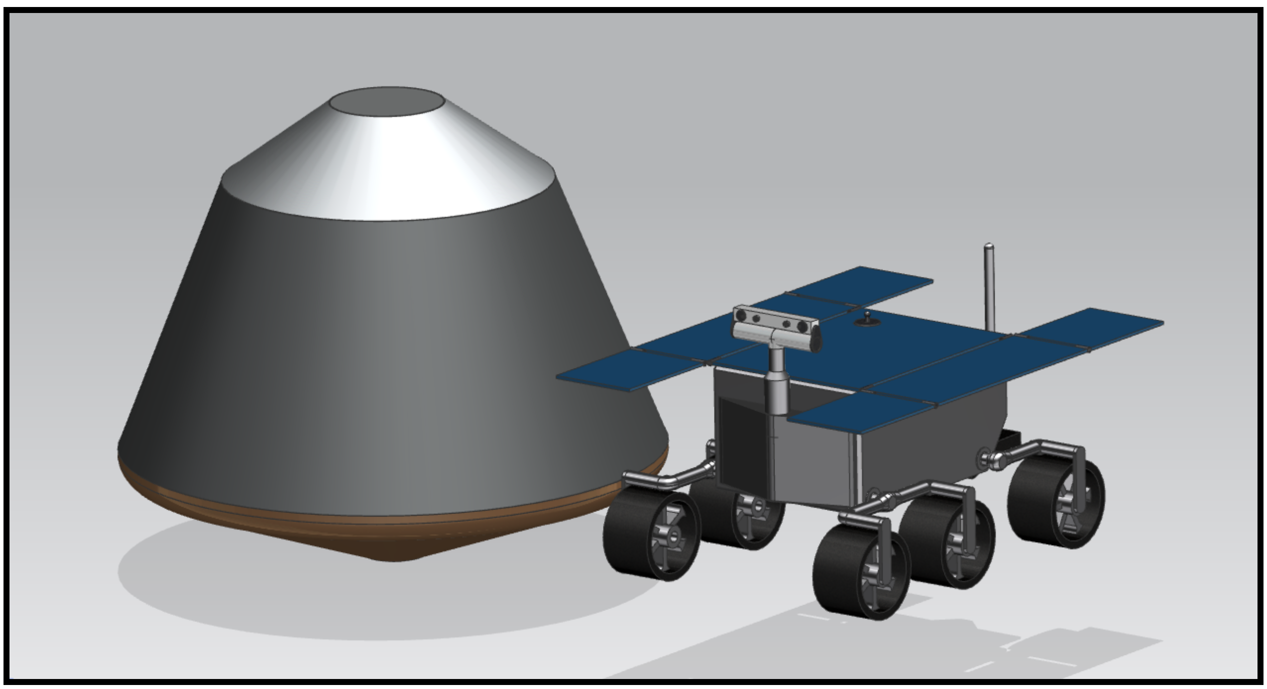
NASA Lucy Student Pipeline Accelerator and Competency Enabler (L'SPACE)
Mission Concept Academy

Preliminary Design Review

Telos-1 Rover

Team 22



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1. Introduction and Summary

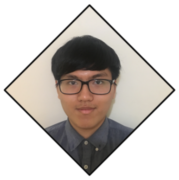
1.1. Team Introduction

Andrew Rich
Project Manager/Payload Engineer
University: University of Wisconsin-Milwaukee
Location: Milwaukee, Wisconsin
Major: Electrical Engineering & Physics
Andrew brings 8 years of military electrical inspector and leadership experience on multiple airframes including the KC-135 In-Flight refueler and the F-16(C/D) Fighting Falcon.

Arielle Pfeil
Deputy Project Manager/Landing Engineer
University: University of Illinois at Urbana-Champaign
Location: Champaign, Illinois
Major: Mechanical Engineering
Arielle brings vast technical and leadership experience with great ambition to guide the team to success. She brings technical knowledge in CAD modeling (Siemens NX, PTC Creo, SolidWorks, Autodesk Inventor, and Autodesk Fusion 360), manufacturing and prototyping, and programming (MATLAB and Python).

Salam Mulhem
Lead Engineer/Suspension Engineer
University: University of Illinois at Urbana-Champaign
Location: Champaign, Illinois
Major: Aerospace Engineering
Salam is a multifaceted individual, bringing proven engineering project leadership experience, money management skills, and a team player mentality that allows her to effectively pivot when issues arise to ensure quick solutions.

Adrian Aguilar
Co-Lead Engineer/Descent Engineer
University: Texas A&M University
Location: College Station, Texas
Major: Mechanical Engineering
Adrian conveys traits of a natural leader, bringing team members together, and communicating to ensure seamless project advancement. He is great with numbers and has a can-do attitude and loves to have fun with the project.

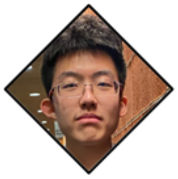


Myeongchan "Joshua" Kim
Descent Engineer
University: Texas A&M University
Location: College Station, Texas
Major: Aerospace Engineering
Joshua brings a diverse background of competencies ranging from CAD to videography to unique PowerPoint projects. He exudes industrious personality, cooperating with team members, and finalizing tasks quickly and effectively.

Jared Sewell
Entry Engineer
University: Texas A&M University
Location: College Station, Texas
Major: Aerospace Engineering
Jared brings experience in Java and Python coding languages, as well as, basic circuit design and a teamwork mentality. Demonstrated ability to quickly learn and adapt to his duties with profound industrious behavior ensuring tasks get done.

Christopher Lopez
Housing Engineer
University: Texas A&M University
Location: College Station, Texas
Major: Mechanical Engineering
Christopher is an enthusiastic team member who brings reliability and responsibility. He has technical experience in Python.

Ian Bell
Lead Scientist
University: Brigham Young University
Location: Provo, Utah
Major: Geology
Ian is an experienced scientist with larger than life aspirations. He brings a vast amount of technical experience in ArcGIS Pro, Adobe Illustrator, and geologic mapping. Ian is a very organized individual and loves working with others. Needless to say he *rocks*!



Haotian Cao
Scientist
University: University of Wisconsin-Madison
Location: Madison, Wisconsin
Major: Physics & Math
Haotian brings many scientific and technical skills to the team. He has experimental experience in mechanics, calculation, and abstract concepts and brings applied knowledge in 3D printing, CAD, and programming.

Bailey Singkhek
Scientist
University: Texas A&M University
Location: College Station, Texas
Major: Mechanical Engineering
Bailey brings many valuable traits to the team including superb technical writing and excels in interpersonal skills.

Tania Cuff
Lead Administrator
University: Southern Methodist University
Location: Dallas, Texas
Major: Engineering Management, Information & Systems
Tania has a very diverse background, living in three different countries throughout her life with multifaceted interests from astronomy to biology. She is an excellent team player, very organized, and a fast learner.

Hoa "Bill" Tang
Administrator
University: Texas A&M University
Location: College Station, Texas
Major: Electrical Engineering
Bill is a reliable team member who is very passionate about the L'SPACE program! Although he is new to the aerospace field, he is very eager to gain relevant knowledge and skills.

Monika Solis
Administrator/Safety Officer
University: Texas A&M University
Location: College Station, Texas
Major: Aerospace Engineering
Monika has a high aptitude to learn quickly and adapt to new situations. She has great time management and organizational skills, ensuring she is always able to complete tasks. Monika brings technical experience in Python programming.

1.2. Mission Overview

1.2.1. Mission Statement

The objective of this mission is to explore and determine the geological history of the Jezero crater on Mars by utilizing the RIMFAX ground-penetrating radar to analyze and map the Martian lithological layers. The Telos-1 mission will strive to identify and characterize the composition of the various layers of stratum, continue the search for sources of water and ice deposits, search for possible trace fossils and scout for future mission core sample sites to piece together the puzzle of the geologic history of Mars and its current subsurface conditions.

1.2.2. Mission Requirements

This mission requires a large concept Mars lander with a maximum mass of 180kg, a volume maximum of 24” x 28” x 38”, which must include the heat shield (volume, not mass), with a budget cap of $100M. The rover must descend to Jezero Crater from 400 km with a forward velocity of 2.38 km/sec. A mass of 0.075 kg and 5W of power will be allocated towards the communications package.

1.2.3. Mission Success Criteria

To be considered successful, this mission must satisfy the following:

1. Safely enter Mars atmosphere, descend to the Martian surface, and arrive within the Jezero Crater landing ellipse at 18.44°N & 77.49°E, on center, with a minimal amount of risk to the payload
2. Dispatch the Telos-1 rover from the lander, deploy photovoltaic panels and perform operational checkout (see *Section 4.1.4: Validation & Verification Plan*, for operational checkout procedures) of rover systems with 100% success rate
3. Activate, receive, and store in memory, the RIMFAX GPR wave propagation data between the 150MHz to 1200MHz ultra-high frequency (UHF) range
4. Successfully take interferogram with Mini-TES
5. Send stored data packets to Earth via local communications package and orbital satellites
6. Telos-1 rover remains fully functional through to the end of the 90-day primary mission profile
7. Perform between 500-720 daily stops along the rover mission path for Mini-TES, Pancam, and RIMFAX instrumentation data collection
8. Successfully travel 6kilometers or more within the primary mission window

1.2.4. Concept of Operations

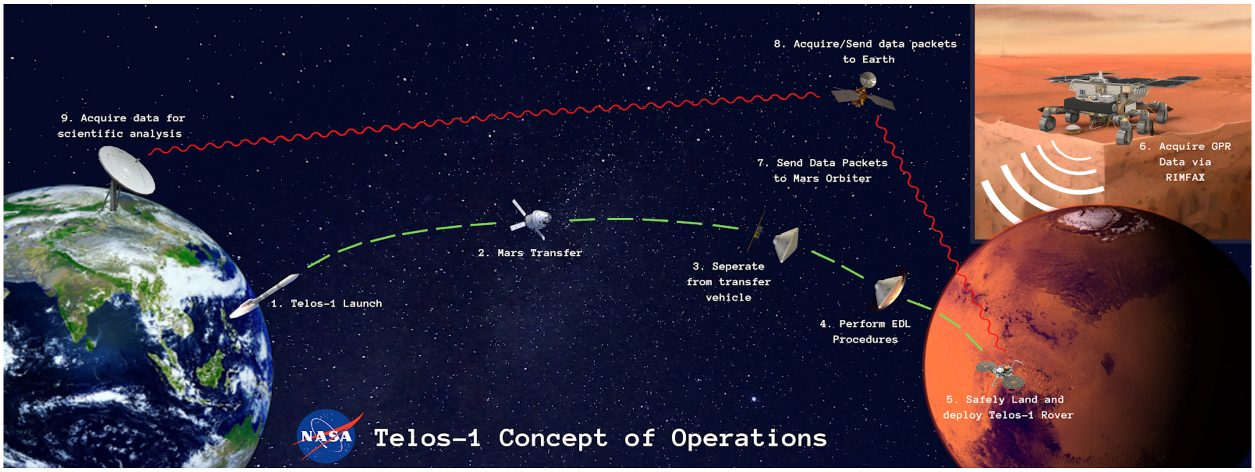


Figure 1. Concept of Operations Graphic depicting the steps to completion of the Telos-1 rover mission.

Telos-1 Lander will be a secondary payload of a future NASA Mars orbiter mission. The Rover will separate from the orbiter at 400km above the Mars surface. Telos-1 will descend and land within the Jezero Crater landing ellipse and verify communications with the separate communications package in the local Jezero area. The Telos-1 rover will then be dispatched to conduct scientific experiments. Each day on Mars, the rover will send data packets to the communications package > Mars Orbiter > Earth, for scientific analysis. The rover will shut down each night to preserve battery and maintain critical support systems to ensure rover operational startup for the following sol. During the primary mission, the Telos-1 rover will traverse approximately 6.8 miles from the landing ellipse on the Jezero Crater floor, to the Jezero fan deposits to the west of the landing area. During this time, the rover will be able to gather GPR data of the lithography of the region, interferograms of the surface, and multispectral analysis of the Jezero watershed geological history.

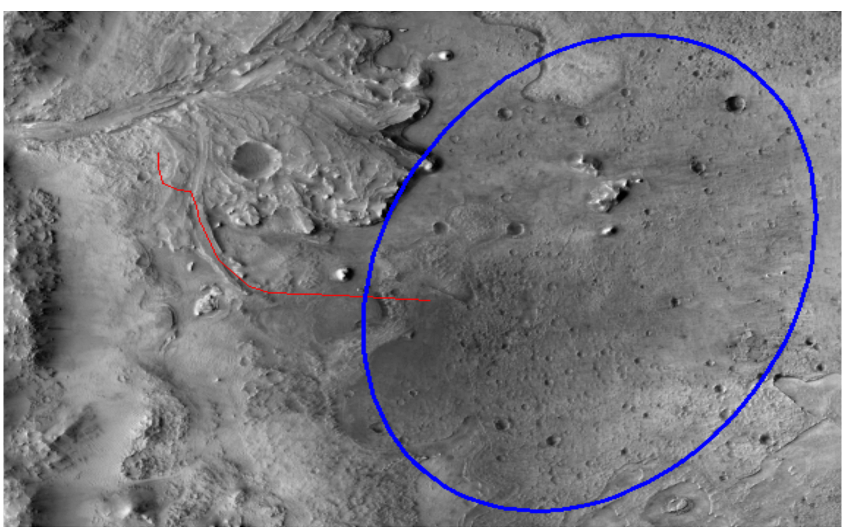


Figure 2. Telos-1 Jezero Crater landing ellipse (blue) and rovers primary mission path (red)

1.2.5. Major Milestones Schedule

The major milestones of the Telos-1 mission are as follows with key review dates.

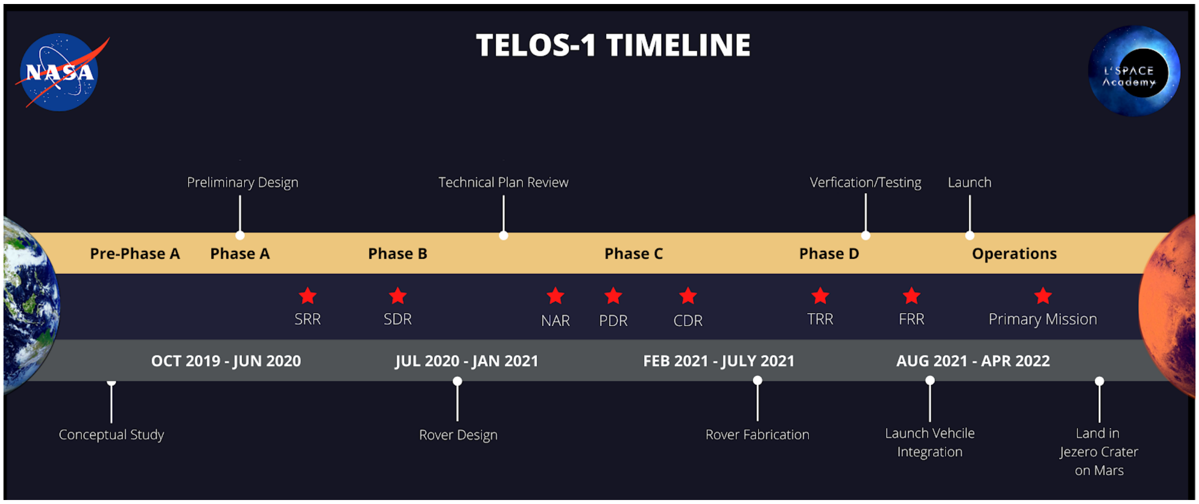


Figure 3. The schedule of the Telos-1 mission follows the full mission life cycle with key checkpoints targeted in the timeline above.

Key reviews include the following:

- **System Requirements Review (SRR)** - *December 01, 2019*
- **System Design Review (SDR)** - *March 03, 2020*
- **Non-Advocate Review (NAR)** - *May 16, 2020*
- **Preliminary Design Review (PDR)** - *August 02, 2020*
- **Critical Design Review (CDR)** - *October 30, 2020*
- **Test Readiness Review (TRR)** - *March 01, 2021*
- **Flight Readiness Review (FRR)** - *May 06, 2021*
- **Telos-1 Launch** - *July 01, 2021*

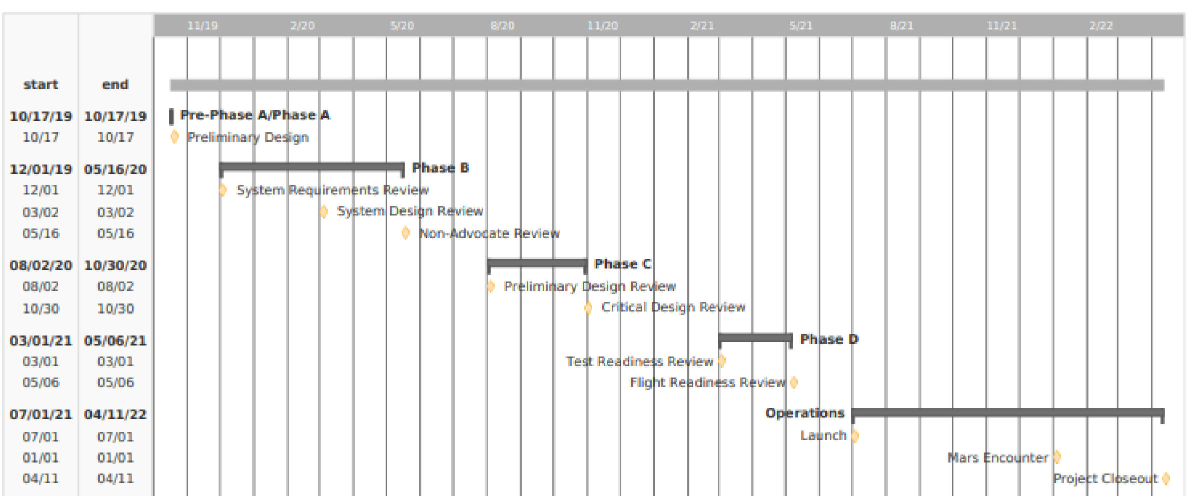


Figure 4. Milestone Gantt Chart for the Telos-1 Mission from Phase A to the end of Operations phase

1.3. Descent and Lander Summary

To safely deliver the scientific payload to the surface of Mars, the lander will be equipped with several structures to allow for strategic entry, descent, and landing of the rover and payload. As the lander enters the Martian atmosphere, a heat shield will serve as the first defense to high temperatures upon descent while beginning to slow the probe. Following peak heat and deceleration, a parachute will be deployed during descent to further slow the speed of the lander. As the lander narrows in on the Martian terrain, separation of the back shell and engagement of back-thrusters will continue to slow and direct the payload on its descent. Final landing on the surface will be relatively soft due to sensitive instruments onboard the rover. Final contact with the Martian terrain will be cushioned by an airbag.

The lander and rover combined will be contained within maximum dimensions of 24" by 28" by 38". The rover possessing necessary payload instrumentation will travel via a 6-wheel structure and weigh approximately 174.5 kilograms. An additional 71.41 kilograms is allocated for the weight of entry, descent, and landing equipment (heat shield, parachute, thrusters, etc.). Upon landing the rover will have the capability to expand and collect geological data as required.

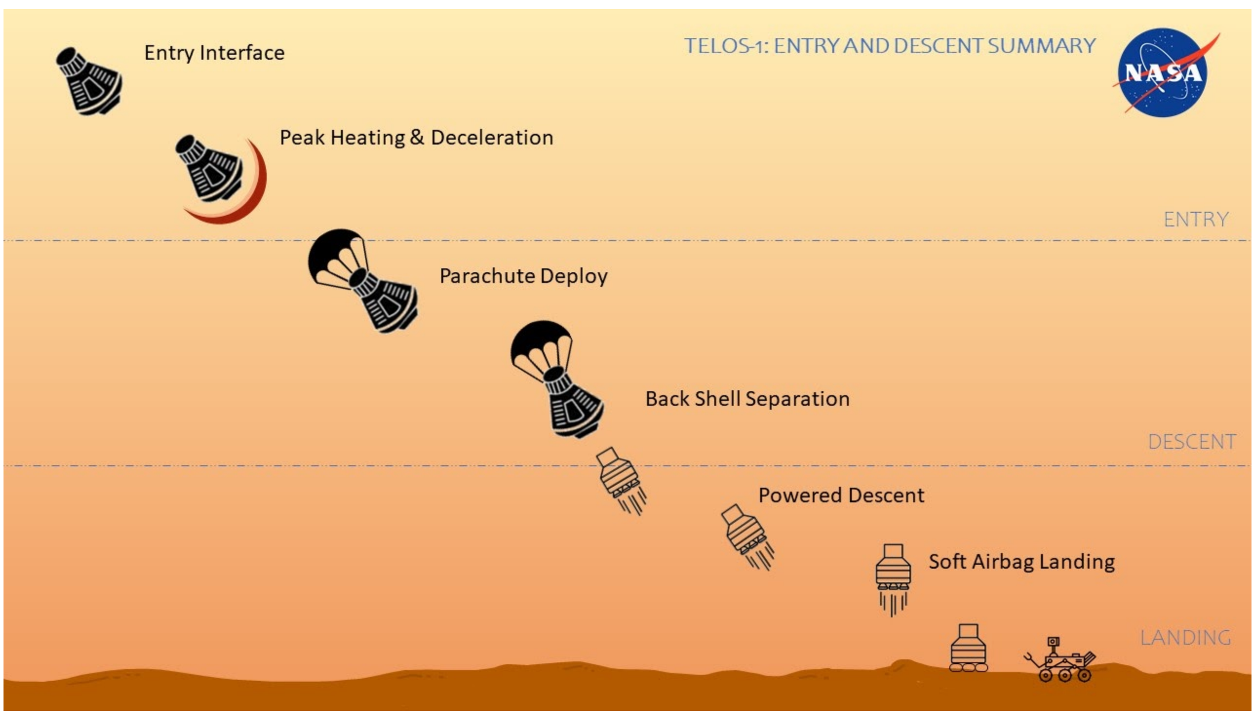


Figure 5. Entry, Descent & Landing (EDL) Summary graphic

1.4. Payload and Science Summary

Telos-1 rover will be equipped with three instruments to collect geological data to map the subterranean and surface composition of Jezero Crater: The Radar Imager for Mars' Subsurface Experiment (RIMFAX), The Miniature Thermal Emission Spectrometer (Mini-TES), and a Panoramic Camera (Pancam).

