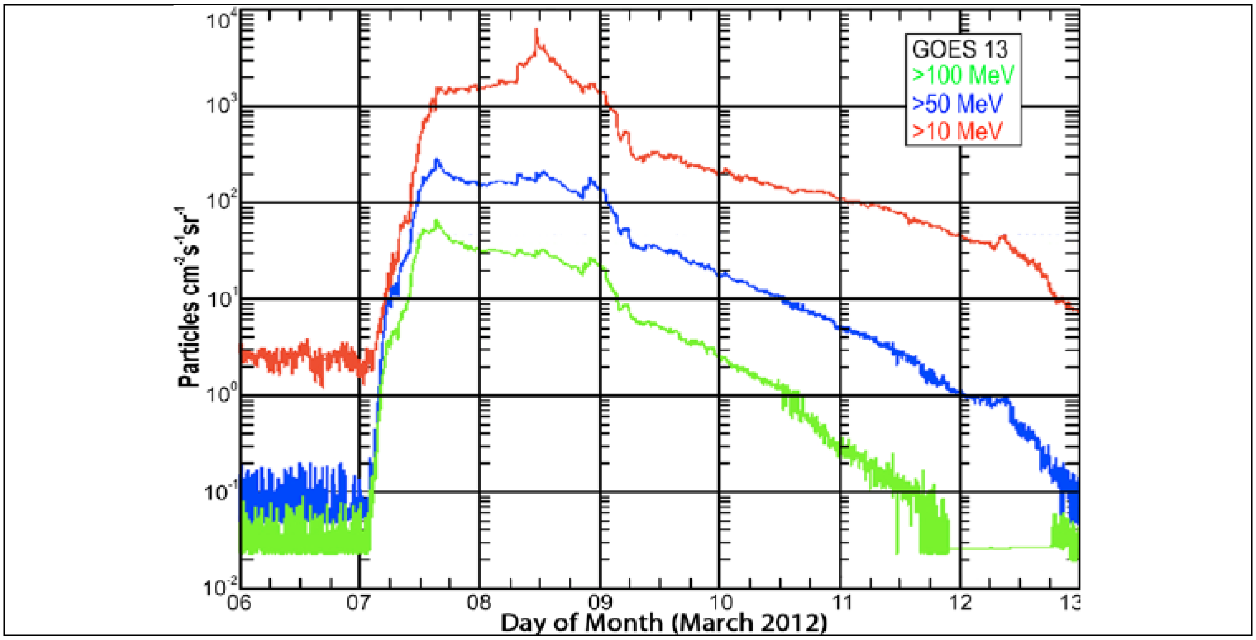
RIMFAX Imaging



The RAD is designed for analysis coverage of the following positive and neutral particles:



The data output from the RAD is used to produce histograms like the one presented below. The RAD outputs a file showing its observations during each sol. The intensity of energy within the ranges of the legend can be analyzed to determine what particles are present during the rover's observations.



5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

Safety Officer: Rey Maldonado
Responsibilities: The Safety Officer is involved in the safety section of the Mission Proposal (PDR). They identify and address all of the safety concerns with all engineering and scientific concepts for personnel and environmental hazards.

5.1.2. List of Personnel Hazards

Employee Dropouts: Team members that leave the mission for other opportunities.
Natural/Environmental/Health Accidents: This includes events that cannot be controlled like employee contracting diseases or sicknesses, employee car or home accidents, etc.
Hazardous Material and Chemical Risks: Any combustible liquid, compressed gas, organic peroxide, or oxidizer that is explosive, flammable, pyrophoric, unstable (reactive), or water-reactive.
Hazardous Physical-Machinery/Equipment Risks: The dangers of handling large or sharp moving equipment.
Site Accidents: This includes power outages, temporary site quarantine, local criminal activity, or site security breaches.

5.1.3. Hazard Mitigation

Reduce Employee Turnovers:

- **Predict and Marginalize Cost:** A percentage of the mission budget will set aside for unexpected expected expenses in hiring a new employee if necessary.
- **Encouraging to stay:**
    - Encourage generosity and gratitude
    - Recognize and reward employees
        - People want to be compensated well. They need to cover standard expenses like housing, utilities, and food most people want enough money for extras.
    - Offer flexible hours
    - Pay attention to engagement
    - Prioritize employee happiness
        - The goal here is to create an encouraging, positive work environment. When employees feel respected, acknowledged, desired, and motivated, they are more likely to stay. Best of all, this method to decrease employee turnover is free.
    - Make opportunities for development and growth

Natural/Environmental/Health Accidents:

- **Predict and Marginalize Cost:** A percentage of the mission budget will set aside for unexpected expected expenses in temporary employee leave.

