Preliminary Design Review

L'Space Mission Concept Academy
Team 16 | Team Oddity



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1. Introduction and Summary

1.1. Team Introduction

Team Oddity consists of eleven undergraduate students. The following is a list of these members and the relevant experiences and skills they bring to the development of this mission. The members are given leadership roles and organized into science and engineering sub teams, which can be referenced in the organization chart in section 6.4.



Yajatra Kulkarni
University of Iowa - Iowa City, IA

Yajatra Kulkarni is an undergraduate senior majoring in mechanical engineering. Yajatra previously participated in NPWEE as a primary investigator. Yajatra has also gained field experience through multiple internships and specializes in working with ArcGIS, Creo, MATLAB, and SolidWorks.



Neal Hext
Texas A&M University - College Station, TX

Neal Hext is an undergraduate senior majoring in mechatronics engineering with a minor in embedded systems technology. Neal participates in many different organizations such as TAMU DJI Robomasters. Neal has experience working with LabVIEW, Creo, MATLAB, and SolidWorks.



Malcolm Lathrop-Allen
Gettysburg College - Gettysburg, PA

Malcolm Lathrop-Allen is majoring in physics and philosophy. Malcolm is a tutor and peer learning advisor to students in Calculus I-III. Malcolm has experience doing research, and is skilled in MATLAB, LaTeX, and Microsoft Excel.



Zac Colovos
Western Kentucky University - Bowling Green, KY

Zac Colovos is a mechanical engineering student and a NASA Pathways Intern in Houston, Texas. He actively participates in organizations such as the American Society of Mechanical Engineers, Society for Physics Students, Hilltopper Astronomy Club, and many more. Zac also regularly volunteers as a host at his local planetarium.



Jessica Gnutek
Joliet Junior College - Joliet, IL

Jessica Gnutek is a computer programming student who participated in the NASA Community College Aerospace Scholars (NCAS) program. Jessica graduated from University of St. Francis with a B.A in Liberal Studies. Jessica has experience with Apple, Windows, and Linux interfaces in addition to four coding languages.



Phoenix Harris
Middle Tennessee State University - Murfreesboro, TN

Phoenix Harris is a physics and astronomy student who is passionate about space exploration. Phoenix is working on an undergraduate research project using NASA's Radio JOVE telescope data at Middle Tennessee State University. From this project, Phoenix has gained experience in Python, SkyPipe, and data reduction using Excel.



Jasmine Cortinas
University of Texas at San Antonio - San Antonio, TX

Jasmine Cortinas is an electrical engineering student at UTSA. Jasmine also works full time at UT Health San Antonio as a building automation technician while taking care of her 5 year old daughter. Jasmine was actively involved in the NASA NCAS program earlier this year.



Aidan Byrne
University of Houston, Clear Lake - Houston, TX

Aidan Byrne is a mechanical engineering student, and works at a petrochemical repair company as an Intern. Aidan is certified in Basic Composites, which includes building carbon fiber parts. Along with this, Aidan is president of Houston Young Aerospace Professionals, an organization dedicated to helping college & high school students learn more about aerospace.



Kevin Baylon
University of Texas at Arlington - Arlington, TX

Kevin Baylon is an undergraduate junior majoring in mechanical engineering. Kevin is part of the UTA Robotics Team and the Society of Hispanic Professional Engineers (SHPE). Kevin is a certified SolidWorks associate and experienced in LabVIEW, MATLAB, and C Programming.



Oluwatosin Shokunbi
Prairie State College - Chicago Heights, IL

Oluwatosin Shokunbi is a pre-engineering student, and a member of Phi Theta Kappa. Oluwatosin has received OSHA General Industry Safety and Health and OSHA construction Safety and Health certifications. Oluwatosin was also a former high school member of Robotics, Drone and FRC clubs.



Didun Oladeji
University of Illinois at Urbana-Champaign - Champaign, IL

Didun Oladeji is an undergraduate junior majoring in mechanical engineering. Didun is also an undergraduate research assistant at the BioNanoPhotonics Lab and a tutor for TRIO Upward Bound. Additionally, Didun is involved with the Women in MechSE organization.

1.2. Mission Overview

1.2.1. Mission Statement

The goal of the NASA Astrobiology Mobile Interface (NAMI) is to detect biosignatures by surveying a Martian cave site, as any evidence of previous or current life would be essential to proving life is sustainable for future manned missions.

NAMI uses Spot, a quadruped robot designed and manufactured by Boston Dynamics, to gather sensory data regarding the presence of organic compounds, water ice, and significant cave structures like speleothems, stalactites, and stalagmites in addition to mineral deposits. Furthermore, by understanding the unique patterns that were formed within Mars lava caves, NAMI will autonomously construct a 3D model of the subterranean environment. The data collected from observing Martian regolith and cave features will be relayed back to the primary payload, and used to identify Martian biology and establish an understanding of the ecosystem on Mars. Thorough analysis of these results can confirm or refute the possibility of microbial life on Mars, both pre-existing and/or current.

1.2.2. Mission Requirements

A list of mission requirements deemed necessary for a successful mission was compiled. The table below categorizes these requirements based on the type of requirement, verification method, and relevant subsystem. The abbreviated identifiers are as follows: customer requirements (CST), system requirements (SYS), and science requirements (SCI).