RIMFAX is a ground-penetrating radar (GPR) that can create a clear picture of what lies beneath the Martian surface. Using ultra-high frequency (UHF) for crisp surface and upper subsurface images and very high frequency (VHF) microwaves for deeper images, geologists can measure the speed and direction of the returning wavelengths to create an accurate map of what lithographic layers are beneath the surface and can pinpoint subsurface water.

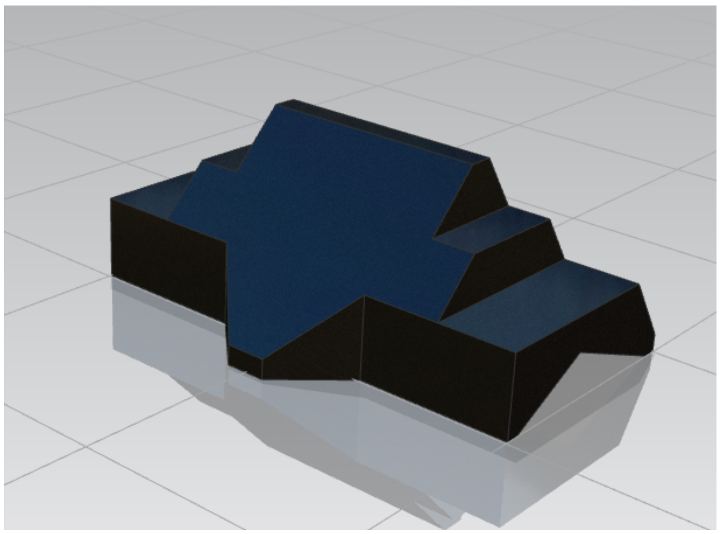


Figure 6. The RIMFAX Antenna located on the lower aft, beveled side of the Telos-1 rover

Mini-TES is an infrared spectrometer (IR) that will be used to identify the composition of surface minerals and rocks using thermal radiation, as well as the atmosphere surrounding the rover. The IR will be used to gather information regarding temperature, water vapor, dust abundance and to search for certain mineral compositions that would suggest a history of water such as olivine, montmorillonite, hydrated carbonates, and evaporite minerals such as gypsum.

Pancam is two CCD cameras that work simultaneously to take detailed, panoramic pictures of the area surrounding Telos-1. Each of the two cameras has multiple filters that allow images to be captured at different wavelengths ranging from 400-1100nm. With these images, the rover will be able to use the blue and infrared filters to view the sun's position in the sky to gather its orientation on the surface, as well as aid scientists in determining the minerals found in the martian rocks, soil, and atmosphere.

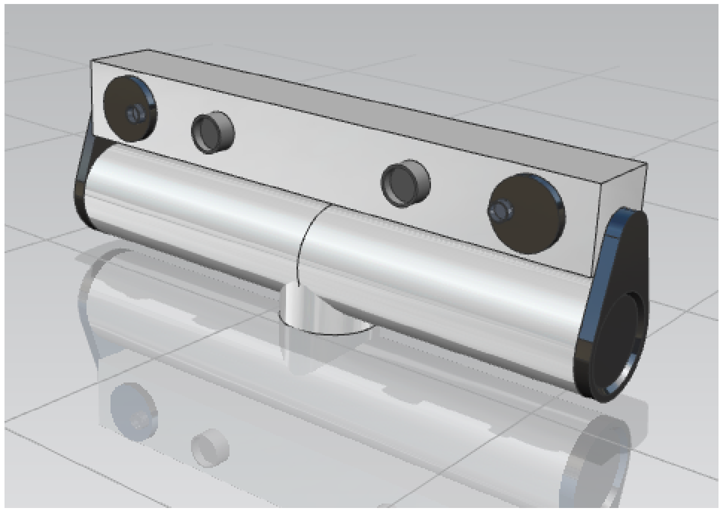


Figure 7. Pancam (upper box with cameras) and Mini-TES viewing port (lower cylinder) assembly

2. Evolution of Project

2.1. Evolution of Descent and Lander

The descent and lander system evolved significantly throughout the development of the Telos-1 mission, with primary design changes driven from the desired payload and the volume/mass constraints of the lander. The descent and lander storyline is based on many previous missions to Mars with entry and contact with the Martian atmosphere beginning with the heat shield. Following this initial deceleration, a single parachute is deployed to further slow the lander. Next, the back shell separates and thrusters further slow the payload on its descent nearing the surface. Finally, the payload is cushioned with airbags.

The overall shape of the aeroshell was investigated in-depth with various design iterations explored based on the make of previous aeroshell designs, including Pathfinder, Viking, and the Mars Science Laboratory.

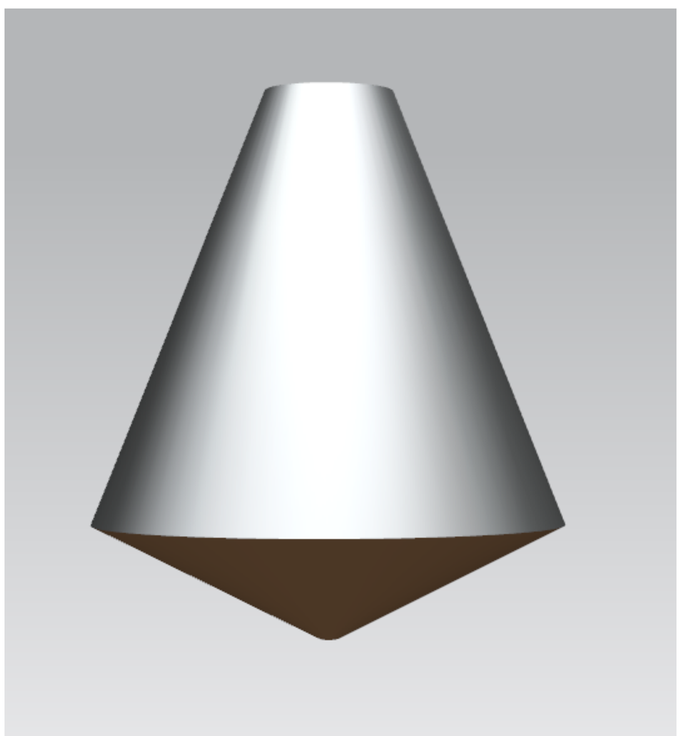


Figure 8. Telos-1 aeroshell design iteration based on Pathfinder design

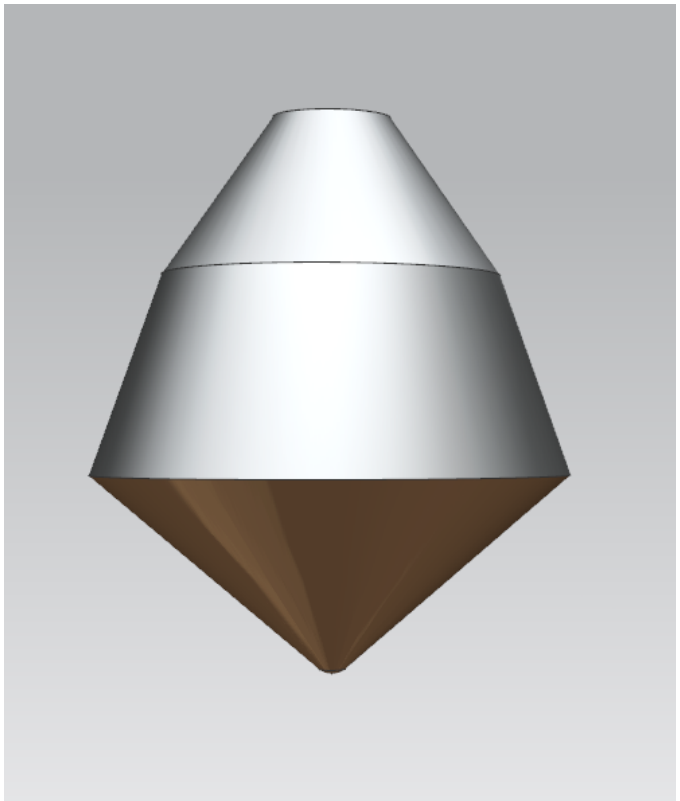


Figure 9. Telos-1 aeroshell design iteration based on Viking design

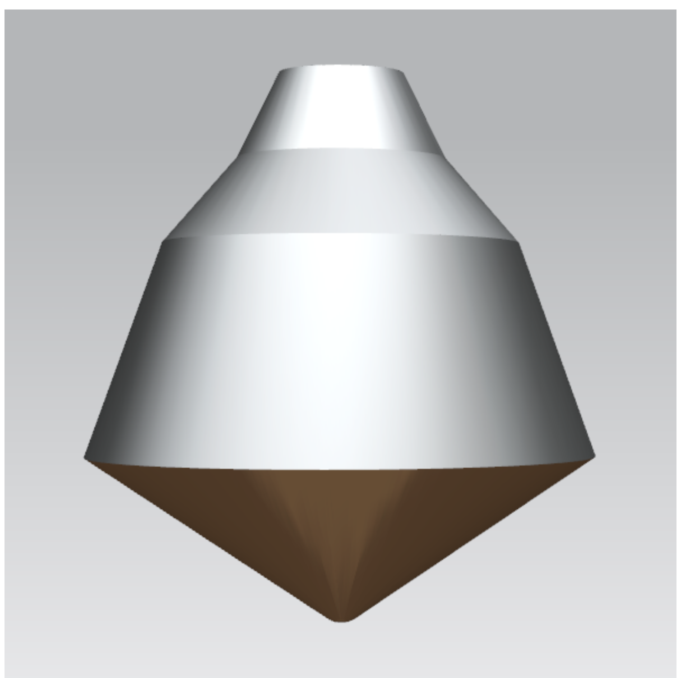


Figure 10. Telos-1 aeroshell design iteration based on Mars Science Laboratory design

Figure 11. Telos-1 final aeroshell design

The final design of the aeroshell was decided based on the Viking aeroshell, with modifications to the overall dimensions based on size constraints on the Telos-1 mission. The decision to use this design was made to optimize the space available for the rover and other components inside the back shell such as rocket-assisted descent motors and the parachute.

Initially, Thiokol rockets similar to those used during the Pathfinder were considered for the rocket-assisted descent portion of the descent stage. However, the size constraints of the aeroshell do not provide enough space for these rockets, necessitating a smaller alternative. MicroSpace micropropulsion systems were considered but ultimately decided against due to a small nominal thrust range of 100 μN to 10mN. Aerojet Rocketdyne MR-107N rockets that were used on Insight were finally decided on. These low weight rockets are small enough to fit inside the back shell while providing enough space for the rover as well as provide enough thrust to slow the rover during descent.

The type of final landing to be used on the Telos-1 mission was also highly explored. Two primary types of landing systems were evaluated based on knowledge of past spacecraft. The skycrane used on the Curiosity Mars mission was considered for its ability to slowly land the Telos-1 rover in its desired location on Jezero Crater. This method, when used with the Curiosity rover, allowed the payload to be gently deposited on the surface with minimal impact on the surroundings of Mars. This system allowed for minimal amounts of dust to be kicked up into the surrounding atmosphere during landing. The second type of landing system explored was airbags. This type of landing would involve a drop onto the Martian surface after the thrusters had sufficiently slowed the lander during its descent. This was seen on past missions including Pathfinder.

Ultimately, the Telos-1 mission narrowed in on an airbag landing due to several factors including landing speed, available space within the lander, and simplicity of design. Once the type of landing was decided upon, several airbag designs were explored to potentially be featured on the Telos-1 mission. Two top contenders were an airbag design seen on Pathfinder, which fully encompassed the payload, and an airbag design featured on the Orion mission, with a double-ring airbag on the bottom of the lander. The Telos-1 mission opted for an airbag design with a double-ring structure on the bottom of the lander. This design was efficient, compact, and allowed for the payload to remain encapsulated until its release onto the Martian surface was desired.

2.2. Evolution of Payload

The design of the payload was scrutinized heavily due to the volume constraints of the secondary payload. The rover was largely limited in size due to the maximum size of the heat shield and aeroshell, which meant that the rover needed to minimize its profile during cruise and EDL procedures but extend into its operational profile upon landing. As the team was deciding on the scientific experiments, the first suggestion was to use a drill to acquire core samples of the area around Jezero Crater or NE Syrtis. Due to the volume restrictions put onto the rover, the team decided to use the ground-penetrating radar, RIMFAX, which is also on the Mars 2020 Perseverance mission, to provide a more specific mission profile under a $100 million budget cap. The RIMFAX was going to allow the rover to map the surface and subsurface down to 10 meters and provide a deeper insight into the stratigraphic layering of the Jezero watershed.

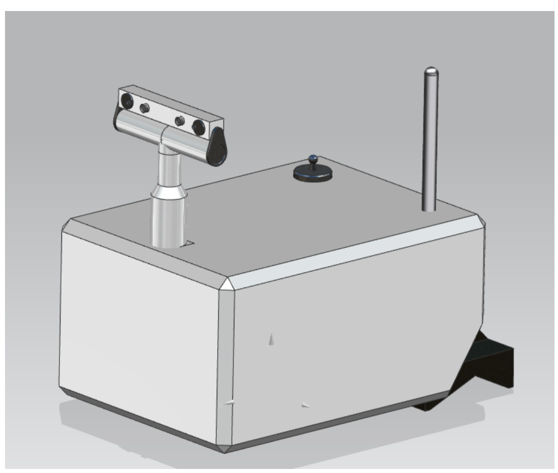


Figure 12. First CAD iteration of the Telos-1 rover

The notable parts of the first rover design was the start of the rover’s Warm Electronics Box (WEB), the addition of Pancam and Mini-TES (beyond the original concept noted above), the UHF antenna on the top of the WEB and the addition of the bow-tie slot antenna for RIMFAX on the back of the rover body. Originally, the rover was to include a multi-directional high gain antenna but was removed throughout the design iterations to make space for the panels, decrease power draw and save money to ensure the team stayed within budgetary constraints. The Pancam instrument was added to the rover for navigation purposes as well as geology objectives. With Pancam, the Jezero Crater landscape can be analyzed for chemicals and minerals at the same time maximizing scientific data with a small volume constraint. Naturally, Mini-TES was selected to accompany Pancam due to the synonymous use on past missions such as the MER: Spirit and Opportunity in 2004. The Pancam was put on the top deck of the rover along with a calibration unit for Pancam and Mini-TES. The UHF antenna was also selected to go on top of the rover deck to ensure polarization and antenna gain was maximized for data transmitting/receiving. The heavy amount of instrumentation put a load on the system and required it to provide a lot more power than originally expected when RIMFAX was the sole instrument within the WEB. The added electronics also created a need for a more robust thermal management system. Due to the budget cap and size constraints of the rover, RTG's were not a feasible power supply for the Telos-1 project. This left the team to work with solar arrays which were limited by the size of the rover as well.

Unfortunately, the rover mast with Pancam/Mini-TES and the UHF antenna on top of the rover deck decreased surface area that could be used for solar cells. This created the need for a full top deck solar array which led the issue of deciding the placement of the cameras. The team moved to the idea that Pancam could be made stationary and could be put on all four sides to create a semi-full, but stationary view of the Martian surface. The image below shows the stationary brick Pancam that would be attached to the side of the rover body, below the deck.

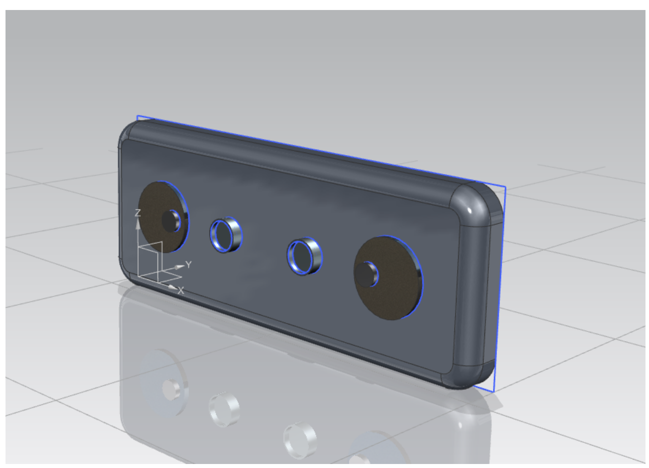


Figure 13. Fixed Pancam/Navcam CAD mockup to take the place of the Pancam Mast Assembly

Removing the mast and mobile Pancam/Mini-TES, took away a lot of the functionality and capabilities of the instrumentation. Due to this fact, the team created a front-mounted mast housing that allowed the Pancam and Mini-TES to operate as normal without reducing top deck solar array space. The UHF antenna was altered to include a 90-degree bend of the base of the monopole and installed on the rear of the WEB, just above the RIMFAX antenna.

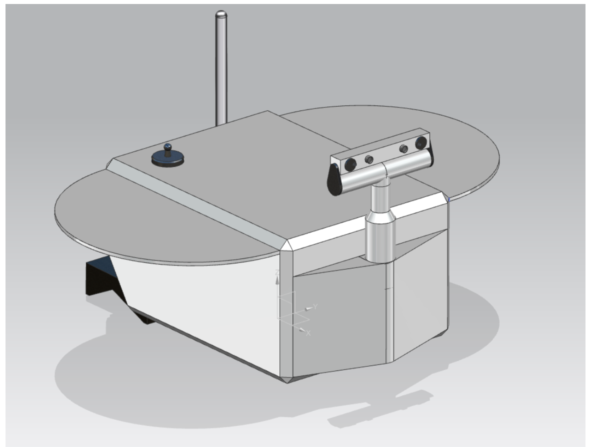


Figure 14. CAD mockup of the folding half-circle ultraflex panels on the Telos-1 rover

The solar panel design went through dramatic change, starting with a fixed solar array on the top of the WEB and two fold-out wings that could be opened 180 degrees and closed to decrease dust coverage and degradation of power conversion, throughout the mission (similar to the Orbital-ATK Ultraflex panels on the Cygnus spacecraft and InSight Lander). This design was altered to a more square profile to maximize the solar array area and the closing solar panels to avoid dust was removed to decrease price and risk of possible motor failure and subsequent power production decrease.

The design of the solar arrays was changed to still deploy after successful EDL procedures but would have multiple stages of panels that would fold out, similar to the ESA Exomars missions. In doing this, the team was able to install 0.35 m^2 of Solaero IMM-α Space InGap/InGaAs/Ge high-efficiency solar cells creating approximately 250 Wh of power per martian sol. The only space that had to be removed from the solar cell was the calibration unit hole that needed to be cut from the fixed solar array on top of the deck but proved to be minimal in terms of area. Another aspect added at this stage was the cold plate on the back of the Telos-1 rover, just to the right of the UHF antenna and above the RIMFAX antenna. This plate was connected to the Loop Heat Pipe (LHP) thermal management system (see *Section 4.1.2: Thermal Management*, for more accurate description on the LHP system) and five radioisotope heater units (RHU's) to provide heat to the instruments and rover battery assembly unit. The rover was now optimized for the stow configuration for Earth-Mars transit and EDL.

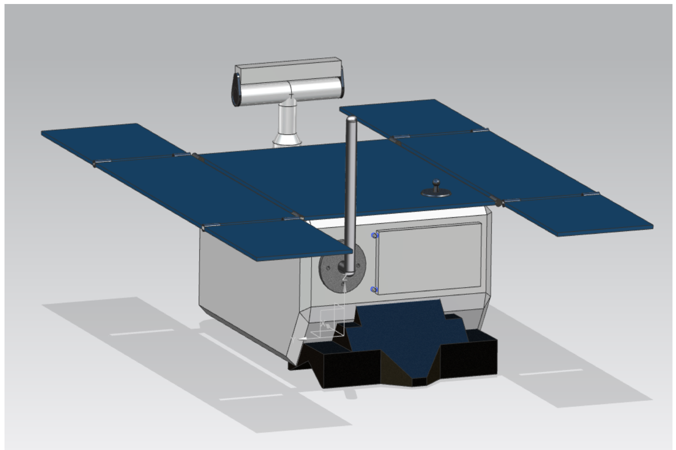


Figure 15. CAD Mockup of the Solaero solar array with deployment capabilities similar to that of the Exomars missions.

To configure the rover for flight and EDL procedures, the team had to minimize the solar array profile, stow the Pancam/Mini-TES and mast assembly, the wheels, and the UHF antenna. The UHF antenna was turned 90 degrees to lay horizontally over the rear-mounted cold plate and is now spring-loaded into the upright position, actuated by the rover main computer upon successful landing. Next, small one-time use deployment motors were installed on the solar panels to allow the folding mobile section to fold into a lower profile. The four smaller outer panels first folded inward onto the top of the side panels. Afterward, the side panels would rotate downwards to the sides of the rover's body. The mast assembly then will retract into the front-mounted mast housing to lower the vertical profile of the rover. The completed stowed position and fully extended position are shown below.