Hazardous Material and Chemical Risks:

- **Hazardous Labels:** Ensure all waste containers must have the Hazardous Waste Accumulation label on the container. The label is to be filled out completely at the accumulation start date including physical state, Hazardous and container contents.
- **Safety Training:** All team members will receive training on safety precautions when dealing with hazardous material and chemical risks.
- **PPE (Personal Protective Equipment):** All personnel will receive and work with safety equipment like HAZMAT suits, respiratory protection, and eye protection.

Hazardous Physical-Machinery/Equipment Risks:

- **Safety Training:** All team members will receive training on safety precautions when dealing with equipment and tools.
- **PPE (Personal Protective Equipment):** All personnel will receive and work with safety equipment like gloves and boots.

Site Accidents:

- **Predict and Marginalize Cost:** A percentage of the mission budget will set aside for unexpected expected expenses in hiring a new employee if necessary.
- **Security Personnel:** The site will not be open to the public and the site will be only open to employees.

5.2. Lander/Payload Safety

5.2.1. Environmental Hazards

Hazard ID	Hazard Title	Description
01	Space Debris	Cause damage to the instruments and rover during descent and landing.
02	Extreme Temperature	Temperatures on the ground can range from 71°F (22°C) during the day to -146°F (-99°C) at night— the most threatening is the extreme cold at night since some of the vital components of the rover (battery, computer, and some electronics) cannot survive at such temperatures.
03	Dust Storms	Mars has semi-frequent dust storms that can occasionally turn into huge/planet-wide dust storms. Since some storms can last days, weeks, or even months, the biggest risk posed by this phenomena is the lack of vital sunlight needed for the rover's function.
04	Ionizing Radiation	Damage within electrical equipment as a result of ionization radiation, occurring especially during conveyance.
05	Transportation	Mobilization on Martian surface could present issues such as getting stuck in the terrain (due to large boulders or small sand like gravel).

5.2.2. Hazard Mitigation

Hazard ID	Hazard Title	Description
01	Space Debris	Constant monitoring to avoid their encounter is necessary. Although the path to be taken has been carefully chosen, monitoring and making changes (if necessary and if time allows) will be of top priority. Preparation is especially important considering the 14 minute delay and the 7 minute window of no communication leading up to the landing.
02	Extreme Temperature	To take care of harmful extreme temperatures, the sensitive equipment will be placed in the warm electronics box (in the rover's body) which will insulate the heat generated by the heaters placed inside. Additionally, a sensor will be located inside to keep track of temperatures and adjust it if necessary.
03	Dust Storms	Mars orbiters will serve as the biggest line of defense from Martian dust storms as they can monitor changes in the atmosphere. Continuous monitoring of atmospheric changes will allow for better preparation in cases such as energy reservation, acknowledging incoming storms will lead to stopping all work to allow the rover to ride in low power until enough sunlight is available to resume operations.
04	Ionizing Radiation	Ionizing radiation will be avoided by implementing radiation shielding on all essential electronic devices. Adequate testing on earth will be performed to ensure the electronics wont get damaged by radiation. The rover's landing site was chosen after thorough review of satellite information and was awarded the most optimal in regards to any debris or hazardous objects.
05	Transportation	The tracks on the rover were specifically designed and tested to withstand the surface of Mars and any unforeseen hazard on the Martian surface.

6. Activity Plan

6.1. Budget

Instrument and Component

Below is a table of the breakdown of mission rover’s instruments and components.

- The rover’s primary instruments for performing tasks in the selected Mars landing sites are the Atmosphere/Wind Sensors, Radiation Sensor, and RIMFAX.
- The rover will resort to solar power to power it’s instruments and necessary components and batteries to store said power.

You can find descriptions about their purpose in section 4.1.1 and 4.1.2 and descriptions about their cost below *Table 6.01*.