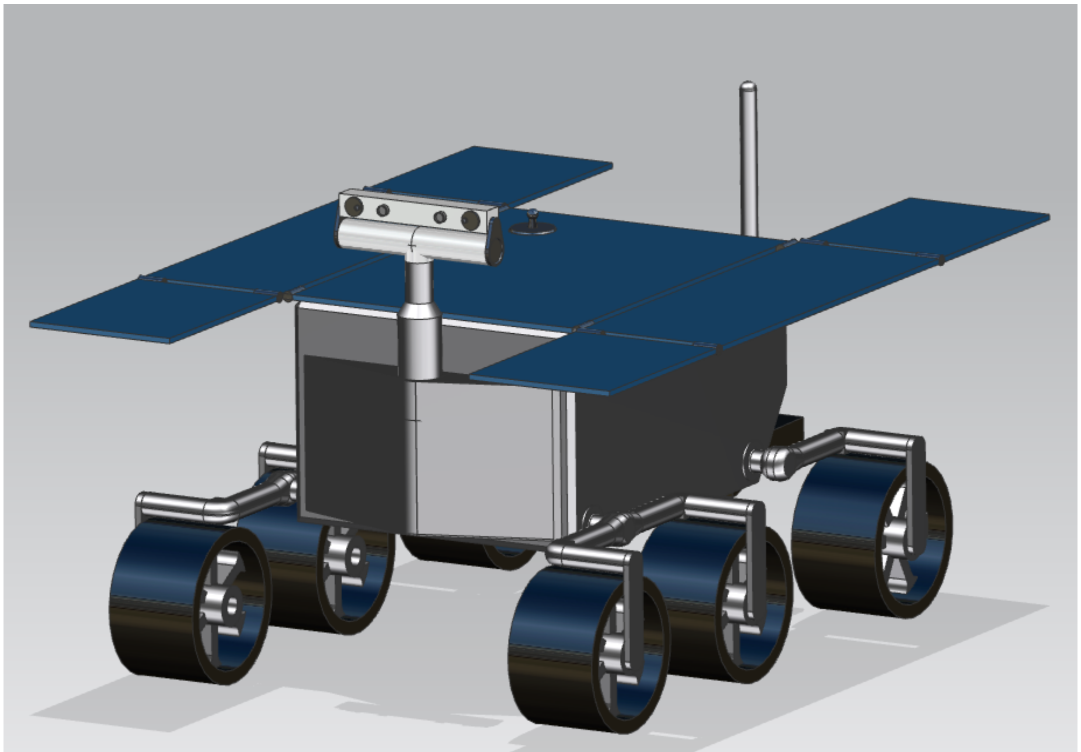


Figure 16. Final CAD of Telos-1 rover in the fully deployed position for the primary mission

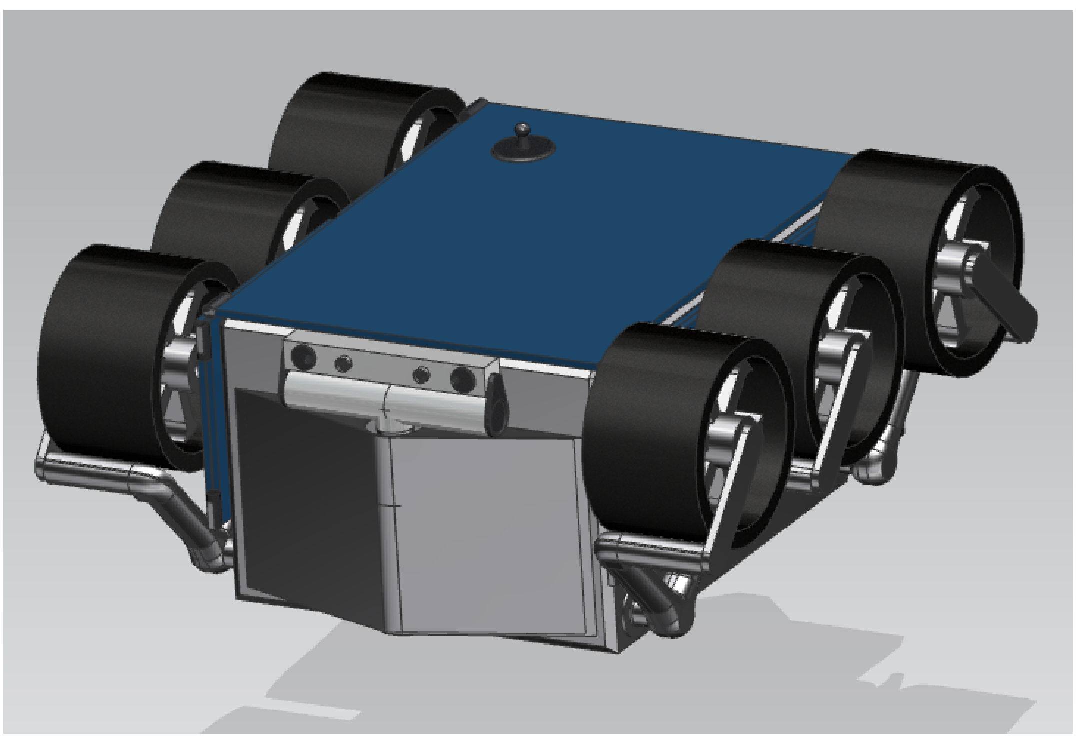


Figure 17. Final CAD of Telos-1 rover in the fully stowed position for cruise phase and EDL procedures

2.3. Evolution of Mission Experiment Implementation Plan

The Telos-1 Mission was, at first, going to be a rover that would utilize a ground-penetrating radar (GPR) system such as RIMFAX with a drill to take core samples. This first iteration rover would have had mobile scientific processing capabilities to analyze the core samples since a sample-return mission would be outside of the budget cap. The addition of a drill, RIMFAX, and mobile processing capabilities was far too heavy, expensive, and complex for the mission profile. This led to the removal of core sampling and mobile processing capabilities.

The main mission, at this point, was to utilize RIMFAX to create a subsurface image between the surface and up to 10 meters beneath the surface, to characterize the geologic lithography of the Jezero region on a smaller budget than the flagship missions. In doing this, the team would provide vital data that could be used for a future larger budget and heavy science payload missions, in deciding routes and areas of scientific interest. To maximize potential science payload, within the volume and budgetary constraints, both Mini-TES and Pancam were added, to also provide vital surface and atmospheric thermal spectrometry and multi-spectral imaging and analysis. In doing this, the Telos-1 rover was now able to understand not only the lithography of the Jezero region but also characterize the surface and atmosphere of the region.

3. Descent and Lander Design

3.1. Selection, Design, and Verification

3.1.1. System Overview

The following information provides a system overview of the descent and lander design. This section is broken down into the various elements of the mission.

Subsystem: Mobility

Body

A rugged, reliable build is critical for the survival of a rover and the completion of its mission. With this in mind, the Telos-1 rover was designed to maximize dependency within the given mass and volume budgets, while accommodating the instrumentation needed to meet the mission's scientific goals. All temperature, moisture, vibration, and dust-sensitive instrumentation is housed within the WEB, which in turn was used to determine the remaining volume available for the rover's suspension.

Suspension

The Telos-1 rover features a modified rocker-bogie suspension, with a six-wheel configuration. All wheels are powered by individual motors, while the 2 front and rear wheels are equipped with one additional motor each for steering.

Subsystem: Entry, Descent, and Landing (EDL)

Heat Shield

During entry into the Martian atmosphere, the heat shield will prevent the spacecraft from burning up and may experience temperatures as high as 2100° C. The heat shield is half of the protective aeroshell that will house the lander and will have a diameter of 710 mm and a height of 154 mm. The shield will be layered with PICA tiles that are each 32 mm thick. PICA on edge will be placed in between each tile as a gap filler. The total mass of the heat shield will be 5.53 kg.

Back Shell

The back shell is the second half of the aeroshell. It will be made out of graphite-epoxy face sheets surrounding an aluminum honeycomb core. A thermal protection system of super lightweight ablative (SLA)-561S will cover the back shell. The back shell will contain devices used later during the EDL process including the parachute, RAD rockets, and separation nuts and springs to release the heat shield. At its widest point, the back shell will be 710 mm and will taper down to 150 mm at the top. The total thickness of the back shell will be 12.7 mm. The total mass of the back shell will be 3.02 kg.

Parachute

Attached to the back shell will be the parachute which will be deployed upon entry into the atmosphere and be detached along with the back shell. Structural components of the parachute will be constructed with Kevlar while the canopy will be made of nylon and polyester. The total mass of the parachute system will be 17.5 kg.

Rocket Assisted Descent (RAD)

Because the Martian atmosphere is so thin, a parachute alone cannot slow the rover to a safe landing speed. As a result, rocket-assisted descent (RAD) motors will be used to bring the rover to a stop above the Martian surface. There will be six MR-107N rockets included in the RAD system. Six rockets provide the necessary symmetry to maintain stability for the eventual rover drop. These rockets are the same as a previous mission, Insight. Each rocket has a diameter of 66 mm and a length of 220 mm. The total mass of the RAD system will be 4.44 kg.

Airbags and Final Landing

During the final stages of landing, rockets will perform a majority of deceleration. However, to ensure as soft of a landing on the rough Martian terrain as possible, airbags will be deployed to cushion final surface contact. Upon termination of the rocket-assisted descent (RAD) sequence, the airbag deployment sequence will be initiated. A ring of six pockets of airbags is tucked and secured in the bottom half of the lander with tight cables wrapping the Vectran fabric. Upon termination of rocket descent, the cables securing the airbags will immediately be let loose and a rapid gas inflation sequence will initiate.

Once on the ground, the primary airbags will slowly deflate. During this time, dust surrounding the lander will have a chance to settle until the rover is ready to be released. At this time, the airbags will be fully deflated and the Telos-1 ground mission can begin as the rover rolls out of its secure encapsulation.

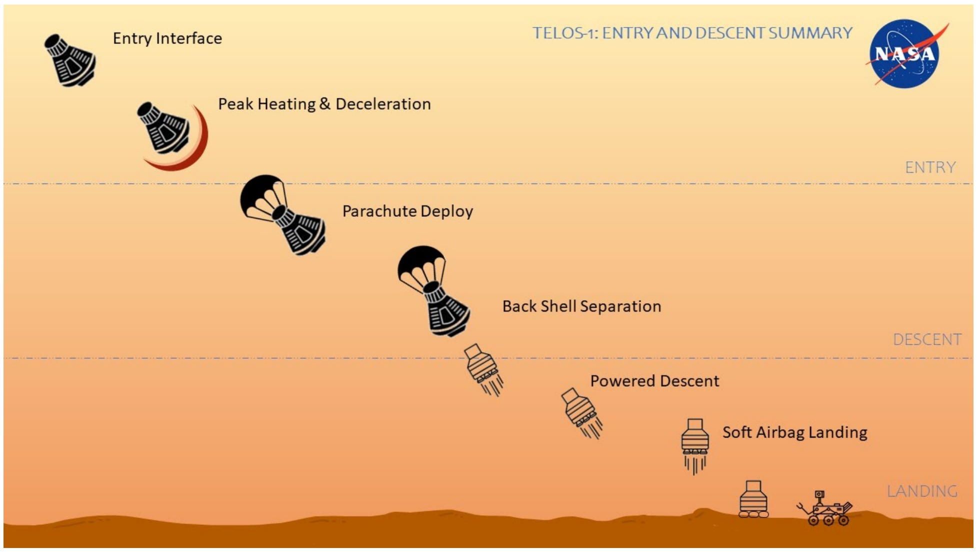


Figure 18. EDL summary graphic depicting major events during entry, descent and landing procedure

3.1.2. Subsystem Overview

Area	Item	Mass (kg)
Suspension	Tire	34.2
Suspension	Wheel (6)	4.88
Suspension	Suspension Arms	25.3
Instrumentation	RIMFAX	3
Suspension	Motors	18.9
Instrumentation	Pancam	2
Instrumentation	Mini-TES	2.4
Power	Solar Array	35
Power	Battery	7.1
Communication	Mandatory Communications Package	0.075
Communication	UHF Antenna	0.075
Thermal	RHU	0.2
Main Computer	BAE RAD750	1
Electronics	Aerogel	0.5
Electronics	Wiring and Misc Components	1.5
Optical	Navcam	0.5
Body	Fasteners and Misc Components	5
Body	WEB Housing	18.2
Body	Pancam Mast	14.8
	Mass Budget	180
	Mass Used	174.63
	Mass Available	5.37

Figure 19. Main mission mass budget breakdown.

Subsystem	Item	Mass (kg)
Entry	Heat Shield	5.53
Entry	Back Shell	3.02
Descent	Parachute	17.5
Descent	RAD Thrusters	4.44
Landing	Airbags	25.42
EDL	Fuel	15.5
	Mass Budget	72
	Mass Used	71.41
	Mass Available	0.59

Figure 20. Entry, Descent, and Landing mass budget breakdown.

Subsystem: Mobility

Body

The body of the rover was iteratively dimensioned, driven by the sizing of the Warm Electronics Box (WEB). The WEB in turn determines the Rover Suspension Equipment Deck, the surface area available for any external instrumentation. The body of the rover features an Aluminum 7075-T6 construction, as it offers the best balance of desired material characteristics.

Wheels

Each wheel is equipped with a cleat tread pattern, a Maxon EC-I 30 brushless drive motor, and a Maxon GP32 planetary gearhead. With this motor and gearhead configuration, the drive system can put out 20 N/m of torque at each wheel. This power, in combination with the bogie suspension, allows the rover to safely traverse rocky and unstable terrain. The front and rear wheels are articulated with additional EC-I 30 motors, providing the rover with the ability to steer. Moreover, these steering motors are paired with absolute encoders to collect information on speed and position. In total, there are ten EC-I Brushless motors - six driving motors and four steering motors. The rims of each wheel will be manufactured out of titanium, while the tires will be aluminum. The tires have a 110mm diameter, and 70mm thickness.

Suspension

By utilizing a rocker-bogie suspension, the rover can maintain equal wheel contact while driving, giving it the ability to maneuver obstacles twice the size of the diameter of its wheels. To climb an obstacle, the front wheels will be pushed against the vertical surface of the obstruction, then powering to climb to the top. The rear wheels and center wheels will then drive, pushing the center wheels forward to meet the same vertical surface. Due to the linkage between the middle and front wheels, once the rear wheels are powered they will be pushed to climb up with the front wheels. Finally, once both the front and middle wheels are stable at the top, they will drive to bull the rear wheels up and over the front of the obstacle. The same can be done in reverse to descend an obstacle. The rover can reach tilts of 45 degrees, but, for safety, is limited to 30 by the use of tilt sensors and obstacle avoidance. To reduce shock, maintain power efficiency, and safely change gears, the rover will move at a rate of about 6.5 cm/s.

Subsystem: Entry, Descent, and Landing (EDL)

Heat Shield

PICA tiles will be used for the heat shield as they are a low-density material that can withstand the high temperatures that will be encountered upon entry into Mars’s atmosphere. PICA on edge provides multiple benefits. PICA as a gap filler prevents gases from flowing between PICA tiles. Additionally, PICA on edge provides an extra attachment point for the tiles. Should a tile become detached from the main structure, the tile will remain attached to the gap filler. The decision to use a PICA heat shield was based on the success of the PICA heat shield used in the Mars Science Laboratory mission. About 20 seconds after the deployment of the parachute, the heat shield will separate from the back shell using separation nuts and push-off springs.

Back Shell

The graphite-epoxy face sheets and aluminum honeycomb core of the back shell provide good structural support and low weight. SLA-561S will provide extra thermal protection for the back shell during entry. The back shell will have a 710 mm diameter at its widest point to provide enough space for the rover to sit during the cruise and EDL processes. The lander will separate from the back shell approximately 10 seconds after the heat shield jettisons at a height of approximately 6,000 meters and will rappel down a tether.

Parachute

The parachute on this mission will be stored at the tip of the back shell and deployed upon entry to the Martian atmosphere. The parachute's canopy will be constructed of nylon and polyester while structural components will be constructed of Kevlar. The single parachute will be 25 feet at its widest diameter. At approximately 10,000 meters above the surface of Mars and 4 minutes after entry into the Martian atmosphere, the parachute will deploy. The lander will be slowed from 400 m/s to 85 m/s during its use in entry and descent into the Martian atmosphere.

Rocket Assisted Descent (RAD)

The RAD system is modeled after that of Insight, due to similar mission characteristics, such as weight. The purpose of the RAD system is to reduce the kinetic energy absorbed by the later airbag landing system. At approximately 100 meters above the Martian surface, the rockets will fire, lowering the velocity to near 5 m/s about 20 meters above the surface. At this height, the already deployed airbag system should produce a safe landing. Each MR-107N rocket weighs about 0.74 kilograms and produces about 50 pounds of pulsed thrust.

Airbag

The design for the airbag landing system on the Telos-1 mission is similar to that seen on the Orion crew module. The inflation of the airbags begins immediately after the rocket-assisted descent (RAD). At approximately 300 meters above the Martian surface, the airbag deployment sequence will begin. In the seconds between airbag deployment and contact with the surface, the binding cables securing the Vectran fabric of the airbags will be released. Immediately after they are freed, a signal is sent to gas generators which inflate the airbags to approximately 10,600 Pa within approximately 1.5 seconds.

Because the lander's mission success on Mars relies on the initial contact with the ground, the airbag subsystem featured on the Telos-1 mission contains a double airbag design. The airbags inflate into a circular ring on the underside of the lander with six separate pockets. The primary airbag absorbs a majority of the shock upon contact with the surface as kinetic energy from the lander's fall is converted into potential energy in the form of compressed gas within the airbag. The secondary airbag is located within each airbag as anti-bottoming protection or in the event of a primary airbag malfunction.

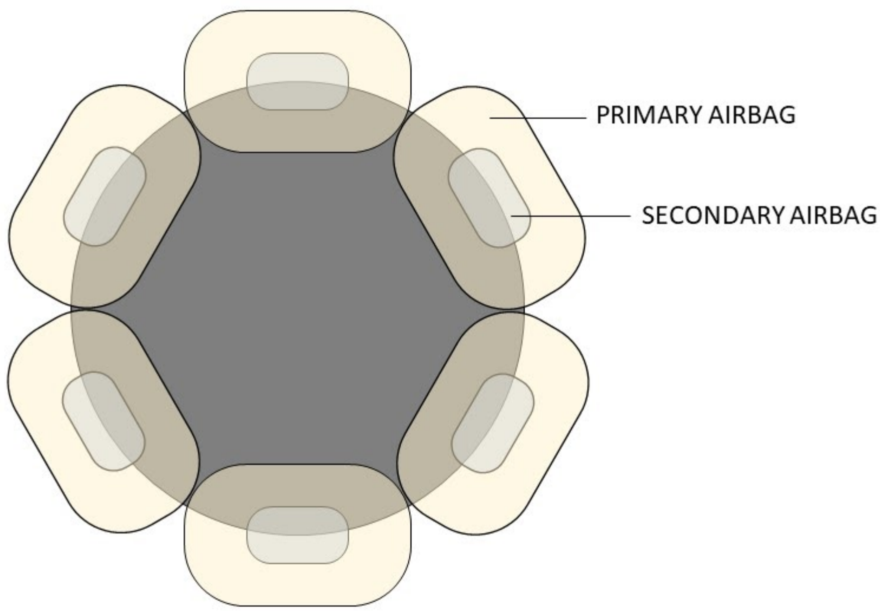


Figure 21. Bottom view of deployed airbags

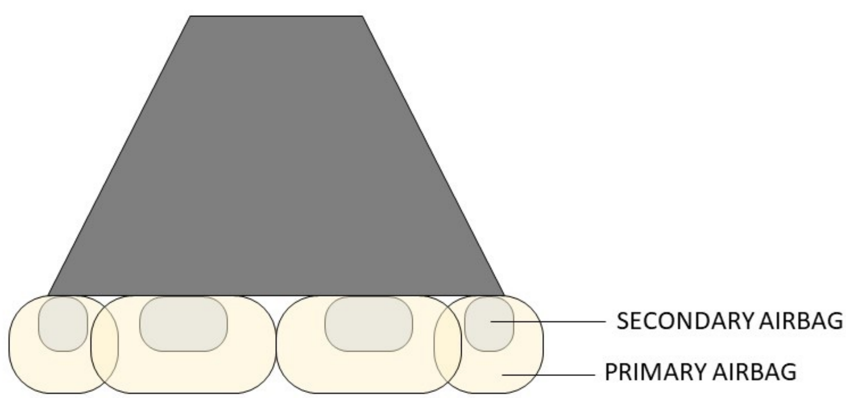


Figure 22. Side view of deployed airbags

Once the land has made contact with the Martian surface, the primary airbags will begin to deflate through actively controlled vents. The lander (with the rover encapsulated) will remain idle until this deflation is complete. The secondary airbags will remain inflated and will serve as a small barrier between the ground and lander while providing a smaller z-height for the rover to drive out of its encapsulation into the Martian environment.

The design described above was selected over a lander fully encapsulated in airbags and over a sky crane due to simplicity in design considering the payload, size, and budget on this mission.

3.1.3. Dimensioned CAD Drawing of Entire Assembly

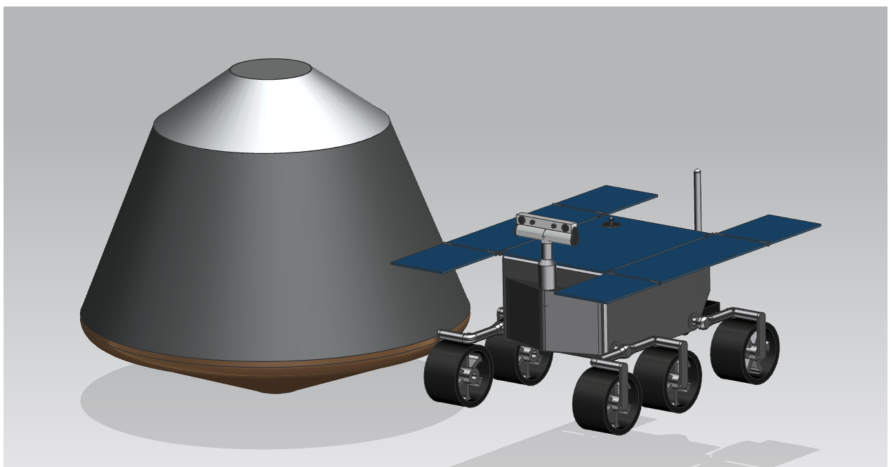


Figure 23. Complete Telos-1 mission CAD components with fully deployed rover (right) and aeroshell/heatshield (left)

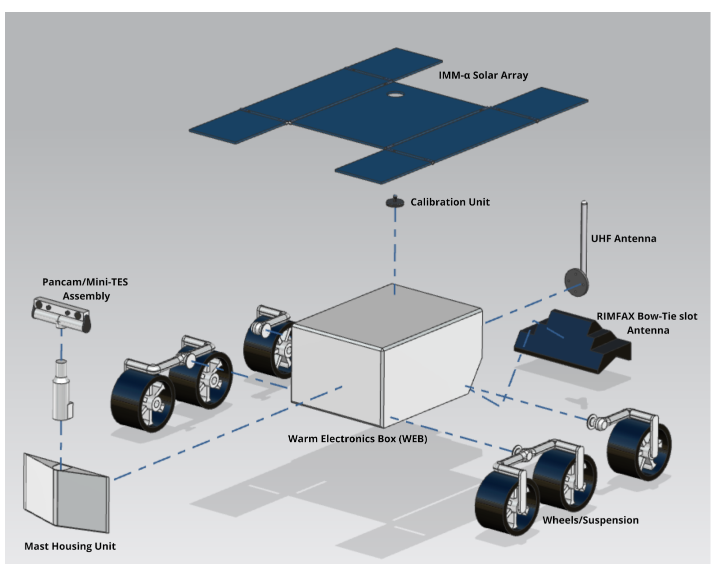


Figure 24. Exploded trimetric view of Telos-1 rover primary payload equipment on the exterior of the WEB

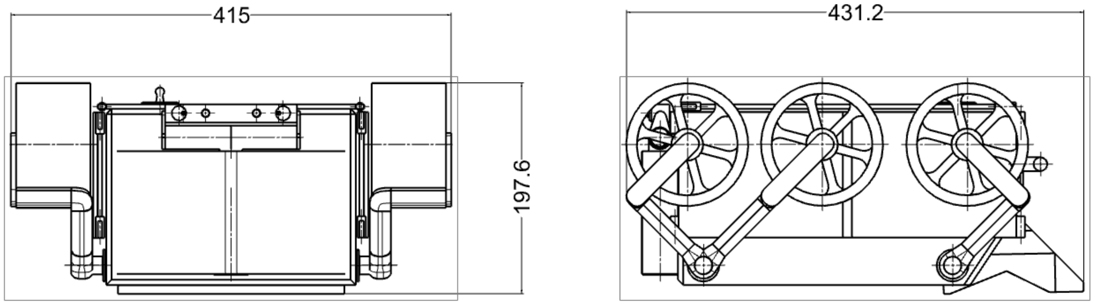


Figure 25. Dimensioned CAD draft of the fully stowed Telos-1 rover for cruise and EDL procedures

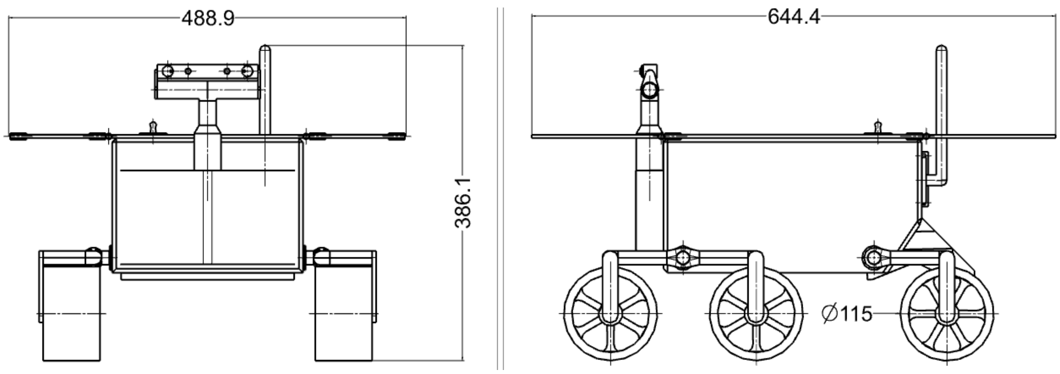


Figure 26. Dimensioned CAD draft of the fully deployed Telos-1 rover for post-EDL procedures and primary mission

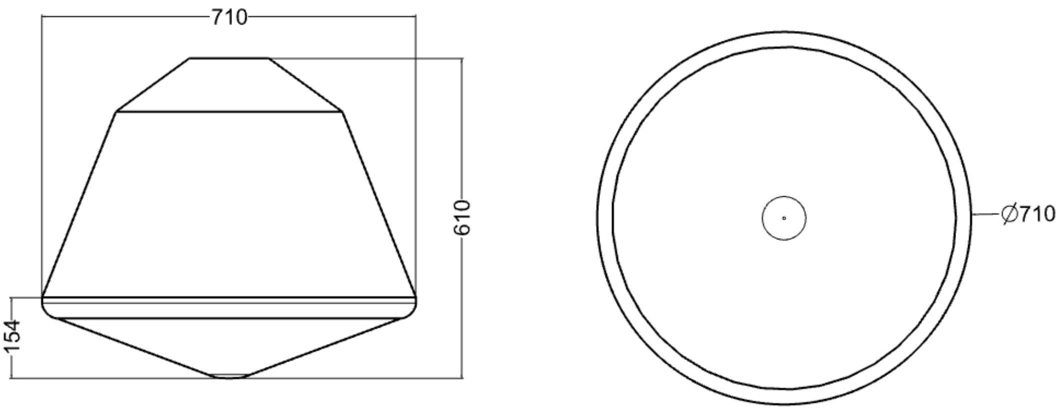


Figure 27. Dimensioned CAD draft of the Telos-1 aeroshell and PICA heat shield

3.1.4. Manufacturing and Testing Plans

Manufacturing

The Telos-1 rover will be manufactured using multiple avenues such as 3D-printing, departmental machine shops as opposed to outsourcing to public vendors and utilizing on-site testing at NASA based testing facilities.

The Telos-1 rover scientific payload consists of multiple instruments that have been utilized in prior endeavors, being adapted to fit within the allowed volume constraints. By using instruments that have been used in previous Mars missions, Telos-1's payload will be more cost-effective and more time-effective in regards to the manufacturing of said payload. The rover's motors, planetary gearheads, and absolute encoders will be picked from Maxons current DC brushless motor lineup. JPL engineers will adapt the motor to Martian conditions by building a wet lubricated housing that will have resistive patch heaters to allow preheating before using each Martian sol.

The UHF antenna system will be designed and built based on the NASA MER missions: Opportunity and Spirit. The re-used UHF monopole antenna system provides a compact and easier method of communication uplink and downlink. The UHF antenna and applicable electronics will be manufactured by L3Harris Technologies, Inc., who is well known for space and sensor technology. The radioisotope heater units (RHU) that will be used in the thermal management system for heating sensitive electronics through the loop heat pipe (LHP) will be manufactured and tested outside of NASA. The Department of Energy is responsible for the development and testing of the Radioisotope Power Systems (RPS) heat source modules.

Carbon bonded carbon fiber (CBCF) insulating material will be produced at Oak Ridge National Laboratory, a Department of Energy specialized facility. ORNL will also source and provide the raw plutonium-238 for the RHU's. Los Alamos National Laboratory will purify and encapsulate the plutonium-238 and the Idaho National Laboratory will assemble, test, and deliver the RHU's to NASA's Jet Propulsion Laboratory for installation into the Telos-1 rover.

All machining and specialized fabrication of aluminum for the body, suspension, and wheels will be completed at the Jet Propulsion Lab's Machine Shop by properly trained technicians. The solar array's deployment system will be designed and built by JPL engineers and equipped with 0.35 m^2 of Solaero IMM-α Space three junction solar cells. The creation of the rover from start to finish will take one year from start to finish due to simple design and strong partnerships with vendors. The final assembly and stowage of the Telos-1 rover into the launch and cruise phase configuration will be done at JPL before the July 1st, 2021 launch date.

Testing

Testing of the Telos-1 rover & EDL components is going to be a multi-facility joint venture that will allow the team to mitigate risk in a multitude of areas, ensuring that most issues that could arise are accounted for. Testing will be done on separate components, as well as, on the whole assembly. The following tests will be performed throughout the Telos-1 rover fabrication and assembly:

Heat shield tests will be performed in the Interaction Heating Facility at NASA Ames Research Center's Arc Jet Complex. The Interaction Heating Facility can heat air to over 14,000 degrees Fahrenheit. This device can be used to simulate temperatures that the heat shield will face during the entry process.

Parachute Testing will be performed in the Ames Research Center full-scale Aerodynamics Complex in California and during high altitude flight testing. Due to the thin Martian atmosphere, the parachute will open differently on Earth than on Mars. To combat this effect, technicians at the Ames Research Center will ensure that the wind tunnel is exerting the same amount of force that would be applied to the parachutes during EDL procedures on Mars.

Thruster testing & airbag landing tests will be performed at the Glenn Research Center - Spacecraft Propulsion Research Facility in Ohio. This facility has the unique capability of being able to test full-scale rocket engines at altitude pressures utilizing the Vacuum Chamber. Testing out the rocket-assisted descent (RAD) motors for the EDL procedures will be done at this facility in a Mars simulated temperature and pressure. With this ability to simulate a Martian atmospheric environment, the airbags and drop tests will be performed in the Space Power Facility of the Plum Brook Station.

Sandbox and terrain testing will be performed at JPL using Martian-like surface features. During this testing, special attention will be put on how the wheels tread, how the rover climbs, and how the motors handle maneuvering through fields of different sized rocks and sands. This is to ensure that the rover will be able to handle moving through its mission path especially along a route with highly sloped hills.

Antenna Testing for both the RIMFAX antenna, as well as the UHF monopole antenna will be performed at the Johnson Space Center - ATF (Antenna Test Facility). In this facility, is an Anechoic Chamber with the ability to measure far-field and near-field antenna radiation distribution patterns and principal plane cuts. The team will be able to test the antennas while on the rover to better understand what the polarization and gain attributes are of the rover and alter the design if needed to enhance mission effectiveness.

Telecommunications Testing will be completed at JPL by telecommunications engineers to ensure instruments onboard the rover can freely transmit and receive data without interfering with each other. This testing will ensure that instruments can interact and work as designed, and if issues do arise, parts can be altered, moved or electromagnetic interference can be mitigated by adding additional protection (such as line filtering, additional shielding...etc.)

Environmental Testing will be done at JPL 25 foot Space Simulator Facility. In this facility, the rover will be put through solar thermal vacuum testing to simulate deep-space and martian surface environments. This system will allow the team to test the rover at extreme pressures, alternating cycles of hot and cold, and the effects of enhanced solar radiation levels.

Vibration/acoustic testing will be performed at the Johnson Space Center where the team will test the as-built rover and descent vehicle in a simulated launch environment that matches the acoustic and vibrational stresses put on the body of the spacecraft during launch and landing on Mars. This will allow evaluation of the structural dynamics of the craft and ensure the rover’s safe delivery to the surface of Mars.

Instrumentation testing and initial calibration will be performed on Earth. RIMFAX testing will be performed in multiple locations on different layers of well-known strata to allow for the team to have a benchmark to go off of when analyzing the martian GPR data. Both RIMFAX and Mini-TES will be tested for operational efficiency and calibrated before installing the craft in the aeroshell for takeoff.

3.1.5. Validation and Verification Plans

As can be seen in the section prior, all elements of the Telos-1 mission will go through multiple rounds of in-depth, rigorous testing. One of the most critical moments for proper validation is during the silent minutes that a mission must autonomously perform its EDL procedures (Curiosity's famous “Seven Minutes of Terror”).

A well developed computer-managed deployment system will be put in place to ensure that Telos-1 can complete all precise milestones of EDL, such as parachute release, RAD powering, and airbag deployment. Using the onboard UHF, Telos-1 will be able to “ping” Earth as it lands, informing mission control of the completion of each of these milestones. However, due to the distance between Earth and Mars and the speed with which EDL occurs, this is the only possible communication to be had with the rover. For this reason, Telos-1 must operate autonomously, as mentioned before.

Once on the surface, Telos-1 will unfold from its collapsed state as shown below. This process is described in-depth in section 4.1.4, along with the verification and validation of the payload.

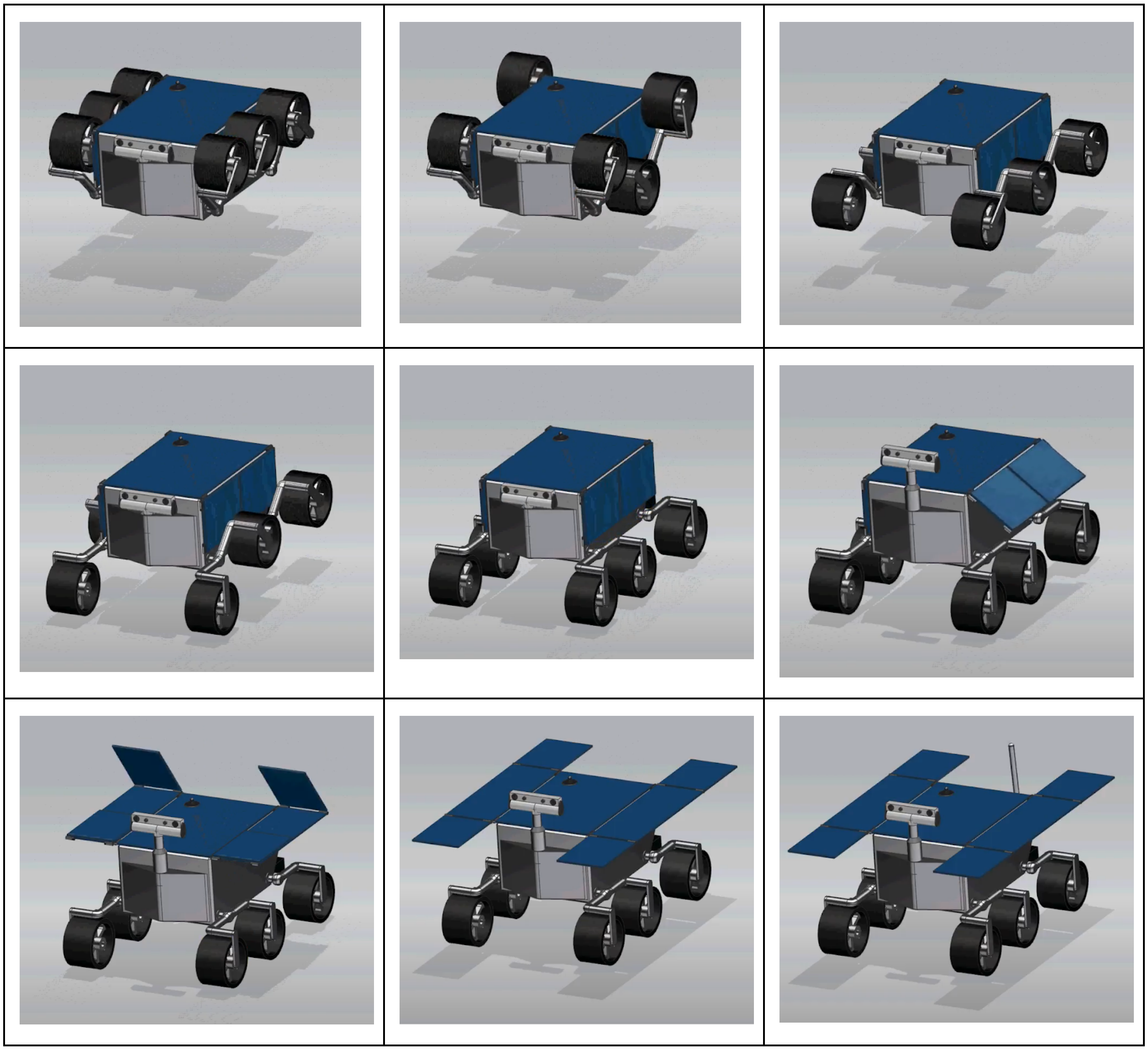


Figure 28. The process of suspension extension and payload deployment.

3.1.6. FMEA and Risk Mitigation

This section features an in-depth explanation of Telos-1's Failure Mode and Effects Analysis (FMEA) and steps for risk mitigation. Additionally, there are descriptions of the action to be taken in the event of specific failure modes. Provided are tables explaining all criteria used in the ranking process.

Effect	Criteria: Occurrence	Ranking
Very High	> 1 in 2	10
	1 in 3	9
High	1 in 8	8
	1 in 20	7
Moderate	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low	1 in 15,000	3
Very Low	1 in 150,000	2
Remote	< 1 in 1,500,000	1

Figure 29. The FMEA Occurrence rankings explained.

Effect	Criteria: Severity	Ranking
Hazardous - without warning	High risk of mission failure. Item failure will occur without warning.	10
Hazardous - with warning	High risk of mission failure. Item failure will occur with warning.	9
Very High	Major impact on daily functionality (eg., total loss of intrumentation functionality)	8
High	High impact on daily functionality (eg., partial loss of intrumentation functionality)	7
Moderate	Moderate impact on daily functionality	6
Low	Low impact on daily functionality	5
Very Low	Very low impact on daily functionality	4
Minor	Minor impact on daily functionality	3
Very Minor	Very minor impact on daily functionality	2
None	No effect	1

Figure 30. The FMEA Severity rankings explained.

Effect	Criteria: Detection	Ranking
Almost Impossible	No known current controls will detect failure mode	10
Very Remote	Very remote likelihood current controls will detect failure mode	9
Remote	Remote likelihood current controls will detect failure mode	8
Vey Low	Very low likelihood current controls will detect failure mode	7
Low	Low likelihood current controls will detect failure mode	6
Moderate	Moderate likelihood current controls will detect failure mode	5
Moderately High	Moderately high likelihood current controls will detect failure mode	4
High	High likelihood current controls will detect failure mode	3
Very High	Very high likelihood current controls will detect failure mode	2
Almost Certain	Current controls almost certain to detect failure mode. Reliable detection controls are known with similar/ prior processes.	1

Figure 31. The FMEA Detection rankings explained.

Failure Mode and Effects Analysis

Project:	Telos -1	Team:	MCA Team 22	No.:	1
Project Area:	Engineering	Manager:	Salam Mulhem	Date:	7/29/20

Subsystem	Part	Functions	Failure Mode	Effects	Severity	Causes	Control Methods: Prevention Control	Occurrence	Control Methods: Detection Control	Detection	RPN	Recommended Action: Action
Mobility	Wheel	To provide mobility to the rover	Cracked tire	Loss of traction, tire slippage	7	Fatigue	Proper material selection, thickness	2	Decrease in mobility, drifting off course, Pancam self-imagery	7	98	1. Continue mission for as long as possible, using wheel as normal
			Scaled Tire			Sand build-up	Tread design	1			49	
			Tread wear			Metal Softness	Proper material selection, thickness	3			147	
			Loose wheel	Loss of wheel, instability, 'dead weight'	9	Under/over torquing, dirt/dust/scaling/excess coating buildup between mating surfaces, rust, vibration, obstacle damage, landing damage	Proper torquing/paint/seal/ coating techniques	2	Sharp change in gyroscope feedback indicating tipping, Pancam self-imagery	3	54	1. If wheel is attached, continue mission for as long as possible 2. If wheel is detached, attempt to continue mission for as long as possible. (Reference Spirit MERS mission)
Mobility	Suspension	To provide a weight bearing structure system that connects the body to the wheels and adapts to terrain.	Main body disconnect	Suspension Failure	10	Fatigue, manufacturing error, obstacle damage	Pre-mission material design, testing and analysis. Good manufacturing techniques	1	Loss of control/electrical feedback, gyroscope feedback	1	10	1. Attempt to relay any instrumentation data for analysis
			Linkage joint failure									1. Continue mission for as long as possible, avoiding all obstacles
			Wheel plate joint failure	Loss of wheel								
Mobility	Motors	To provide the power/torque necessary to move	Driving Motor Failure	Wheel loses drive power	9	Electrical failure, bearing failure	Motor sizing, manufacturing techniques, safe packaging	3	Loss of control/electrical feedback, inability to move, drifting off course	1	27	1. Continue mission for as long as possible, using wheel as normal
			Steering Motor Failure	Wheel loses ability to turn								
Body	Pancam Mast	Deploys Pancam to height, allows for 360 degree rotation	Damage or misalignment of telescoping tubing	Pancam cannot reach full height or rotate	7	Landing damage, obstacle damage	Motor sizing, manufacturing techniques, safe packaging	1	Control of motors yet lack of deployment	6	42	1. Use Pancam at collapsed height, without rotation
			Deployment Failure	Pancam cannot reach full height.		Motor failure, dirt/dust/scaling/excess coating buildup, obstacle damage			Loss of control/electrical feedback	1	7	1. Use Pancam at height that it can deploy to 2. If Pancam cannot deploy at all, the Pancam also cannot rotate due to WEB interference
			Rotation Failure	Pancam cannot rotate								1. Use Pancam at height, without rotation
Body	WEB Paneling	Protects and houses all sensitive instrumentation and electrical elements	Weld Failure	Exposure of elements in WEB	9	Fatigue, manufacturing error, landing damage, obstacle damage	Manufacturing techniques, material thickness, safe packaging	2	Temperature fluctuation, electrical efficiency/responsiveness . Pancam self-imagery	6	108	1. Continue mission for as long as possible, minimizing daily routine as electrical efficiency decreases
			Panel Damage							5	102	
EDL	Heat Shield	To protect the rover from high temperatures during entry into the Martian atmosphere	Destroyed Tile	Burning up of rover and other aeroshell contents	10	Shield could not withstand high temperatures	Proper material selection, thickness	1	Failure to make contact with rover	1	10	1. Mission cannot continue if heat shield fails to protect rover during entry
			Detached Tile			Failure to secure tile to heat shield structure during construction	Ensure attachment during testing, PICA-on-edge gap filler as extra tile attachment point					
			Failure to jettison from back shell	RAD motors cannot slow descent, air bags cannot cushion landing, rover crash lands	10	Faulty separation nuts or push-off springs	Pre-mission testing	2	Failure to make contact with rover	1	20	1. Mission cannot continue if heat shield fails to jettison
EDL	Back Shell	Houses rover, RAD motors, parachute, and other	Structural Damage	Burning up of rover and other aeroshell contents	10	Failure to withstand high temperatures	Sufficient thermal protection system, structure materials, thickness	1	Failure to make contact with rover	1	10	1. Mission cannot continue if rover burns up due to back shell failure

Figure 32. FMEA Chart for the EDL and lander aspects of Telos-1 Mission. FMEA gives the ability to analyze high risk areas and ensure that risks are properly mitigated using the Risk Priority Number (RPN) to identify the most critical failure mode items.