Instrument and Component Summary		
Item(s)	**Weight**	**Cost per Unit**
Atmosphere/Wind Sensor (Rover Environmental Monitoring Station (REMS))	0.9 kg	4,000,000
Radiation Sensor (Radiation Assessment Detector (RAD))	0.5 kg	7,500,000
Radar Imager for Mars' subsurFAce eXperiment (RIMFAX)	3 kg	5,000,000
Medium-Power Solar Panel (Triple Junction Gallium Arsenides Solar Array)	7 kg	6,320
On-board Battery (Two Lithium-Ion Batteries with a charge of 42 Ah)	2.3 kg	1,500,000
Standard Microprocessor (RAD6000)	0.5 kg	700,000
Main Bus (VMEbus)	2.3 kg	1,000,000
Low-gain Antenna (Endurosat X-Band Patch Antenna)	0.5 kg	2,000,000
Main Memory Card (Rad Hard 256 Mb SDRAM 8-Meg X 8-Bit X 4-Banks Memory)	0.5 kg	20,000
GROVER (Greenland Rover and Goddard Remotely Operated Vehicle for Exploration and Research) Tracks	3.8 kg	4,500,000
Medium-Resolution Camera (PANCAM)	0.5 kg	5,000,000
Payload Total	**21.8 kg**	**$31,226,320**
EDL Supersonic Parachute	8 kg	3,000,000
EDL Airbags	4 kg	2,000,000
EDL Transmitter Package	.075	50,000
EDL Total	**12.075 kg**	**$5,050,000**
Final Total	**33.875 kg**	**$36,276,320**
		Table 6.01

Atmosphere/Wind Sensor (Rover Environmental Monitoring Station (REMS)):

- **Cost:** $4,000,000
- **Weight:** 0.9 kg
- **Cost Description:** The cost of the of radiation sensor is $5,000,000 according to Astrobiobound, but was given a 20% is cut because the complete range of capabilities of the original instrument is not necessary for this mission. The final cost is $4,000,000.
- **Source(s):** Astrobiobound

Radiation Sensor (Radiation Assessment Detector (RAD)):

- **Cost:** $7,500,000
- **Weight:** 0.9 kg
- **Cost Description:** The cost of the of radiation sensor is $15,000,000 according to Astrobiobound, but was given a 50% is cut because the complete range of capabilities of the original instrument is not necessary for this mission. The final cost is $7,500,000.
- **Source(s):** Astrobiobound

Radar Imager for Mars' subsurFAce eXperiment (RIMFAX):

- **Cost:** $5,000,000
- **Weight:** 3 kg
- **Cost Description:** The cost for the RIMFAX instrument was an educated guess. The individuals tasked with finding a cost could not find a cost.
- **Source(s):** N/A

Medium-Power Solar Panel (Triple Junction Gallium Arsenides Solar Array):

- **Cost:** $6,320
- **Weight:** 7 kg
- **Cost Description:** The team will be going with an outside manufacturer on this particular part whom has a known history in the manufacturing of solar cells for the space industry: AzurSpace. Due to an agreement of mutual confidentiality, their exact price for these parts could not be disclosed. However, they were willing to disclose that the cost of a single Solar Cell Assembly was roughly $300, with an additional $320 for transportation of the final order. Assuming an array of less than or equal to 20 cells, the final cost of the Solar Array in parts alone would be $6,320. Assembling these parts into the final array will be done in-house.
- **Source(s):** AzurSpace

On-board Battery (Two Lithium-Ion Batteries with a charge of 42 Ah):

- **Cost:** $1,500,000
- **Weight:** 2.3 kg
- **Cost Description:** The $5,000,000 cost of the On-board Battery stated in Astrobiobound are the Li-On batteries used for the Curiosity rover. Since the mission rover’s solar panels cannot generate as much power as the Curiosity rover and does not require to store as much power, the cost will be cut by 70% and will therefore cost $1,500,000.
- **Source(s):** Astrobiobound

Standard Microprocessor (RAD6000):

- **Cost:** $700,000
- **Weight:** 0.5 kg
- **Cost Description:** The Curiosity was fitted with a BAE RAD750 microprocessor, a direct successor to the RAD 6000 used on the Opportunity and Spirit. Reported to have a unit cost somewhere between US$200,000 and US$300,000, RAD6000 computers were released for sale in the general commercial market in 1996. Assuming rarity of this product has been created due to the cessation of production, its price would likely be closer in the range of $300,000. It is unreasonable to expect already Radiation-Hardened components to need extensive R&D Costs. However as this is now a 30-year old microprocessor, some light testing is still expected.
- **Source(s):** Wikipedia

Main Bus (VMEbus):