3.1.7. Performance Characteristics and Predictions

Similar to the relationship between the Mars Exploration Program's Curiosity and Perseverance, the design of this rover was heavily inspired by the successful aspects for prior missions.

Mobility

The motors and gearheads used to power Telos-1's wheels and actuating panel elements have been selected through Maxon, NASA's choice motor supplier for the past five missions. These elements have been sized to surpass the needs of the mission to ensure that they last the duration required. The wheels are similar to those on Perseverance, with mimicked materials (aluminum tire, titanium rims) and tread patterns. The rocker-bogie system has been the choice suspension system for NASA since 1988's Sojourner rover.

Entry, Descent, and Landing (EDL)

Similar to the mobility subsystem, EDL opted to modify the most advanced and successful aspects of prior missions. The heat shield and back shell were designed with materials used primarily in the Curiosity mission, but the back shell thermal protection system material was used in the Pathfinder, Mars Exploration Rovers, and Phoenix missions. The back shell geometry is derived from the Viking missions. The MR-107N rockets used in the Rocket Aided Descent system are based on the Insight mission, coming from the MR-107 line of rockets which have been used by NASA since the 1990s. The airbag configuration is similar to the thoroughly tested system to be used for the Orion capsule, which has been sized and modified to suit the mission's needs and EDL goals. The material for both the airbags and parachute have been selected based on those which have been proven in prior missions.

3.1.8. Confidence and Maturity of Design

Overall, Telos-1 boasts a wealth of advanced technology, providing an incredible balance of scientific capability and small concept sizing. Aside from its complex payload which will be described in depth int section 4, the highlights of the rover are its lightweight and dependable build, its adaptable rocker-bogie suspension, its robust motor system, its complex airbag and parachute system, and its refined aeroshell and rocket assisted descent system. All materials and the majority of designs have been proven in prior missions and scientific studies - this mission is built on the shoulders of the science that came before it.

3.2. Recovery/Redundancy System

With every life-critical element on the rover, there are mechanical and electrical redundancies available, large safety factors, or alternate methods of accomplishing tasks in the case of failure. Within EDL, the six RAD thrusters can successfully complete landing procedures, even if only five of the thrusters remain functional. There are a sufficient number of airbags to support the rover in case of an airbag failure, supported moreover with the nested airbag system.

In the case of issues with the mobility system, there are sufficient redundancies in place. Should the rover suffer drive motor loss, all five other wheels are also equipped with drive motors, giving the rover the ability to continue traveling. The same goes for the steering motors - should one fail, the other three are capable in guiding the rover.

3.3. Payload Integration

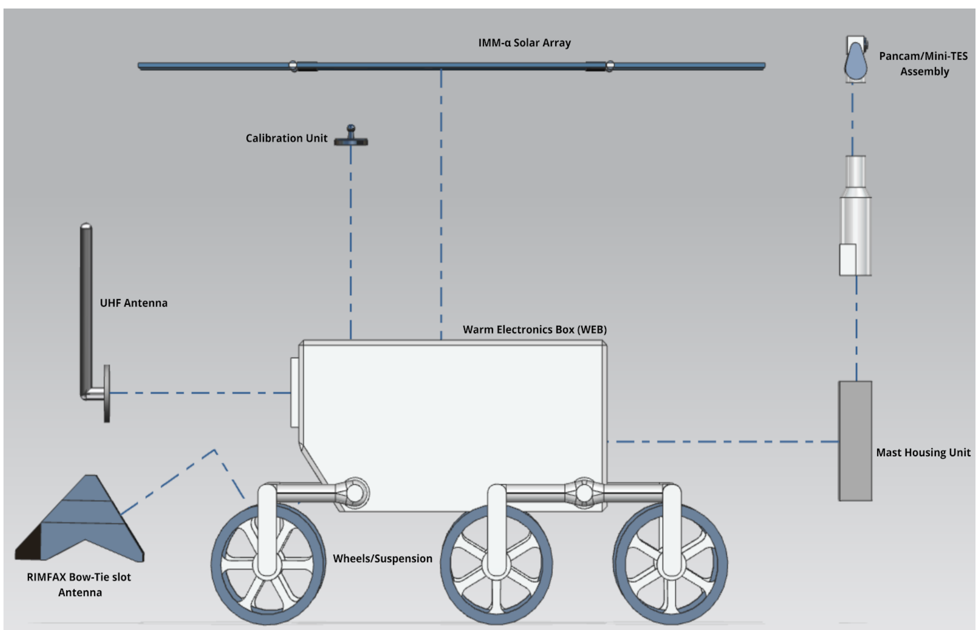


Figure 33. Exploded side view of the Telos-1 rover

The Telos-1 rover payload was designed around the Warm Electronics Box's (WEB) sizing and shape as well as to support the sensitive electronics that are inside. All exterior parts outside of the WEB are branched off with trace lines to the parts' original mounting position, as shown below. The central solar panel is fixed onto the top of the WEB deck, with a small hole to the back right side for the Pancam/Mini-TES calibration unit. The UHF antenna and LHP system cold plate are fixed on the flat upper backside, while the RIMFAX antenna is mounted to the beveled, lower backside of the WEB.

Attached on the front side of the WEB is the Mast Housing Unit, the Mast Assembly, and the Pancam/Mini-TES Assembly. The Mast and Pancam/Mini-TES assemblies are retractable into the housing unit to allow for a low profile, to ensure the rover fits in the mission profile volume constraints. The UHF Antenna rotates clockwise to a horizontal position over the LHP cold plate and the solar arrays fold downwards onto the sides of the rover.

4. Payload Design and Science Experiments

4.1. Selection, Design, and Verification

4.1.1. System Overview - N^2 Chart

Mobility (Motors)					
	Payload (Instruments)	Acknowledge retrieval of scientific data	Raw data		
Movement Commands	Science procedure commands	**Rover Compute Element (RCE)**	Transmission of Data Packets Acknowledge receipt		
		Acknowledge transmission	**Communications**		
10 Watts to motors for movement/steering	20.2 Watts to Instruments for operation	10 Watts to Rover Computer	10 Watts to antenna package	**Power**	30 Watts to survival heaters
Pre-heating to operating temperature	Pre-heating to operating temperature				**Thermal**

Figure 34. N^2 Chart showing system operational overview for Telos-1 rover

This matrix represents the functional interfaces between all of the rover system elements. The arrows represent a system relationship with a small description of the purpose of the connection. Using this N^2 chart, the team can conceptualize a complicated system and give non-payload engineering fields and readers an overview of system interconnectivity and relationships.

4.1.2. Subsystem Overview

Instruments

The Telos-1 rover will be equipped with three instruments necessary to complete the mission of surveying the surface and subsurface geology of Jezero Crater, which include the following: RIMFAX, Pancam, and Mini-TES.

<u>Radar Imager for Mars' Subsurface Exploration (RIMFAX)</u>

RIMFAX is a nadir-point ground penetrating radar (GPR) capable of providing higher definition images of the subsurface of Mars in a more conveniently small package that includes a small prismatic electronics box installed within the Rovers Warm Electronics Box (WEB) and a Bow Tie Slot Antenna mounted on the rear exterior of the Telos-1 rover body. Using a Gated Frequency Modulated Continuous Wave

(FMCW) waveform pulling between 5-10 watts of electrical power when operating, the RIMFAX instrument can produce a UHF/VHF frequency range between 150-1200MHz. Given this frequency range, the rover will be able to focus the GPR on specific depths ranging from a few inches into the martian regolith to 10 meters, or 30 feet, into the surface. The range of depth is highly dependent on the composition of the subsurface being examined, with highly conductive materials such as clay or salt-laden soil limiting depth, as well as heterogeneous soil conditions causing signals to scatter. The RIMFAX radar, as stated earlier, operates within the 150-1200MHz range. The lower frequency ranges will provide greater depth of penetration at the expense of resolution, while higher frequency ranges will allow for very high definition from the surface into the immediate subsurface.

Panoramic Camera (Pancam)

Pancam is a multi-wavelength set of CCD cameras set approximately 3.5” apart, used to view the Martian surface, take images, acquire orientation of the rover, as well as, do spectral analysis of the minerals that make up the regolith or atmosphere with a filter wheel mounted over each camera. The majority of the use for the instrument is for the 360° panoramas using red filter images at full resolution in both CCD cameras and green/blue filter images at a compressed resolution in the left camera. In doing this the rover will provide high resolution morphologic and textural information, near true-color information, and adequate stereo ranging around the rover. Each eye is outfitted with an 8-position filter wheel that has 400-1100nm wavelength filters allowing for near-UV to near-IR analysis of its surroundings. Thirteen out of the fifteen filters are geology filters meant for imaging the surface or atmosphere and the other two are meant for imaging the sun.

Pancam allows for 360° of rotation and ±90° of elevation, making it extremely versatile and allowing it to get a full picture of its surroundings without moving the rover itself, therefore saving power. The camera itself operates off of 3 Watts of electrical power, but does require a 3.5 Watt heater to ensure the cameras stay within the instrument survival temperature range of -110°C to 50°C. The heater will also ensure that the cameras are within the optimal operating temperature range of -55°C to 0°C before turning on the cameras and viewing the Martian surface. The Pancam coupled with the Mini-TES data will allow for near full spectrum analysis of the surface. Between the two lenses for the Pancam are the two navigational cameras that allow for hazard avoidance and terrain guidance. The rover system uses sophisticated artificial intelligence software to take in data about its surrounding environment and plot a course that will allow for the lowest amount of risk to the rover. In doing this, the rover will be able to travel autonomously during its planned daily route and ensure mission survival.

Miniature Thermal Emission Spectrometer (Mini-TES)

Mini-TES is a Fourier Transform Spectrometer that views its surroundings in the spectral range of 5-29 micrometers, working off of the concept that different compounds will be at different temperatures when exposed to the same concentration of sunlight. The Mini-TES calibrated radiance is converted to effective emissivity and surface temperature by fitting a Planck function to a calibrated spectrum using the two calibration units in the PMA and on the rover body. This data can be converted into mineral abundance and can be fitted to a known mineral spectra matrix. The data can then be used to produce thermal inertia images using data taken throughout the day.

Mini-TES works in conjunction with the Pancam's mast assembly, using a fixed fold mirror and rotating elevation scan mirror to project light down the hollow mast assembly into the instrument to analyze the patterns of thermal radiation from a distance. Since the actual Mini-TES instrument is mounted within the warm electronics box just below and aft of the mast assembly, this allows the mirrors to push light to the box with 360° azimuth travel and 30° above/50° below nominal horizon travel. This instrument uses a DC power converter to take anywhere between 11-36VDC of unregulated input voltage to supply a constant, regulated output of 5 and 15VDC. This sensitive instrument also requires its own survival heater to keep it above -38°C, if the radioisotope heater units (RHU's) are not able to maintain instrument survival temperature.

Power

Power throughout the mission on the Telos-1 rover is one of the most precious resources that define the extent of the rover's abilities. The main systems for powering the rover and instrumentation are the Rover Battery Assembly Unit (RBAU) and the Photovoltaic panels.

Rover Battery Assembly Unit (RBAU)

RBAU has a long-standing heritage since 2004, well known for being used on MER, Spirit, and Opportunity missions. It has been tried and tested spanning 14 years of use with greater than 5000 discharge/recharge cycles. The battery assembly consists of two parallel batteries each with eight Yardney prismatic Li-Ion cells in series providing 24V-32.8V rated at a 16Ah BOL battery capacity. This will provide the Telos-1 rover with approximately 480Wh of power on a single charge for use during high loads during the day and maintaining systems during the cold night. The operating temperature range of the RBAU is -20°C to 30°C, meaning the RBAU will be outfitted with its own RHUs and survival heaters to ensure the battery temperature stays within operating range.

Photovoltaic Panels

Photovoltaic panels on the rover will be of two different types. Fixed mounted panels will be used on the top of the Telos-1 rover WEB and small deployable panels on the sides similar to the panels used on the ESA Exomars mission, but adapted to accommodate the rover's mission profile. The cells on the photovoltaic panels will be SolAero Technology IMM-α Space InGap/InGaAs/Ge Solar cells. These solar cells provide a 32.0% minimum efficiency on the Martian surface. Along with the cells not being susceptible to efficiency degradation due to dust coverage, they will provide the key answer to allowing not only the primary mission completion but increasing the chances of extending the mission to provide other key science data on Mars.

The Telos-1 rover will be equipped with 0.35 square meters of the solar array, with the ability to produce approximately 266 Wh of power a day. This power will allow for the recharging of the RBAU after the night, preheat the wheel drive/steer motors and instruments, and allow the rover to travel approximately 168 feet per martian sol. With the 266Wh of BOL solar cell power production and a calculated max power draw of 259Wh per sol, the solar cells have a slight tolerance allowing for the degradation in solar efficiency due to dust and climate.

Power Reduction

Part	Quantity	Wattage Req (W)	Time/day (Hr)	Heater Wattage (W)	Time/day (Hr)	Totals (WH)
UHF	1	10	0.5	0	0	5
RIMFAX	1	10	2	0	0	20
MINI-TES	1	5.6	2	0	0	11.2
PANCAM	1	3	2	3.5	1	9.5
NAVCAM	2	2.2	2	3.5	1	12.3
MOTORS (STR)	4	5	0.1	10	2	22
MOTORS (DRV)	6	5	1	10	2	50
SURVIVAL HEATERS	6	5	1	0	0	30
COMPUTER	1	10	8	0	0	80
Totals		55.8	18.6	27	6	160

Power Storage

Part	Quantity	Wattage Req (W)	Daily drain	Totals (WH)	Notes
Battery	1	480	80	400	Recharge battery is the first priority
Totals w/ batt		480	80	0	
			240		

Power Generation

Part	Performance Ratio	Solar Efficiency	Irradiance (W/m^2)	Area (m^2)	Output (W)	Peak hours	Wh/day
PV Panels	0.75	32%	593	0.35	49.812	5	249.06

Rover Travel Details

speed (in/sec)	travel time (sec)	travel time (hr)	Distance (in)	Distance (ft)	Daily stops	Stop time (sec)	Total active time (sec)	Total hrs
0.75	3600	100%	2700	225	720	10	10800	3

Figure 35. Power charts depicting the generation and usage of power by the Telos-1 rover

Communications

The rover is planned to have a separate communications package dropped in the local area of Jezero Crater. This rover will transmit to the communications package and then to a local Mars orbiter that will send the data packets back to earth. The antenna that will be in use is the Monopole UHF antenna.

UHF Antenna

The main means of communication with the communication package in the local area will be a monopole style UHF antenna system working in the 300MHz to 3GHz frequency range and works at data transfer rates of 8, 32, 128, and 256 kbps to an orbiter. The system was used on many early rovers such as Opportunity and was made by Cincinnati Electronics. To maximize toroidal shape gain pattern and linear polarization of the UHF antenna, the engineering team needed to consider clearing the WEB deck as much as possible to ensure minimal distortion of data-volume transfer. The UHF monopole design was selected because it is tried and tested and works well for the mission profile but also if the local communications package has issues or is out of range to connect, the rover will still be able to connect to the orbiters overhead directly and send 150-250 megabits of data which will then be sent to earth even when the rover is not connected to the orbiter anymore. The UHF antenna will be stowed sideways and upon landing will be spring actuated 90 degrees into the upright position.

Thermal Protection

Radioisotope Heater Units (RHU)

Due to the cold climate of the Martian landscape, the use of multiple Radioisotope Heater Units is necessary to ensure that the instrumentation and electronics boxes are kept at an optimal operating temperature and minimal survival temperature when not being used. RHU's generates approximately 1 watt of heat energy from the decay of a small pellet of plutonium dioxide (Plutonium-238). The plutonium is within a multi-layered containment system that prevents the release of fuel. The outer material is made of fine-weave pierced fabric and a graphite-based insulator to protect the fuel from extreme EDL conditions, impacts, and fires. The rover will employ 5 RHU's which will be connected directly to the battery and parts that have minimum operating temperatures as well as be used to apply heat to the miniature loop heat pipe system during the night hours to allow passive heat delivery throughout the WEB.

Loop Heat Pipe System (LHP)

The miniature loop heat pipe system will be used to assist the RHUs in maintaining proper temperature across the electronics within the WEB. The LHP is passive, no power required thermal regulation system consisting of an evaporator with a sintered nickel primary wick (1.2-micron pore size) and a secondary wick, a 3-way solenoid, a thermal control valve (TCV), internally-finned aluminum tubing, a condenser, a compensation chamber and uses RHU's for the evaporator heat source. The system will provide consistent heat distribution throughout the WEB to ensure critical items are well heated such as the Rover Battery Assembly Unit (RBAU). The system works by applying heat to the aluminum evaporator that is filled with liquid ammonia, vaporizing the liquid within the primary wick, and pushing the hot vapor through the aluminum vapor lines to a 3-way solenoid valve.

The rover will use a Type E Thermocouple on the temperature-sensitive equipment that will control the 3-way solenoid valve to either route the vapor through the equipment in colder conditions or bypass the equipment during hot conditions and push directly towards the condenser before going back to the compensation chamber. In doing this, the rover will be able to use less power for the electric heaters on the equipment and put less stress on the electrical system. After the vapor goes past the temperature-sensitive equipment it will be routed through a TCV and depending on the temperature of the incoming vapor it will either be routed directly to the compensation chamber for additional heating or it will be routed towards the condenser where it will be cooled. If the battery or other equipment begins overheating, the TCV will automatically switch the flow through the condenser to ensure proper cooling of ammonia before its return to the compensation chamber.

Aerogel

To prevent the loss of heat from the WEB, the rover will use a solid silica aerogel material as a thermal insulator. Aerogel is 99.9% air, making it extremely light and effective in decreasing thermal conductivity. The aerogel will be in two layers with a thin layer of gold plated kapton, to protect the internal components from harmful radiation. The final thermal control devices used are six, 5-watt resistive patch heaters, being used to supplement the LHP heat in the event of a specific instrument or electronic component being within 10 degrees celsius of its low survival temperature. These patch heaters are attached directly to the components that have a temperature that they need to stay above to survive and are only used to supplement and not meant to be the sole means of heating unless issues arise with the passive LHP system.

Electronics

The Telos-1 rover will have two identical BAE RAD750 3U CompactPCI single-board computers. These computers have a heritage in multiple NASA missions including InSight, Curiosity, and multiple orbiters. The rover will only employ the use of one of the computers at a time and if any issues arise, will swap operation to the other unit, so troubleshooting can be done on the defective unit. The RAD750 is a radiation-hardened system able to withstand up to 100,000 rads and survive in temperatures down to -55°C.

4.1.3. Precision of Instruments, Repeatability of Measurement, & recovery system

Radar Imager for Mars' Subsurface Exploration (RIMFAX)

Instrument Precision

The RIMFAX antenna and associated electronics (see *Section 4.1.2: Subsystem Overview* for component description) will be working between the 150 MHz to 1.2 GHz frequency range, sounding the ground at different frequencies depending on the desired depth. This is going to create interleaved pairs of shallow-deep soundings with a vertical resolution of 3-12" thick. Depending on the materials, the penetration depth could be greater than 10 meters with the lower frequency settings.

Repeatability of Measurement

Due to the individual soundings being done every 4-5" of rover movement, the images produced will be compiled and produce a total snapshot of the subsurface along the track of the rover.

Data Recovery System

Each sounding creates a 5-10 kb data segment that will be sent to the main computer for processing. It will be combined with the other soundings to create a total snapshot of the rover's track and will be compressed into a singular data packet that will be sent to the communications package for delivery to Earth for analysis.

Miniature Thermal Emission Spectrometer (Mini-TES)

<u>*Instrument Precision*</u>

The Miniature Thermal Emission Spectrometer or Mini-TES (see *Section 4.1.2: Subsystem Overview* for component description) is a fourier transform spectrometer covering the spectral range between 5 - 29 micrometers. The radiometric calibration of the device is done by two calibration units: one in the Pancam masthead where it is protected from dust and one on the rover body both of which consist of a beam-filling blackbody target with platinum thermistors bonded to the underside. The thermistors have an absolute temperature accuracy of 0.1°C for temperatures from -130°C to 110°C. The radiometric precision of the Mini-TES, with which two spectra are collected during each observation, is ±1.8 × 10−8 W cm−2 sr−1/cm−1 between 450 and 1500 cm−1, increasing to ~4.2 × 10−8 W cm−2 sr−1/cm−1 at shorter (300 cm−1) and longer (1800 cm−1) wavenumbers, for both mineral determination and atmospheric studies.

<u>*Repeatability of Measurement*</u>

The interferograms are taken multiple times per day allowing you to see the results throughout multiple surfaces or atmospheric temperatures and different lighting conditions. Worst-case radiance errors correspond to ~0.4K for a surface temperature of 270K and ~1.5K for a surface temperature of 180K.

<u>*Data Recovery System*</u>

An interferogram can be taken every 2-3 seconds, with each one being sent to the rovers main computer for Fast Fourier Transform, spectral summing, lossless compression and the formatting of the data before the information is stored into system memory for transfer to the local data package to be sent to Earth.

Panoramic Camera (Pancam)

<u>*Instrument Precision*</u>

The geology filters were designed and fabricated to have peak transmission >85%, transmission ripple within the passband of <10%, central wavelength uniformity and central wavelength shift resulting from angle of incidence variations across the FOV of <1%, and a wavelength-integrated rejection band response in the 400 to 1100 nm region of <1% of that filter's integrated in-band response. For the two filters designed for solar imagery, the filters are coated with metallic attenuation film to provide an additional factor of 105 reductions in overall transmission.

Repeatability of Measurement

The calibration of the instruments is important to ensure proper post-processing of the images. The rigorous instrument calibration pipeline is used to constantly monitor the stability spatial response pattern and radiometric calibration. The Pancam will view the calibration target and fiducial marks multiple times per martian sol, under multiple lighting conditions to ensure proper calibration of the camera before images are taken and digitized.

Data Recovery System

The Pancam electronics amplify the CCD output and convert analog voltages to a 12-bit digital signal. A unique camera identification number is inputted into the telemetry of each one of the cameras to simplify processing and managing the data. Due to the amount of data needing to be transferred, the rover computer will do the majority of the image processing before sending it to earth. The UHF antenna will send the data through the communication package chain to earth for use in planning for next day operations and scientific analysis.

4.1.4. Validation and Verification Plan

Shortly after landing and the deployment of the rover on the martian surface, the rover will perform a full BIT operational checkout of all systems on the rover. This will be done to validate the correct system operation post-EDL, before the first experiments are started. Validation and verification of systems include:

1. Telos-1 rover will power up the RAD750(A) computer system.

2. The rover’s 3-bogie chassis will extend from the stowed position to its operational position using deployment motors.

3. The main computer will initiate the unfolding of the solar arrays and verify power production on the system by reading voltage at the computer and ensuring the battery system is under no-load/reduced load.

4. The computer will take temperature readings from within the WEB using the Type E Thermocouples on the instruments and RBAU system. If the temperature reading is below -55 degrees celsius, the LHP Thermal Control system will automatically route RHU heated ammonia through the 3-way solenoid past the instruments to begin a process of preheating all equipment.

5. The computer will release the spring-actuated switch on the UHF antenna, moving it from the stowed position to the 90 degrees, upright position. A second mechanical switch will verify the antenna is in the upright position prior to powering up the system. The rover will then power up the UHF system, verify a good connection to the communications package and transmit it to earth via local

orbiters or the communications package, and to verify uplink/downlink capabilities.

6. The mast will then extend vertically and the Pancam's 3.5-watt heater will power up to ensure the operational temperature range is met.

7. Pancam will take a panorama image, digitize, and send RAW imagery to earth to verify full deployment of the solar array and full mast extension.

8. Start up Mini-TES and take the first interferogram of the surrounding environment, digitize and send RAW imagery to earth to verify Mini-TES functionality

9. Stay through the first martian sol - verify the thermal protection system LHP & survival heaters are working optimally throughout the night. Monitor temperature of equipment using the Type E Thermocouples and activate all survival heaters once throughout the night, verifying equipment temperature rises when activated and falls when deactivated, so as to ensure proper operation of resistive heaters.

10. Start wheel drive and steering motor heaters to prepare for first rover movements. Test steering motors using absolute encoders attached to the steering motors to verify range capabilities both left and right.

11. Disconnect from the lander, roll forward 5 feet, take panorama using Pancam, digitize and send to earth for successful movement verification

12. Power up RIMFAX and take first GPR subsurface soundings between the full frequency range of 150 MHz to 1.2 GHz, send the data packet to earth for first RIMFAX sounding verification.

13. Perform primary mission functions.

4.1.5. FMEA and Risk Mitigation

FMEA Failure Mode and Effects Analysis					
Product / Part:	Rover Payload	Team:	MCA TEAM 22	FMEA No.:	1
Project:	Telos-1	Engineer:	Andrew Rich	Manager:	Salam Mulhem
				Original Date:	7/10/2020

Part	Function	Failure Mode	Effects	Severity	Causes	Control Methods: Prevention Control	OCC	Control Methods: Detection Control	Detection	RPN	Recommended Action: Action
Battery (RBAU)	To provide sufficient DC power during martian night for system survival and times of large power draw during day time operations	Battery out of survival temperature range	Battery life severely shortened/battery failure	10	Insuffienct thermal control system	Loop Heat Pipe system and Survival Heaters	3	Temperature test using electrical equipment thermocouples	1	30	1. Battery thermal control system to be tested in varying temperature ranges alike the of Jezero Crater
		Battery no longer holds rated/actual 16/20Ah charge	Operational efficiency decreased; prioritization of daily tasks necessary to conserve power and ensure asset	6	Natural decay of battery cathode	Optimization and prioritization of operational task to put less stress on battery; reducing cycles	8	Battery Capacity test done by rover computer	2	96	1. Battery capacity check performed before launch 2. Perform discharge/recharge cycle testing at operational temperature ranges of Mars.
Photovoltaic Panels	To provide power to the rovers computers and equipment throughout the day and recharge rover batteries	Panels covered in dust from landing	Solar Efficiency reduced; function with less daily power	6	Natural placement due to Martian environment	Upgraded solar cells that provide power over a wide spectrum	10	Visual Inspection by Pancam	2	120	1. Perform dust coverage/effeciency testing on earth 2. Select solar cell types that are efficient at multiple wavelengths to maximize efficiency
		Failure to deploy	Will only be producing power off static PV panels on rover WEB	9	Damage to the deployment mechanism	Single use opening motors or pyrotechnics?	2	Visual inspection by Pancam	2	36	
UHF Antenna	To provide optimal communications uplink/downlink to earth via local communications package and orbiters	Loss of comms link/operation failure of ground communications package	No communications relay to orbiters/earth via communications package	3	Electronic failure of local comms pacakge Sustained damage via EDL procedures	Proper ESD procedures during assembly; UHF direct connect to orbiters at high data rate xfer	7	Uplink/downlink checkout of comms package upon landing	1	21	
		Operational failure of UHF electronic equipment	No communications with comms package or orbiters	10	Shorting of Electronics Sustained damage via EDL procedures	Proper ESD procedures during assembly	2	Uplink/downlink checkout of comms package upon landing	10	200	1. Perform connection testing at full uplink/downlink capacity before stowage for launch 2. Properly ground equipment to case and use ESD safe procedures during assembly of rover.
Mini-TES	Provide insight into the thermal properties of surrounding surface and atmosphere	Out of calibration	Data cannot be used due to lack of data control/constant	5	Varying ranges for temperature on Martian surface	Blackbody calibration units	10	Instrument Calibration Test	1	50	1. Calibration campaign before launch at earth conditions 2. Calibrate immediately upon arrival
		Electrical failure	Failure of equipment to function	7	Shorting of Electronics	Proper ESD procedures during assembly	1	Initial operational checkout upon landing	1	7	
Pancam	CCD Cameras used to provide panaramic views, navigation, hazard avoidance,and scientific analysis using multi-spectral filters	Out of calibration	Multi-spectral filters and true-color imagery rendered useless	5	Changes in atmospheric dust content and ambient lighting conditions	Calibration units	10	Insturment Calibration Test	1	50	1. Calibration campaign before launch at earth conditions 2. Calibrate immediately upon arrival
		Lens dust coverage	Deterioration of viewing clarity	8	Natural placement due to Martian environment	Self-ejecting lenses	10	Picture clarity	1	80	1. Eject lens when viewing quality has been compromised

Figure 36. This is the Failure Mode & Effect Analysis chart for the different payload components that have the highest chance of failure. FMEA gives the ability to analyze high risk areas and ensure that risks are properly mitigated using the Risk Priority Number (RPN) to identify the most critical failure mode items.

4.1.6. Performance Characteristics

The Telos-1 rover is using proven technology that has been used on prior NASA or Mars Rover missions. The following addresses various aspects of the system which will operate under expected conditions.

Power

The RBAU was used on both Spirit and Opportunity rovers with well over 5000+ discharge/recharge cycles making it a lightweight Li-Ion battery option with a wider temperature range than other options. The solar cells on the panels are the same high-efficiency Solaero cells that were used on InSight and they are mounted in both a static configuration on the warm electronics box, as well as, fold-out panels on the side that are similar to the of the ExoMars missions of 2016 and 2022.

Communications

The UHF monopole antenna is true and tried on many different rovers including Sojourner, Spirit, and Opportunity. It will allow for connection to local communications packages or landers and also to orbiters flying over. The UHF antenna provides optimal bandwidth for higher data transfer rates and requires less power and time to transmit large quantities of data to the orbiter so it can be sent to earth using the orbiter's much larger and powerful antennas.

Instruments

The RIMFAX is the only new instrument that is set to be sent on the Mars Perseverance 2020 mission to the Jezero Crater. The RIMFAX instrument was tested in many places such as Moab, Utah, The Mojave Desert, Antarctica, and more.

The Mini-TES is a miniaturized version of the Mars Global Surveyor (MGS) TES instrument, that has also been used extensively on the Spirit and Opportunity rovers. The Telos-1 rover will have a similar Mini-TES configuration in the Pancam mast to ensure similar conditions to the instrument's heritage rover vehicles, to not stray away from performance conditions.

The Pancam was designed specifically for the martian environment, being used in some sort of configuration in many past missions on Mars. The Pancam has a well known calibration pipeline that engineers and scientists can use to calibrate, filter and correct mistakes on images such as bad pixel correction, shutter smear remover and more.

Thermal Protection

The thermal protection system is using heritage system parts such as RHU's and LHP's to ensure parts are kept within survival or operating temperature ranges. Radioisotope Heater Units are safe and well used to take the operational load off of the electrical heaters in ensuring the proper temperature is kept on the electronics. Loop heat pipe systems have also been used and are a great way to passively distribute heat throughout the rover, using a TCV and thermocouple to maintain temperature range.

4.2. Science Value

4.2.1. Science Payload Objectives

The science objective of Telos-1 is to map the subsurface and surface features of Jezero Crater, and in doing so locate any trace history of chemical compositions that would suggest a history of water. This mission will also search for the remains of microorganisms within the layers of the lithosphere in Jezero Crater. The presence of chemicals and minerals mainly H_2O, water-ice, olivines, clays (such as Fe-Mg smectite), and Mg-rich carbonates that suggest a prior history of water being present is highly sought in this mission. Telos-1 will be implemented to locate these minerals and chemicals using RIMFAX, Mini-TES, and Pancam.

4.2.2. Creativity/Originality and Uniqueness/Significance

The mission will be focusing almost solely on analyzing the Martian surface and subsurface of the western Jezero crater delta system using RIMFAX, a ground penetrating radar (GPR) technology, Mini-TES, and Pancam.

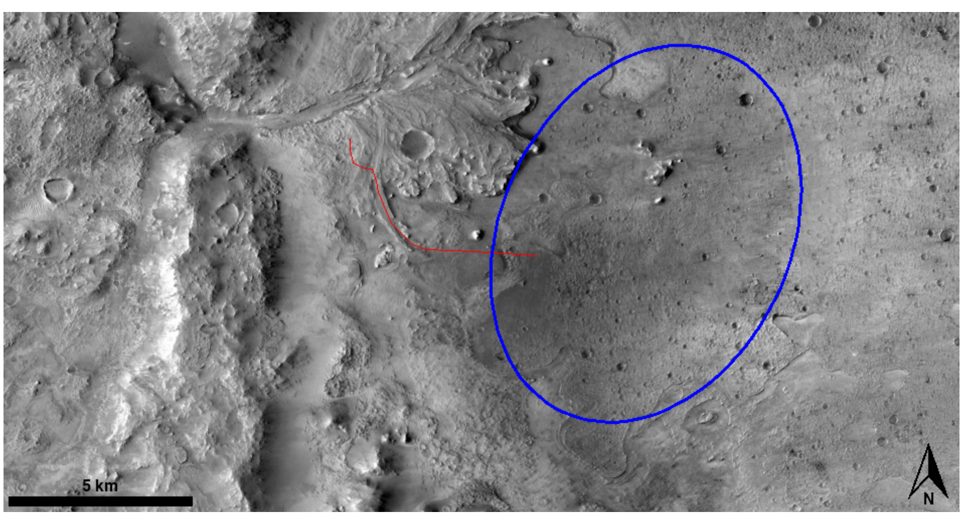


Figure 37. The image shows the western half of Jezero crater, Mars. The blue ellipse is the designated landing area of Telos-1. The line in red represents the proposed path of the rover. Telos-1 will travel a distance of ~6.8 km during the 90-day primary mission. The image was collected from the JMARS application Jezero Mosaic (USGS) layer.

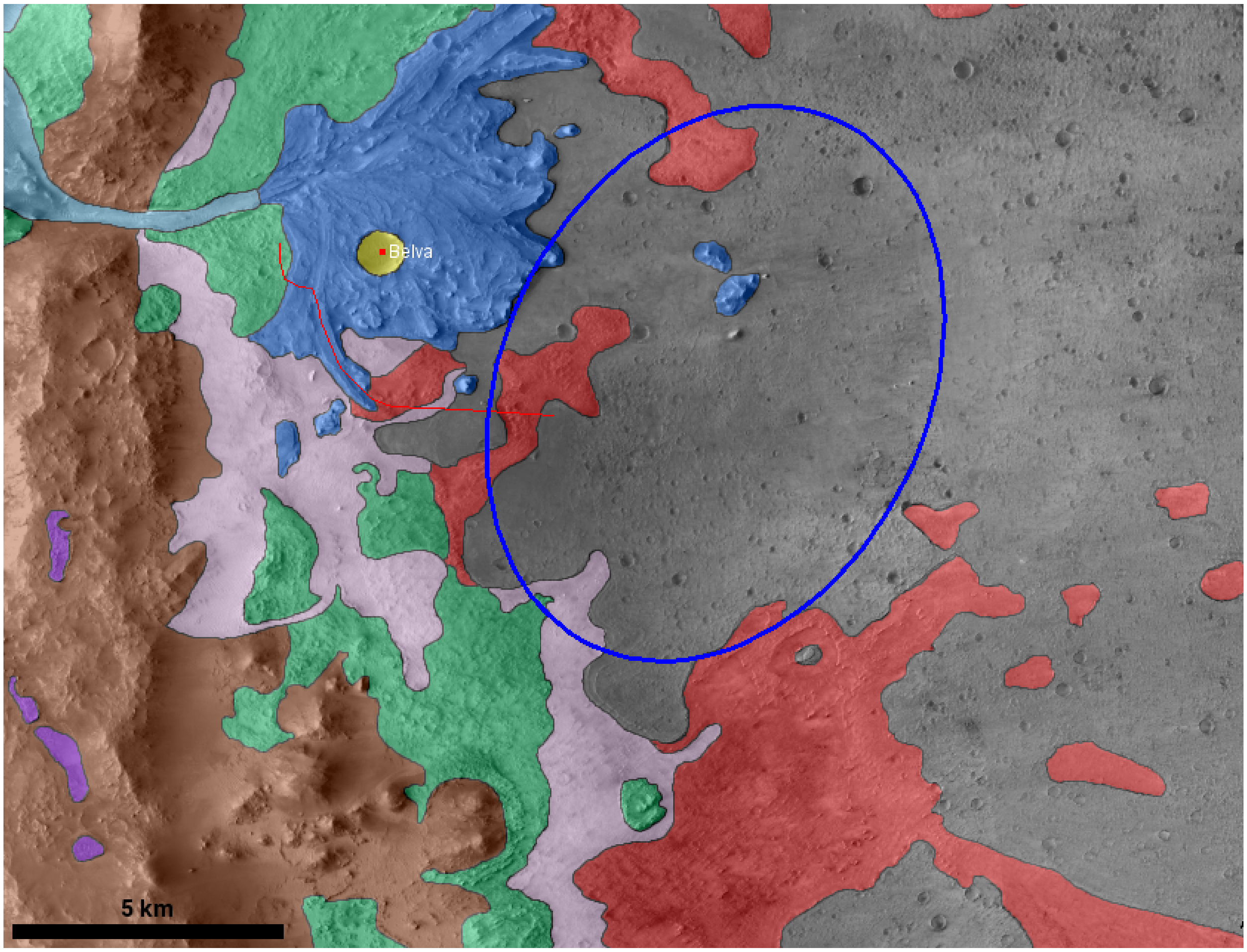


Figure 38. Telos-1 will cross 5 different geomorphic units. The different colored layers represent the different geomorphic layers of Jezero crater. The base layer or gray layer is the crater floor. The layer in red shows the light-toned floor unit. The blue layer is the western fan deposit. The green layer is the mottled terrain unit. The layer in pink is the surficial debris cover unit. The brown layer is the Jezero crater rim. The purple layer is the older material or capping unit. The yellow unit shows younger crater impacts. The data and images were collected from the JMARS application Jezero watershed 2015 layer. Geomorphic units layer was taken from Gouge et al. 2015.

Center L...	Center Lat	Horizontal A...	Vertical A...	Angle	Elevation	Thermal Inertia	Slope	...	Dust Index
77.49	18.439	10.7 km	8.3 km	65	*Avg:* -2593.2641 *Max:* -2473 *Min:* -2650 *StDev:* 32.63232	*Avg:* 265 *Max:* 276 *Min:* 258 *StDev:* 7.74597	*Avg:* 0.97484 *Max:* 4.86414 *Min:* 0.10267 *StDev:* 0.69365		*Avg:* 0.96956 *Max:* 0.97512 *Min:* 0.96354 *StDev:* 0.00373

Figure 39. The above table shows the dimensions, elevation, thermal inertia, slope and dust index of the landing area as seen by the blue ellipse. The data and image were collected from the JMARS application MOLA 128ppd Elevation layer.

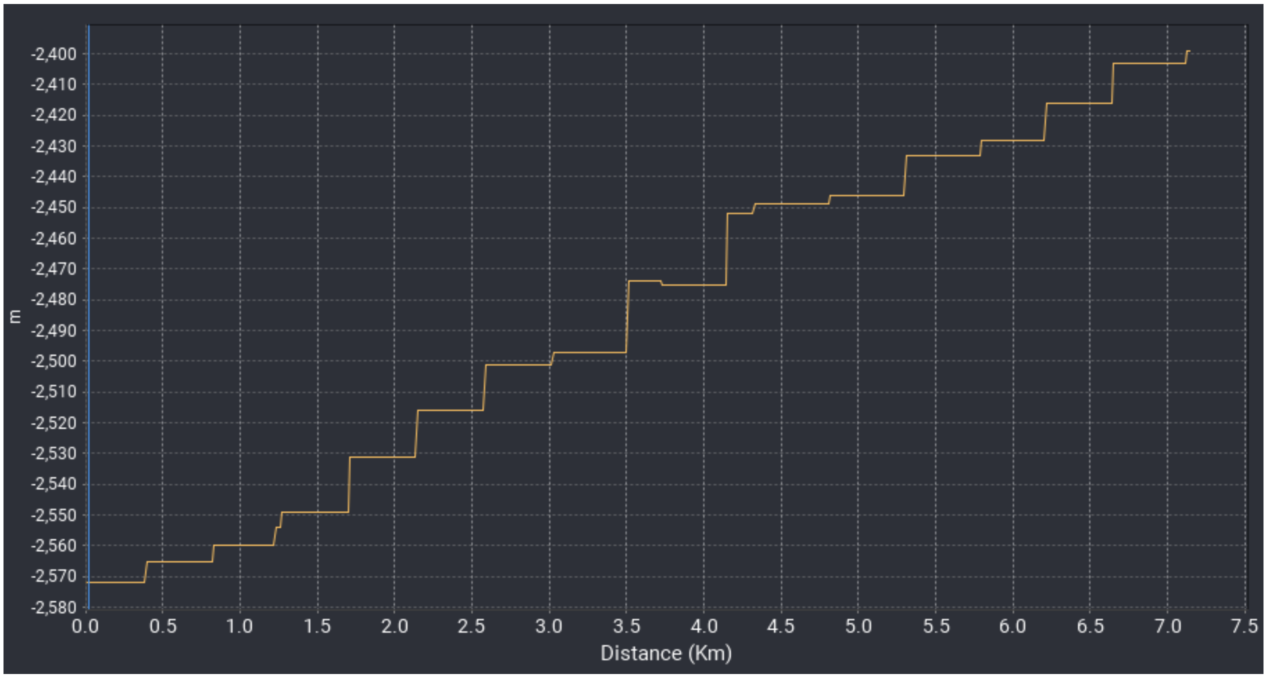


Figure 40. This image shows the slope of the Telos-1 path which is ~6.8 km. The max climb the rover must take is 25 meters at marker 3.5 km. The data and image were collected from the JMARS application MOLA 128ppd Elevation layer.