- **Cost:** $1,000,000
- **Weight:** 2.3 kg
- **Cost Description:** VMEbus is a computer standard similar to PCI slots, used to interface components with the computational parts of the system. More specifically in the case of a rover, it's used to interface the instruments and memory with the microprocessor. The Main Bus used on the Opportunity rover is reported to be a ruggedized, 6 to 8 slot bus. As this has slowly became an antiquated standard in the consumer space, it is not readily available in a Radiation-Hardened form, and such a bus would have to be specially manufactured. However, given the more limited scope of the project rover, it could be argued that the necessary number of slots decreases from 6~8 to 5~6. Off the shelf, a 5 slot VMEbus costs $2,200. Therefore, one million dollars will be allocated to the purchase of the product and the modifications to make it space-ready and satisfy the requirements to allow the rest of the rover to properly function.
- **Source(s):** nVent

Low-gain Antenna (Endurosat X-Band Patch Antenna):

- **Cost:** $2,000,000
- **Weight:** 0.5 kg
- **Cost Description:** Endurosat is a developer of satellite-ready antenna systems for larger companies. The products necessary for an X-Band ready antenna from their consumer-grade line costs roughly $100,000. Testing and research necessary to ensure that said antenna is space-ready would sum up to be $2,000,000.
- **Source(s):** Endurosat

Main Memory Card (Rad Hard 256 Mb SDRAM 8-Meg X 8-Bit X 4-Banks Memory):

- **Cost:** $20,000
- **Weight:** 0.5 kg
- **Cost Description:** DDC is a manufacturer of Rad-Hard/Rad-Tolerant memory components, both Flash and DRAM. They also list NASA among their clientele in their pamphlets, meaning their components are more than likely space-ready. If the number of science instruments onboard the project rover is lower than those onboard the Curiosity, the required specs of the memory cards decreases. After receiving a quote from DDC, there could now be an estimate of the cost of either an SSD or DRAM within the requirements of the rover system will be $10k each. Thus, the entire memory system of the rover will cost roughly $20,000.
- **Source(s):** Data Device Corporation (DDC)

GROVER (Greenland Rover and Goddard Remotely Operated Vehicle for Exploration and Research) Tracks:

- **Cost:** $4,500,000
- **Weight:** 3.8 kg
- **Cost Description:** The tracks will be modeled after the earth-bound NASA rover named GROVER (Greenland Rover and Goddard Remotely Operated Vehicle for Exploration and Research). This rover is designed to trail the Greenland ice caps to perform subsurface scanning routines, investigating changes in the ice. How effective these treads would be on the Martian surface is entirely up for debate, but as it is presented as an option for the exercise, it will be explored. The cost in Astrobiobound is said to be $15 million, but because it was meant for a rover weighing 180 kg in total and the mission rover weighs 21.8 kg, it was given a 70% cut in cost. Therefore, the final cost is $4,500,000. The 3.8 kg weight of the tracks is an accurate estimate of the tracks.
- **Source(s):** Wikipedia, Astrobiobound

Medium-Resolution Camera (PANCAM):

- **Cost:** $5,000,000
- **Weight:** 0.5 kg
- **Cost Description:** The cost of the Medium-Resolution Camera in Astrobiobound was given a 50% cut. The reason behind this is that this mission isn't a photography mission and the Medium-Resolution Camera is only needed for visual perception of the rover's surroundings.
- **Source(s):** Astrobiobound

EDL Supersonic Parachute:

- **Cost:** $3,000,000
- **Weight:** 8 kg
- **Cost Description:** The mission rover will not be using retrorockets like the opportunity rover. The team will be taking advantage of the capabilities of the supersonic parachute used in the opportunity rover mission even though it was about nine times the weight of the mission rover; therefore, the cost will only be cut by 40%. The final cost will be $3,000,000.
- **Source(s):** Astrobiobound

EDL Airbags:

- **Cost:** $2,000,000
- **Weight:** 4 kg
- **Cost Description:** The airbags for the opportunity rover cost about $10 million and because the mission rover will weigh less, the airbags will cost less and weigh less since it doesn't need as much cushion to slow down its landing. The rover weighs 21.8 kg and the Opportunity rover weighs 185 kg, which is 12% the weight of the Opportunity rover. As a result, the cost will be cut by 80%, leaving 8% for hazard mitigation, and the weight is estimated to be 50% less than the airbags used in the Opportunity rover. The cost adds up to 2 million and the weight adds up to 8 kg.
- **Source(s):** Astrobiobound

EDL Transmitter Package:

- **Cost:** $50,000
- **Weight:** 0.075 kg
- **Cost Description:** The Transmitter Package cost will remine unaffected as it satisfies all requirements as it is.
- **Source(s):** N/A

Manufacturing

The manufacturing costs include all of the “Rover Instrument and Components”, “Materials and Supplies”, and “Equipment” expenses. The “Equipment” expenses will be accounted for as the team will be assembling the mars rover in the NASA Kennedy Space Center (KSC) and would therefore, not need to account for the cost in equipment when the team will be taking advantage of the pre-bought equipment. There will also be a 50% manufacturing margin to account for unexpected expensive like changes in the cost of supplies and Rover Instrument and Components. The manufacturing costs are a “start-up” or one-time expense.