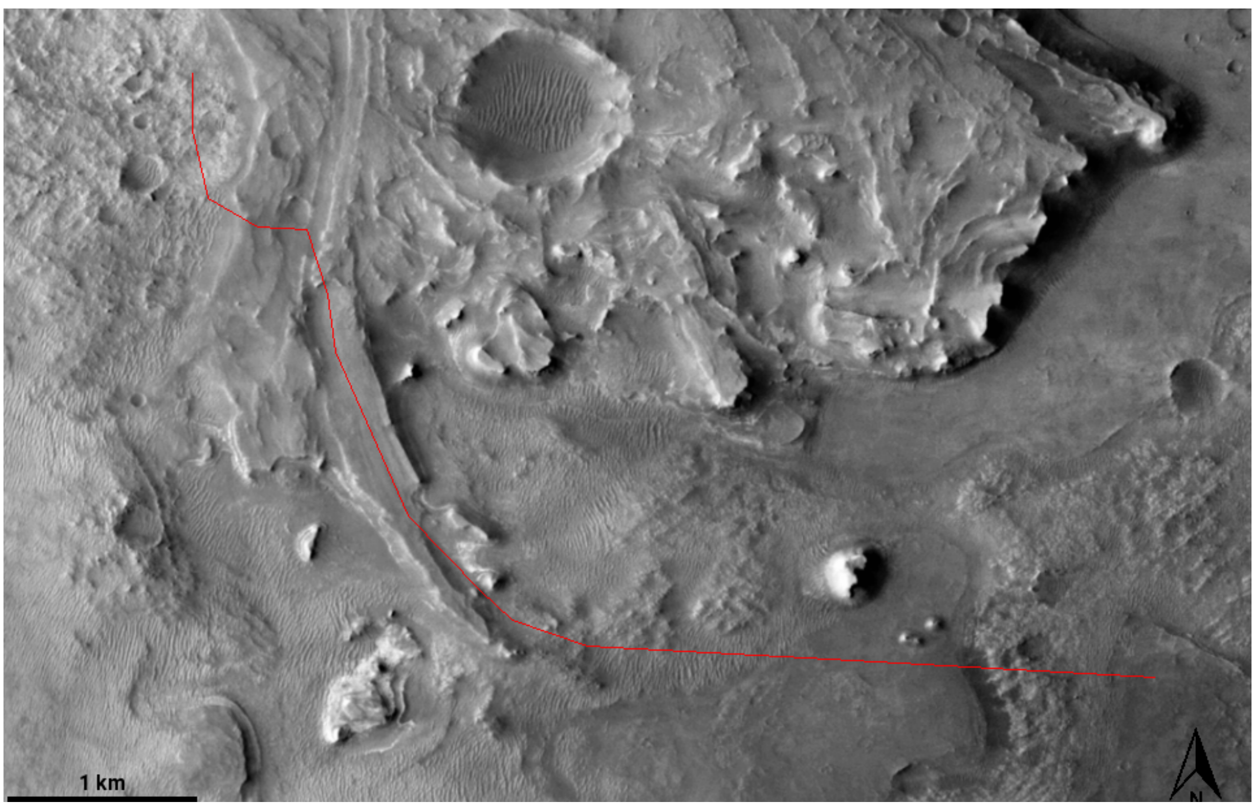


Figure 41. The image is a close up view of the Jezero Crater western delta. The red line is the proposed Telos-1 rover path. The image was collected from the JMARS application Jezero Mosaic (USGS) layer.

4.2.3. Payload Success Criteria

RIMFAX, Mini-TES, and Pancam will work in conjunction to create a comprehensive underground and surface picture as well as a surface overview of Jezero Crater and locate any H_2O, water-ice, olivines, Smectites, and carbonates present.

RIMFAX will use radar waves to determine the composition of the subsurface geology along Telos-1's ~6.8 km path. This will give information regarding what lies beneath the surface up to 10 meters (33 feet), including minerals, chemicals, and lithologies. RIMFAX will allow Telos-1 to accurately map the underground of Jezero Crater and its ancient delta system.

Mini-TES is an infrared spectrometer that uses thermal radiation to determine the chemical composition of minerals and rocks within Jezero Crater. This can also determine temperature, water vapor, and dust abundance to determine how atmospheric conditions have effects on the subterranean contents of Jezero Crater.

Pancam will be used to construct a 3D panoramic picture of the Martian surface in Jezero Crater and can use its filters to create multi-wavelength images that can produce information regarding the chemical composition of surrounding rocks and structures.

4.2.4. Describe Experimental Logic, Approach, and Method of Investigation

By designing a smaller rover with a ground-penetrating radar attached to the bottom of this rover, RIMFAX, the team will get images of the subsurface down to 10 meters. The science team will be able to process the data and differentiate lithologies and structures of the subsurface. The science team will also be able to identify where liquid water or ice may be present. Mini-TES and Pancam will give specific chemical components of rocks on the surface. This will be important to compare what the surface chemical composition is compared with the subsurface geophysical data.

4.2.5. Describe Testing and Measurements, Including Variables and Controls

Radar Imager for Mars’ Subsurface Exploration (RIMFAX)

RIMFAX operates by simultaneously emitting two waves into the ground, the first of which are used for calibrating the antenna for the reflections. The radar can switch to a calibration cable and measure the reflection from the end of the cable, which is used to monitor the instrument performance and calibrate the radar response.

Miniature Thermal Emission Spectrometer (Mini-TES)

Mini-TES will be calibrated on Earth in a near-vacuum environment from a temperature range to simulate Martian weather, from 223K to 283K. This will also include vibration and thermal vacuum testing to ensure the correct alignment of the camera and the field of vision is 20 milliradian (mrad). Mini-TES completed its testing in an atmosphere containing 6 mbar of nitrogen.

Panoramic Camera

The Pancam will be calibrated inflight, it will be performed by occasional imaging of the martian sky (if the azimuth and elevation relative to the Sun are chosen properly, should be acceptably flat over the field of view of Pancam). If variations are detected because of, for example, dust particles on the Pancam external sapphire window, then these flat fields may be used in place of the pre-flight ground flat fields in the Pancam calibration pipeline.

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

Images of possible data for Pancam, RIMFAX, and Mini-TES are shown below.

Radar Imager for Mars' Subsurface Exploration (RIMFAX)

RIMFAX will take ground-penetrating radar data to a depth of 10 meters below the surface. At the ancient delta in Jezero crater, RIMFAX will encounter different rocks and layers below the surface. The instrument will most likely encounter ice or water below the surface which will reflect as strong soundings. Due to differences in electric conductivity, olivine and other minerals, especially clay minerals such as montmorillonite and kaolinite, and hydrated carbons, above and below the surface, may also be differentiated.

RIMFAX will perform a frequency sweep from 300MHz-1.2GHz which will create interleaved pairs of shallow-deep sounding images with a vertical resolution of 3-12" thick. These will be combined to create images such as those below. The higher the frequency, the higher the resolution will be as shown in the regolith and upper layers of the subsurface, while lower frequency results in lower resolution data as shown deeper into the martian crust.

Misinterpretations may occur if resolutions are not definitive enough at low depths. If too much water is present in the subsurface, reflections will be highly deformed as well.

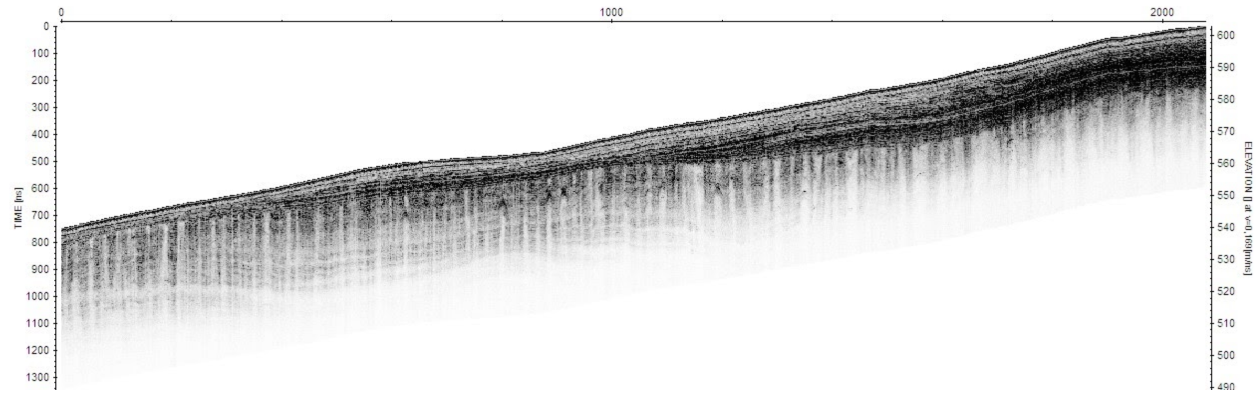


Figure 42. RIMFAX GPR radargram taken showing the subsurface.

Panoramic Camera (Pancam)

The geology filters were designed and fabricated to have peak transmission >85%, transmission ripple within the passband of <10%, central wavelength uniformity and central wavelength shift resulting from angle of incidence variations across the FOV of <1%, and a wavelength-integrated rejection band response in the 400 to 1100 nm region of <1% of that filter's integrated in-band response. For the two filters designed for the solar imagery, the filters are coated with metallic attenuation film to provide an additional factor of 105 reduction in overall transmission.

The Pancam will view the calibration target and fiducial marks multiple times per martian sol, under multiple lighting conditions to ensure proper calibration of the camera before images are taken and digitized. Due to the amount of data needing to be transferred, the rover computer will do the majority of the image processing before sending to earth.

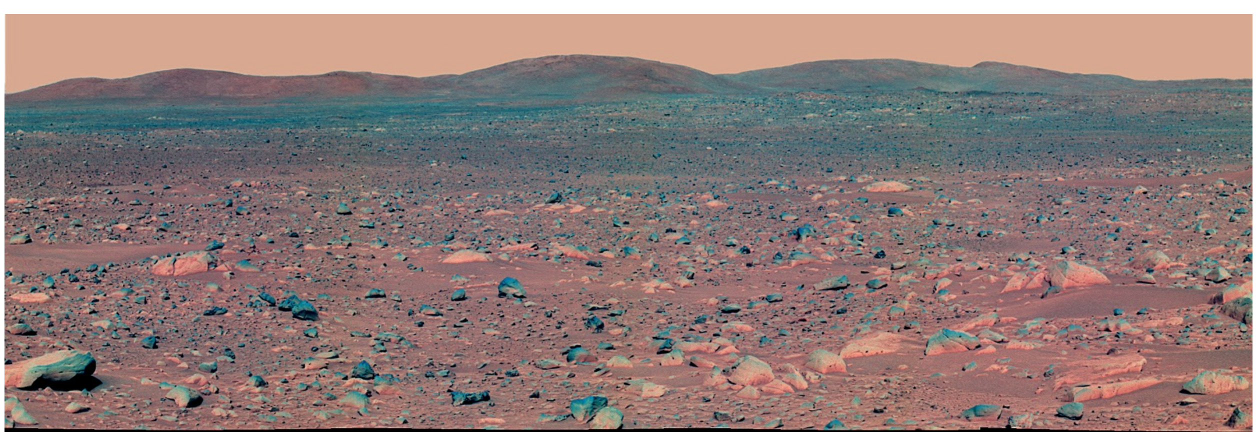


Figure 43. Pancam multispectral false color image taken on the martian surface by Spirit Rover.

Miniature Thermal Emission Spectrometer (Mini-TES)

The Mini-TES will be able to provide additional data to Telos-1 on the chemical composition of the surface of Mars. The interferograms are taken multiple times per day allowing you to see the results throughout multiple surface or atmospheric temperatures and different lighting conditions. The radiometric calibration of the device is done by two calibration units: one in the Pancam mast head where it is protected from dust and one on the rover body both of which consist of a beam-filling blackbody target with platinum thermistors bonded to the underside. The thermistors have an absolute temperature accuracy of 0.1°C for temperatures from -130°C to 110°C. The radiometric precision of the Mini-TES, with which two spectra are collected during each observation, is $\pm 1.8 \times 10^{-8}$ W cm^{-2} sr^{-1}/cm^{-1} between 450 and 1500 cm^{-1}, increasing to $\sim 4.2 \times 10^{-8}$ W cm^{-2} sr^{-1}/cm^{-1} at shorter (300 cm^{-1}) and longer (1800 cm^{-1}) wave numbers, for both mineral determination and atmospheric studies.

Worst-case radiance errors correspond to ~0.4K for a surface temperature of 270K and ~1.5K for a surface temperature of 180K. An interferogram can be taken every 2-3 seconds, with each one being sent to the rovers main computer for Fast Fourier Transform, spectral summing, lossless compression and the formatting of the data before the information is stored into system memory for transfer to the local data package to be sent to Earth.

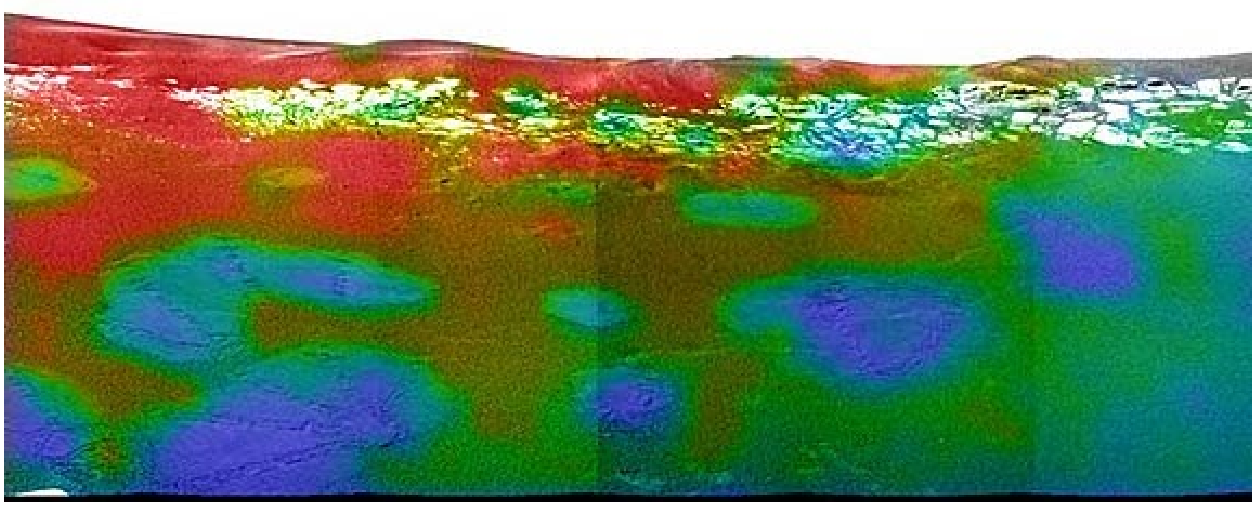


Figure 44. Mini-TES interferogram superimposed onto Pancam imagery depicting high/low concentrations of hematite.

5. Safety

5.1. Personnel Safety

5.1.1. Designated Safety Officer

The team’s safety officer is Monika Solis and the following are the responsibilities and the research she has done to ensure the team's safety during the mission. Prior to the start of the production, there will be thorough research done on every instrument that will be used to be able to provide hazard mitigations for all equipment. In addition to the research done on the instruments, there will be research done on all current health and safety protocols and regulations to be able to develop risk prevention plans. One will also make sure to read and follow the NASA system safety handbook to ensure a safe workplace. Moreover, research will be conducted to find all certifications and training that the personnel will have to complete to ensure their safety and the safety of others. One will make sure that every employee will obtain the proper training before handling any machinery or testing the rover. One will also find ways to prevent accidents and develop proper safety plans for any situation that may arise. Furthermore, one will make sure that everything is up to code and following all the current policies and regulations. During production, one will be monitoring that everyone is following regulations, make sure that all equipment is working well, and replace any malfunctioning equipment. One will conduct risk assessments and share weekly health and safety reports with the leadership team. In addition to meeting with the leadership team, one will continue to present training and educate all personnel on protocol throughout the entire mission to help in preventing accidents and hazards.

5.1.2. List of Personnel Hazards

LIKELIHOOD					
5	7	16	20	23	25
4	6	13	18	22	24
3	4	10	15	19	21
2	2	8	11	14	17
1	1	3	5	9	12
	1	2	3	4	5
	CONSEQUENCE				

Figure 45. The following graph will be used to asset the risk in every hazard. The risk will be judged through two categories. The likelihood of the hazard occurring and how severe is the consequence if the hazard does seem to occur.

- **Manufacturing Hazards:** Manufacturing hazards may be caused by many different reasons. The risk level can be seen in the above matrix showing the likelihood to be 2 and the consequence to be 2.

- **Falls:** Falls are one of most common hazards in the workplace. The risk level can be seen in the above matrix showing the likelihood to be 2 and the consequence to be 3.

- **Electrical Hazards:** Electrical hazards may be caused by improper wiring, exposed wires, and many different situations. The risk level of electrical hazards can be shown with the likelihood of 1 and the consequence of 3.

- **COVID-19 Pandemic:** Currently, the pandemic is something that the team must handle with extreme precaution. The risk level of the pandemic can be seen in the above matrix showing the likelihood to be 4 and the consequence to be a 3.

- **Welding Fires:** Welding fires can occur when the rover is being made. The risk level of these fires can be seen in the above matrix showing the likelihood to be a 2 and the consequence to be a 3.

- **Electrical Fires:** Electrical fires may occur in the facility if there are not precautions taken. The risk level of it can be seen in the above matrix showing the likelihood to be a 2 and the consequence to be a 3.

- **Rover Testing Fires:** While testing the rover, a fire may occur so all personnel must be ready for it. The risk level of this fire can be seen in the above matrix showing the likelihood of 1 and the consequence of 3.

- **Radiation Hazards:** The Radioisotope Heater Units may cause a radiation leak. The risk level of this can be seen in the matrix above showing the likelihood to be a 2 and the consequence to be a 4.

- **Battery Fires:** Rover battery assembly unit contains a chemical that may cause a fire. The risk level of this fire can be seen in the matrix above showing the likelihood of 1 and consequence of 3.

- **Dust and Debris Hazard:** The aerogel insulation is a hazard when it is inhaled or comes in contact with one’s skin. The risk level of this dust can be seen in the matrix above showing the likelihood to be 1 and the consequence to be 2.

5.1.3 Personnel Hazard Mitigation

Manufacturing Hazards

Through the production and testing of the rover, all the personnel will be required to wear the proper Personal Protective Equipment to help in preventing manufacturing hazards. All personnel will have to take the appropriate training before being able to handle any machinery and suitable machine guards will be provided to ensure machine safety. In addition, cell phones will not be allowed to be used in the workspace to prevent distractions.

Falls

To mitigate falls, the facility will be equipped with anti-slip floors, and employees will be informed of this hazard during their training. There will also befall safety procedures in case of a fall, and proper footwear will be mandatory when entering the workplace.

Electrical Hazards

There will be an inspection before the start of the project to ensure that all machines are properly wired, that there are no exposed wires, and that all electrical panels are properly locked. Furthermore, the designated safety officer will be checking all electrical wiring weekly to continue monitoring all electrical hazards. In addition, there is a possibility of a fire occurring because of an electrical issue.

COVID-19 Pandemic

Due to the pandemic, before the start of the mission, all personnel will be tested to make sure no one has COVID-19. Through the project, the team will be abiding by the CDC, NASA, and OSHA guidelines to make sure that the risk of spreading is properly diminished. One of the steps that will be taken will be daily temperature checks to help catch contamination as soon as possible. Also, all personnel will be asked to self-quarantine as much as possible to diminish the chances of obtaining the virus. If any personnel gets the virus, the facility will be shut down for a week so that it may be deep cleaned. The personnel will all get tested again to ensure that every person that obtained the virus takes the right measure to prevent a further spread. If needed, there will be virtual meetings instead of in-person as to lower the chances of spreading the virus. In addition, face masks will be required where they may be worn and hand sanitizer will be in every room of the facility.

Welding Fires

To help prevent welding fires, there will be designed welding areas. If there is on-site welding needed during testing the site will be checked beforehand to make sure that all combustible materials are covered with fire-resistant materials or are cleared out of the area. As well, the welders will be required to wear fire-resistant clothes as a safety precaution. In case a fire does occur, there will be fire extinguishers and fire blankets available in the areas. There will also be first aid kits available and personnel will go through training beforehand and will be required to know the fire safety exit plan and procedure.

Electrical Fires

To aid in the prevention of electrical fires, all the wiring in the building will be checked beforehand and hazard sites will be identified. Wiring and electrical areas will be checked constantly to be able to detect threats as soon as possible. If a fire does occur. There will be fire extinguishers, fire blankets, and first aid kits readily available, and all personnel will go through fire safety training.

Rover Testing Fires

Through any testing of the rover, there will be a fire extinguisher and first aid kit in the area. In addition, a plan of action will be created in the instance that a fire does occur, and all personnel will go through the procedure beforehand.

Radiation Hazard

While handling the Radioisotope Heater Units, there is a danger of the fuel being released causing the release of Plutonium-238. This may be dangerous if anyone were to inhale this chemical because it can cause serious health issues such as damage to the kidneys. In case of a leak, the fuel will be handled with care and the personnel will have the proper PPE, which includes masks to prevent the inhalation of the chemical. The facility will be equipped with proper ventilation. In the rare case that the chemical comes in contact with someone’s skin or eyes, they will wash the contact area thoroughly and will seek medical attention afterward. These chemicals will be disposed of properly to follow OSHA’s and NASA’s guidelines.

Battery Fires

The Rover battery assembly unit is made up of Li-Ion cells and there must be safety precautions in case of a malfunction. The chemical may cause a fire, so while working with the battery there will be fire blankets and extinguishers at hand in case they are needed. In addition, there will be a fire safety plan created and personnel will be asked to learn it. Lastly, all chemicals that may be spilled, unused, or not needed will be disposed of properly.

Dust and Debris Hazard

While handling the aerogel insulation, the personnel will be required to wear the proper PPE to prevent any contact with the dust it releases and one's skin. In addition, the area will be equipped with proper ventilation. If the dust is inhaled, the personnel must leave the air and go get fresh air, clear their throat by drinking water, and blow their nose. If the dust makes contact with the skin, one will go to the assigned area, so that they may remove their clothes and wash the contaminated area with soap and water. If the dusk comes into contact with a person's eyes, they must go to the eyewash station and wash their eyes. If there is irritation after any scenario, seek medical attention.

5.2. Lander/Payload Safety

5.2.1. Environmental Hazards

Upon arrival to the Martian terrain, the Telos-1 rover will face environmental hazards in three primary categories: landing conditions, natural hazards, and weather patterns.

Upon initiating the entry, descent, and landing protocol, the Telos-1 rover will enter into largely unknown terrain. This poses risks to the mobility of the rover and its ability to cover large distances throughout the course of its mission. To help mitigate these concerns, AI control implemented in the rover will assist in the creation of maps to identify hazards surrounding the rover. This technology will help in navigation throughout Telos-1 mission's data collection.

Once the Telos-1 rover has safely landed on the surface of Mars, there will be constant risks of natural hazards accompanying the Martial climate. The primary identified risk involves the temperature fluctuation on the Martian surface. At night, the rover may be at risk of enduring cold temperatures as low as -80 degrees Fahrenheit. This poses a risk to equipment failure in such cold temperatures and forces the rover into an idle mode. To mitigate the damage extreme temperatures may pose to the equipment, internal heating units (RHU's) will maintain a sense of homeostasis in these conditions.

The final largest hazard and likely the most unpredictable, that the Telos-1 rover will face is Martian weather patterns. Dust on the surface of Mars can become embedded in moving systems within the rover and cause deterioration over time. Some key areas which may be impacted include motors and lenses on cameras, as well as dust coverage on the solar panels causing degradation of power production. In the event that there is a large dust storm in the area the rover is surveying, data collection may be paused for several days and much of the equipment may be at high risk.

5.2.2. Environmental Hazard Mitigation

To mitigate the above hazards, the Telos-1 team will perform preliminary tests on Earth to mimic conditions that the rover might face while on Mars. This includes testing AI control capabilities performing simulation experiments for Martian conditions, including temperature control and abrasion testing again fine dust contaminants.

One of the largest risks to the rover is the terrain itself. The rocky and sandy terrain can prove to make driving the rover slow and tedious. This fact coupled with an average 58 million mile separation between Earth and Mars will not allow scientists and engineers to actively operate the vehicle due to signal delay and communications blackout. To combat this, the rover was installed with advanced artificial intelligence that has the ability to utilize the navcams on Telos-1 to create a hazard map that will take surrounding environment slopes, rock counts, and stability of terrain, to create possible safe routes.

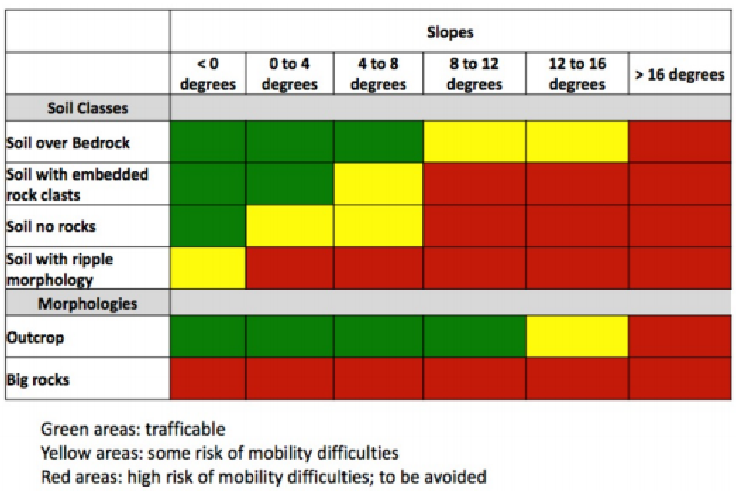


Figure 46. An example table on how rover will self-drive using a risk based system

The rover will take in the data it views around its environment and create a roadmap of safe zones to stay. This will allow the rover to traverse larger amounts of the martian landscape while reducing risk to the rover itself, without constant mediation of the flight engineers at NASA headquarters.

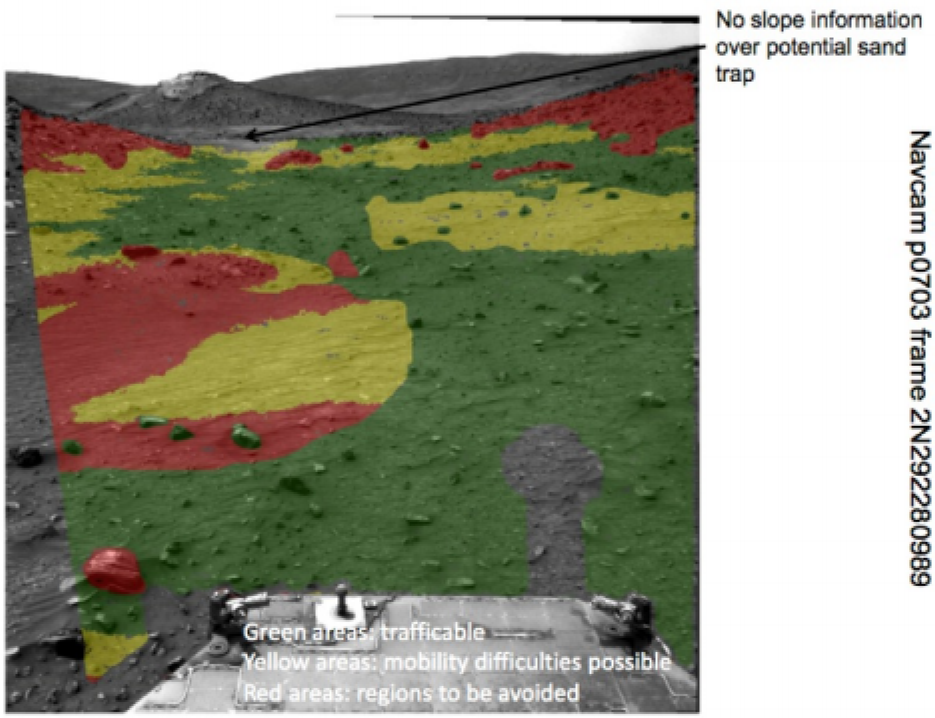


Figure 47. Graphical depiction of the hazard map that the Navcam will create to traverse the surface

Temperature fluctuations are a large concern for the rover as well, with temperatures that can be found between 70°F to -195°F. Due to this radical swing in possible temperatures and sensitive onboard electronics, the rover was outfitted with a robust thermal management system that includes an ammonia-based loop heat pipe system, temperature control valve (TCV), radioisotope heater units (RHU's), a cold plate for liquid cooling, and a thick layer of aerogel insulation around the WEB. This system is optimal for the design of the rover because it is a completely passive system that does not draw power from the system and it can circulate the heat throughout the entire WEB, keeping a well balanced thermal profile. The rover is also outfitted with resistive patch heaters that will keep the sensitive equipment above its minimum survival temperature at the expense of power.

The other major factor that affects components on the rover will be largely unpredictable weather patterns around Mars. This has the potential to cover solar panels and reduce power production, bind motor bearings, inhibit the rover's camera capabilities and more. The largest issue that affects the rover the most is the decrease in power production if the rover was to be covered with martian dust throughout the mission. To ensure the rover stays operational, the engineering team added more solar array areas to the rover to allow for a decrease in power production without inhibiting the rover's ability to perform as planned. If power production were to decrease beyond what was planned, the rover will have to decrease daily distance driven, due to the motors having the largest pull on the power system than any other part. The engineers are also going to create a completely hermetically sealed motors assemblies that will ensure dust and carbon dioxide do not affect the internal motor in any way.

6. Activity Plan

6.1. Budget

The following tentative budget outlines the expected costs for the Telos-1 mission. A year-by-year breakdown is provided for various expenses (personnel, materials, and supplies, etc.) with the current final mission total predicted to be approximately $56,754,582 million.

NASA L'SPACE Mission Concept Academy Budget SU 2020 - TELOS-I							
TELOS-I	Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Operations	
	2018	2019	2020	2021	2022	2023	
Year	**Yr 1 Total**	**Yr 2 Total**	**Yr 3 Total**	**Yr 4 Total**	**Yr 5 Total**	**Yr 6 Total**	**Cumulative Total**
PERSONNEL							
Scientist (80,000/yr)x3	240000	240000	240000	240000	240000	240000	**1440000**
Engineer(80,000/yr)x5	400000	400000	400000	400000	400000	400000	**2400000**
Admin(80,000/yr)x5	400000	400000	400000	400000	400000	400000	**2400000**
Total Salaries	$ 1,040,000.00	$ 1,040,000.00	$ 1,040,000.00	$ 1,040,000.00	$ 1,040,000.00	$ 1,040,000.00	**$ 6,240,000.00**
ERE							
Scientist	$ 67,200.00	$ 67,200.00	$ 67,200.00	$ 67,200.00	$ 67,200.00	$ 67,200.00	**$ 432,000.00**
Engineer	$ 112,000.00	$ 112,000.00	$ 112,000.00	$ 112,000.00	$ 112,000.00	$ 112,000.00	**$ 720,000.00**
Admin	$ 112,000.00	$ 112,000.00	$ 112,000.00	$ 112,000.00	$ 112,000.00	$ 112,000.00	**$ 720,000.00**
Total ERE	$ 291,200.00	$ 291,200.00	$ 291,200.00	$ 291,200.00	$ 291,200.00	$ 291,200.00	**$ 1,747,200.00**
TOTAL PERSONNEL	$ 1,331,200.00	$ 1,331,200.00	$ 1,331,200.00	$ 1,331,200.00	$ 1,331,200.00	$ 1,331,200.00	$ 7,987,200.00
OTHER DIRECT COSTS							
Head Shield	$2,000						
Parachute	$10,000						
Receiver	$5,000						
Antenna	$ 3,850.00						
3-D Printer	$ 1,500.00						
Maxom Brushless Motor GP32 Planetary Ge	$ 2,470.00						
Maxom Brushless Motor With Absolute Enco	$ 1,462.00						
Fuel Tanks	$1,600						
UHF Antenna System	$6,500						
Airbags	$7,500						
Aluminum Honeycomb 8697.86 cm^3	$1,150						
Graphite epoxy sheet	$1,548						
Aerogel Insulation	$1,500,000						
IFM Nano Thruster	$276,000						
Solaero IMM-α Solar cells (.35m^2) - $500/W	$ 170,000.00						
RIMFAX	$ 20,000,000.00						
MINI-TES	$ 15,000,000.00						
MR-107 N Rocket x 6	$ 1,200,000.00						
Radiation Hardened Main Computer BAE RA	$ 400,000.00						
Rober Batterys	$ 116,158.00						
PamCam	$ 10,000,000.00						
Total Materials and Supplies	$ 48,706,738.00	$ -	$ -	$ -	$ -	$ -	**$ 48,706,738.00**
Publications	$ 3,500.00	$ 3,500.00	$ 3,500.00	$ 3,500.00	$ 3,500.00	$ 3,500.00	**$ 21,000.00**
Total Travel	$ -	$ -	$ -	$ -	$ 9,644.00	$ -	**$ 9,644.00**
Community Outreach	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	**$ 30,000.00**
Total Equipment	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Total Subcontracts(Not applicable)	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Total Participant Support(Not applicable)	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Tuition Remission (not applicable)	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Total Direct Costs	$ 50,046,438.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,349,344.00	$ 1,339,700.00	**$ 56,754,582.00**
Total MTDC	$ 50,046,438.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,349,344.00	$ 1,339,700.00	**$ 56,754,582.00**
Total Subcontract F&A(Not applicable)		$ -	$ -	$ -	$ -	$ -	**$ -**
College or University F&A(Not applicable)	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Total F&A	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Total Project Cost	$ 50,046,438.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,349,344.00	$ 1,339,700.00	**$ 56,754,582.00**
FED FLOW THROUGH (JPL, ARC, etc.)	$ -	$ -	$ -	$ -	$ -	$ -	**$ -**
Total Project Cost	$ 50,046,438.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,339,700.00	$ 1,349,344.00	$ 1,339,700.00	**$ 56,754,582.00**

Figure 48. Telos-1 Mission budget breakdown

6.2. Schedule

The following schedule outlines the lifecycle of the Telos-1 mission from start to end. The project will be divided into sub-phases or milestones starting with Pre-Phase A/Phase A in concept development all the way to launch and execution in Operations.

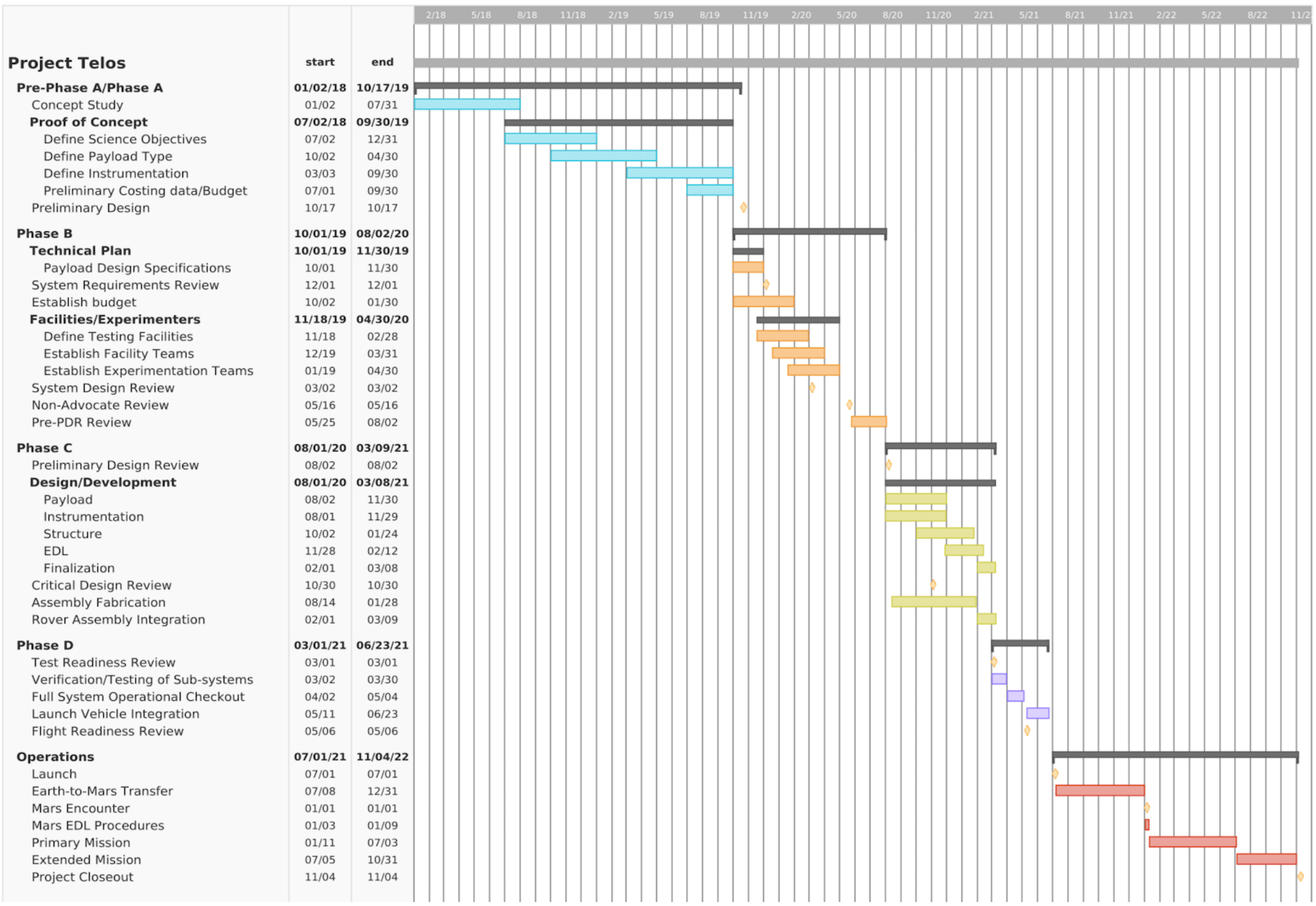


Figure 49. Telos-1 Project Management scheduling

6.3. Outreach Summary

<u>*Outreach Summary*</u>

This a summary of all community outreach plans to be completed for the NASA project Telos-1. As stated, Telos-1 is going to explore Jezero Crater on Mars to obtain and analyze its lithological Martian. The community outreach plan includes both in-person outreaches as well as online outreach. The goal is to reach as many people as possible to not only bring awareness about the scientific value of the project but also find people that later would become interested in supporting the project. Public engagement is going to provide valuable information about the people who form the community.

In-Person Outreach

In-person outreach is going to be conducted by the management members of the team. The events are going to be timed according to the schedule plan to gradually motivate interest from the community.

Outreach will be held in-person by visiting three different types of institutions, with dates and visit times pre-scheduled. Additionally, promotional materials are going to be distributed in each event.

- Visit universities and schools
- Science workshops and conferences (Guest speaker)
- Astronomy festivals and events

Online Outreach

There is no doubt that in this digital era it is vital to have an online presence. Telos-1 is going to pursue a strong online presence by making use of the main online channels. For this, the following have been considered:

- *Website*; The website is going to be designed to inform the public about the project as well as answer any doubt the consumers may have. The website is going to be integrated with content on YouTube and social media accounts.

- *YouTube*; YouTube is Google's most popular service with over 1.8 billion users monthly. Telos-1 development and launch events will be live-streamed through YouTube in addition to traditional radio and television channels.

- *Social Media (Facebook, Twitter, Instagram)*; To gain access to larger audiences and to have a direct connection with them, Telos-1 is going to be constantly sharing advances in the project, launch, and further discoveries.

Figure 50. Custom Mission Logo for public use.

6.4. Program Management Approach

The Mission Concept Academy Team Telos-1 was structured in a highly collaborative hierarchical organization model. Positions were chosen mainly on strengths and backgrounds, but also if a team member was looking to expand a personal skill set. The team members were divided into four separate teams: Management, Science, Engineering and Administrative. One or two team leads were appointed to ensure proper upward and lateral information flow to help delegate tasks and keep task timelines according to the Gantt chart.

Leads were responsible for collaborating with other teams to ensure any multi-team tasks were properly communicated. Doing this ensured a more organized flow of information and created a natural system of accountability. Although separate teams were chosen, team members were urged to help make project decisions, sit in on other teams' calls, and were encouraged to give ideas. Issues were addressed by the appropriate team and at the appropriate level to ensure quick resolution of problems. Larger issues would be resolved using a whole team concept, ensuring all opinions on the matter were equally considered. An environment of mutual respect allowed team members to openly speak ideas and concerns and obtain constructive criticism.

7. Conclusion

This preliminary design review (PDR) provides a high level plan of the Telos-1 mission: the next generation of Mars exploration. The Telos-1 mission will explore and determine the geological history of the Jezero Crater on Mars by utilizing the RIMFAX, Mini-TES, and Pancam instrumentation to analyze the surface mineral compositions and map the Martian lithological layers. These specific goals will advance the understanding of the geological history of Mars, revealing clues to natural phenomena and potential biosignatures of the past.

The Telos-1 mission features advanced technology which will allow for cutting-edge understanding of Earth's neighbor, Mars. The payload on the mission includes three primary technologies which will allow for a comprehensive underground and surface mapping of Jezero Crater, specifically the western delta system. RIMFAX will use radar waves to determine the composition of the subterranean surrounding the Telos-1 rover. This will provide information regarding what lies beneath the surface up to 10 meters (33 feet), including minerals, chemicals, and lithologies. RIMFAX will allow Telos-1 to accurately map the underground of Jezero Crater and can successfully locate targets of interest. Mini-TES is an infrared spectrometer that uses thermal radiation to determine the chemical composition of minerals and rocks within Jezero Crater. This instrument can also determine temperature, water vapor, and dust abundance to determine how atmospheric conditions affect the subterranean contents of Jezero Crater. Pancam will be used to construct a 3D panoramic picture of the Martian surface in Jezero Crater, and will use its filters to create multi wavelength images that can produce information regarding chemical composition of surrounding rocks and structures.

The lander system developed for the Telos-1 mission will provide a safe landing for the payload. The descent and lander course is based on previous missions with entry and contact with the Martian atmosphere beginning with the heat shield. Following this initial deceleration, a single parachute deploys to further slow the lander. Next, the back shell separates and thrusters further slow the payload on its descent nearing the surface. Finally, the payload is cushioned with airbags.

The Telos-1 team plans to conduct the Critical Design Review (CDR) beginning October 30th, 2020 with plans to continue working towards the target launch and encounter dates on Mars. Several milestones lie ahead for a successful mission including the Test Readiness Review (TRR) and Flight Readiness Review (FRR). The scheduled launch from Earth for the Telos-1 mission is July 1st, 2021, with a target Mars encounter on January 1, 2022. The final encounter with Jezero Crater on Mars is planned to occur on April 11, 2022.

The Telos-1 mission is a collaborative effort between a diverse group of engineers and scientists from across the United State of America. The goals and ambitions of this project represent the hopes and dreams of the future to explore and better understand the solar system and universe.

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