Manufacturing	
Item(s)	**Annual Cost**
Instruments and Components	$36,276,320
Materials and Supplies	$3,000,000
Equipment	N/A
Total	**$39,276,320**
Manufacturing Margin (50%)	$19,638,160
Final Total	**$58,914,480**

Table 6.02

Personnel

Every team member will receive a $60,000 salary per year regardless of their role as a manager, lead, scientist, engineer, or administrator. The salaries are not divided based on different roles because many members of the Hella Impact team hold multiple roles. There will also be a ERE 28% margin to account for the expense in unexpected employee dropouts and replacements.

Personnel			
Title(s)	**Number of Personnel**	**Individual Salary**	**Annual Salary**
Scientists, Engineers, and Administrator Team	12	60,000	720,000
Total			**$720,000**
ERE Margin (28%)			201,600
Final Total			**$921,600**

Table 6.03

Travel

The mission project participants will be provided airfare to the NASA Kennedy Space Center (KSC) as a one-way-trip, live in the Discovery Beach Resort near KSC, and receive compensation for meals and UberPool transportation costs to KSC and back to the resort.

Travel			
Item(s)	**Quantity**	**Cost per Unit**	**Annual Cost**
Total Flights Cost	12 individuals	$359 per fight	4,308
Total Hotel Cost	12 individuals	$222 per 2-night	486,180
Total Transportation Cost	16 miles	$1.29 per mile	15,067.20
Total Per Diem Cost	12 individuals	$200 per week	127,200
Total			**$632,755.20**

Table 6.04

Below are the final expense calculations spread out to five (5) years which is about the full lifespan of the mission from the planning of the rover to operating it on the mars surface.

- The only one-time expense is the manufacturing costs.

NASA L'SPACE Mission Concept Academy Budget SU 2020 – Hella Impact Rover Mission Final Cost Calculations						
Item(s)	**Annual Totals**					**Cumulative Total**
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	
Manufacturing Total	58,914,480.00	0	0	0	0	58,914,480.00
Personnel Total	921,600.00	921,600.00	921,600.00	921,600.00	921,600.00	4,608,000.00
Travel Total	632,755.20	632,755.20	632,755.20	632,755.20	632,755.20	3,163,776.00
Total	60,468,835.20	1,554,355.20	1,554,355.20	1,554,355.20	1,554,355.20	**66,686,256.00**
F&A Total (10%)	6,046,883.52	155,435.52	155,435.52	155,435.52	155,435.52	6,668,625.60
Total Projected Cost	66,515,718.72	1,709,790.72	1,709,790.72	1,709,790.72	1,709,790.72	**73,354,881.60**
Total Cost Margin (30%)	19,954,715.62	512,937.22	512,937.22	512,937.22	512,937.22	22,006,464.50
Total Project Cost	86,470,434.34	2,222,727.94	2,222,727.94	2,222,727.94	2,222,727.94	**95,361,346.10**

6.2. Schedule

The following schedule illustrates the time frame of the proposed Mars mission from start to finish, dividing the mission into its distinct phases with start/completion dates for each phase, accompanied by a Gantt chart which includes dates for more specific tasks and milestones. There is some tolerance/flexibility in order to mitigate the effect of a possible accident or unforeseen delay, such as issues with development and/or communications.

- **May 19, 2020:** Pre-Phase A - Conceptual Study
- **May 20 - June 21, 2020:** Phase A - Preliminary Analysis
- **June 22 - July 12, 2020:** Phase B - Definition
- **July 13 - July 22, 2020:** Phase C - Design
- **July 23, 2020 - July 22, 2021:** Phase D - Development
- **July 23, 2021:** Launch Date
- **July 23, 2021 - February 23, 2022:** Spacecraft Conveyance
- **February 24 - March 23, 2022:** Phase E - Verification
- **February 24, 2022 - February 24, 2025:** Phase E - Operations Phase

6.3. Outreach Summary

Using Social Media to Increase Awareness for STEM

The L'Space Hella Impact team will increase the public awareness for STEM with the use of social media and getting into contact with schools that range from the elementary level all the way through University to be able to give fun demonstrations of what it is that professionals do in STEM. The use of social media will enable the team to spread knowledge on the specific project at hand and potential future projects. This gives the global audience a look at what STEM is all about and the enjoyable features it has to offer. Posting the process of Day 1 of the project until its Final Day on social media, such as Instagram, Twitter, Snapchat, and YouTube, will let the audience know of the amount of teamwork that projects have to have in order to become a reality.

Recording a SolidWorks or Siemens NX time lapse of creating a project and posting it on YouTube from beginning to end will help current students that struggle with utilizing the tools in these programs or just ignite the fuel of curious, prospective students in the realm of STEM. In this case, the main videos that will be posted by the team will be a rover headed to Mars. This will greatly increase the curiosity in STEM of people that are not already interested in this profession because it gives a direct demonstration as to what staggering software is used in STEM. The videos posted on YouTube can also be posted on Instagram, Twitter, and Snapchat and a link to the original video can be attached to these platforms, which in turn, have a cycle of recognition for the project that the team is working on and/or STEM in general.

Giving School Demonstrations to Increase Appreciation for STEM

By giving demonstrations in schools, the team can gain interest in the students in attendance by briefly explaining what the rover to Mars project is about. An engaging way to interact and gain the true attention of the audience at the school is to possibly have a trivia game about STEM or about space in general and whoever gets a question right, they would receive a miniature model of the rover and/or whatever project the team is working on. The difficulty of questions would have to depend on the certain grade level the team is interacting with. For obvious reasons, elementary schools would have the easier questions while the high school and Universities would have somewhat difficult questions. As for creating the miniature models, the CAD documents that the L'Space Hella Impact team has of the rover, or rocket, can be altered from the realistic dimensions to a miniature dimension, which will then head to a 3-D printer to turn into reality. This will raise public awareness for STEM since all these features is what STEM is all about and it will give the students a memory of the Mars rover project and they will have a souvenir to show off. The beneficial use of social media in this case is that majority of people have social media nowadays and not only the students can follow what the team has to offer, but the adults in attendance can also continue the path with us. It is a cycle of public awareness and appreciation for STEM.

6.4. Program Management Approach

Team Organization & Approaching the Problem

The current problem that the L'SPACE Hella Impact team is trying to solve is to send the team's version of a rover to Mars. In a sense, everyone has been working together but in separate teams. There is an Engineering team and a team of Scientists. Although these teams work separate, the Engineers and Scientists communicate together efficiently to get the job done.

Team Structure

In terms of team structure, the Project Manager, coinciding with the team, agreed that whoever has the most experience or skill in a specific part of the project, will be the one in charge of that task. If a certain individual of the team thinks they have a great amount of skill in a certain area, an email or overall presentation of previous experience is then demonstrated to the rest of the team and is either chosen to be in charge of the task or given to someone else.

Issues Arising

The biggest conflict that the team faces is the many different schedules that are present. The members of the Hella Impact Team have diverse school and work schedules and if an issue with the project were to become apparent, whoever notices the issue will report to the Project Manager and a decision will be made in regards to solving this problem in the best manner possible. The team members that are readily available will take a huge part of the solving process while the rest of the team can give feedback at a slightly later time.

7. Conclusion

The goal of the mission is to retrieve data of sites that can be potential sites for human exploration. This will be accomplished starting in Jezero Crater and then neighboring sites.

The mission rover's EDL sequence involves a heat shield, supersonic parachute, and airbags respectively. The payload contains the basic components for a proper functioning rover like a main bus and microprocessor, and antenna. Some of the more unique components are the solar panels for power and tracks for transportation of the payload. What makes the mission rover unique is the instruments selected that can satisfy it's objective. This is the Subsurface Radar (RIMFAX), Rover Environmental Monitoring Station (REMS), and Radiation Assessment Detector (RAD); all sensor instruments. Scanning the environment for data (surface, atmosphere, and radiation) that could directly affect the habitability of humans at a potential site.

The next step for the team would be the Development (Phase D) stage as the Design (Phase C), Definition (Phase B), Preliminary Analysis (Phase A), and Conceptual Study (Pre-Phase A) stages have all been completed. This includes the ATLO (Assembly, Test, and Launch Operations) aspect of the mission or in simpler words, the actual fabrication of the rover and testing for launch. Next is the launch, spacecraft conveyance, the verification of systems upon landing (Phase E), and Operations Phase (Phase E). Soon after the launch, much of the team will spend their time using social media to increase awareness for stem and give school demonstrations to increase appreciation for STEM.

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