Req #	Requirement	Rationale	Parent	Child	Verification method	Relevant Subsystem
CST.1	System shall not exceed a mass of 50 kg	Defined by customer			Inspection	All
CST.2	System shall fit within a 1.5m x 1.5m x 1.5m cube	Defined by customer			Inspection	Structural
CST.3	System cost shall not exceed $300 million	Defined by customer			Inspection	All
SYS.1	System shall perform mission tasks autonomously	Human intervention is not possible due to communication delays and outages		SYS.1.1	Demonstration	CHD/Navigation
SYS.1.1	System shall be able to communicate to primary lander, from inside Martian caves	Control of robot is essential for NAMI	SYS.1		Demonstration	Communication
SYS.2	System should be able to operate in Martian environment	The harsh Martian environment contains extreme temperatures, dust, low sunlight, and many other obstacles.		SYS.2.1, SYS.2.2, SYS.2.3, SYS.2.4	Demonstration	All
SYS.2.1	System shall be able to operate in temperatures between 203K and 300K	Going outside the temperature range would damage the system	SYS.2		Demonstration	All
SYS.2.2	System shall provide needed electricity for systems	Without power, NAMI will fail	SYS.2		Demonstration	Electrical
SYS.2.3	System shall be able to operate in low light environments where a light source may not readily be available	Martian dust and caves do not provide an environment conducive to science equipment that relies on visual data	SYS.2		Demonstration	Electrical, Science
SYS.2.4	System shall be capable of tolerating shock and impacts	The robot must be undamaged/operational during transportation and in-cave activity	SYS.2		Demonstration	Structural
SCI.1	System shall investigate biosignatures within Martian caves	Goal of NAMI		SCI.1.1	Scientific Review	Payload, Science
SCI.1.1	System shall analyze surface materials within Martian caves	Onboard cameras can be used for acquiring surface-level data on Martian cave composition with spectroscopy equipment	SCI.1		Test and Demonstration	Science

1.2.3. Mission Success Criteria

Specific to mission NAMI, the criteria for success is centered around the science objectives identified in the Mission Statement in section 1.2.1. and Science Traceability Matrix in section 4.2.2. The mission success criteria is as follows:

Criteria 1:

Identifying complex organic compounds and minerals using various levels of carbon (C), hydrogen (H), oxygen (O), sulfur (S), and nitrogen (N) and their percent concentration with 95% accuracy. Mission success is marked by the identification of one or more known biomarkers such as amino acids, methane, water, hydrogen sulfide, and carbon dioxide that may indicate microbial life.

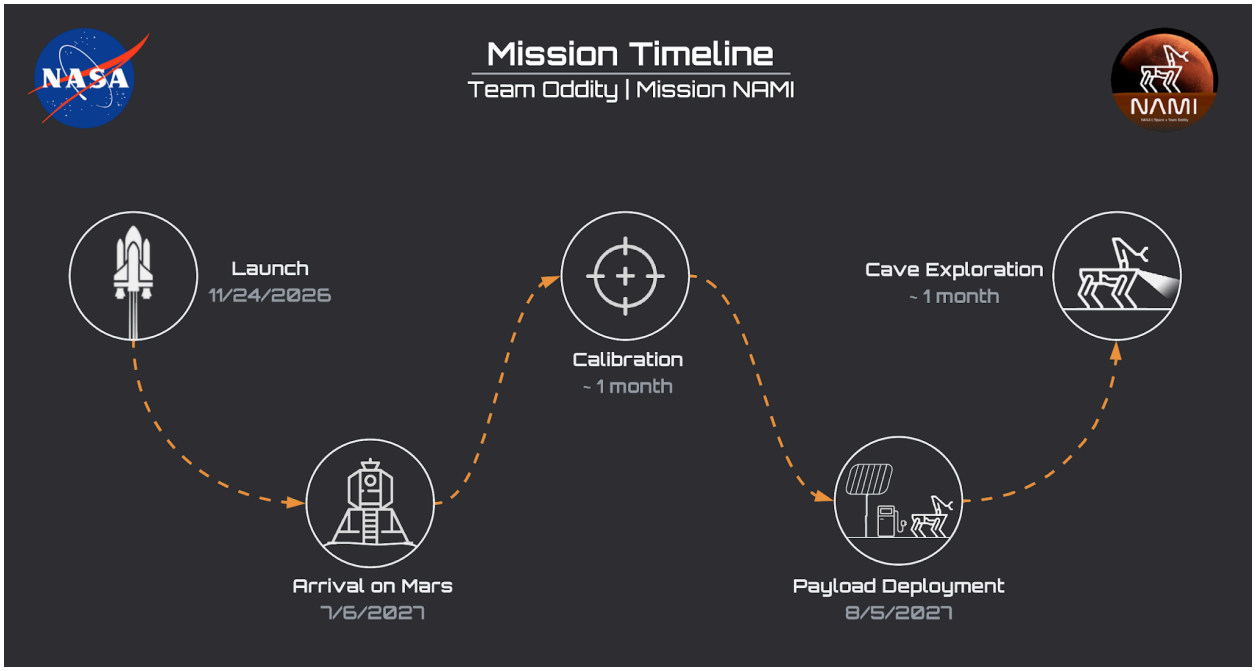
Criteria 2:

Measuring how much of the minerals that make up speleothems (such as Stalactite, Helictites, and Stalagmites) are in Martian cave soil. Speleothems are formed below a water table in a zone of saturation but begin to deposit once caves are in the zone of aeration which is above water level. The goal is to identify speleothems (specifically calcite, sulfate, and carbonate material) using image recognition with a 93% accuracy. The percent measurements will be sent back to Earth with at least 95% accuracy.

1.2.4. Concept of Operations (ConOps)

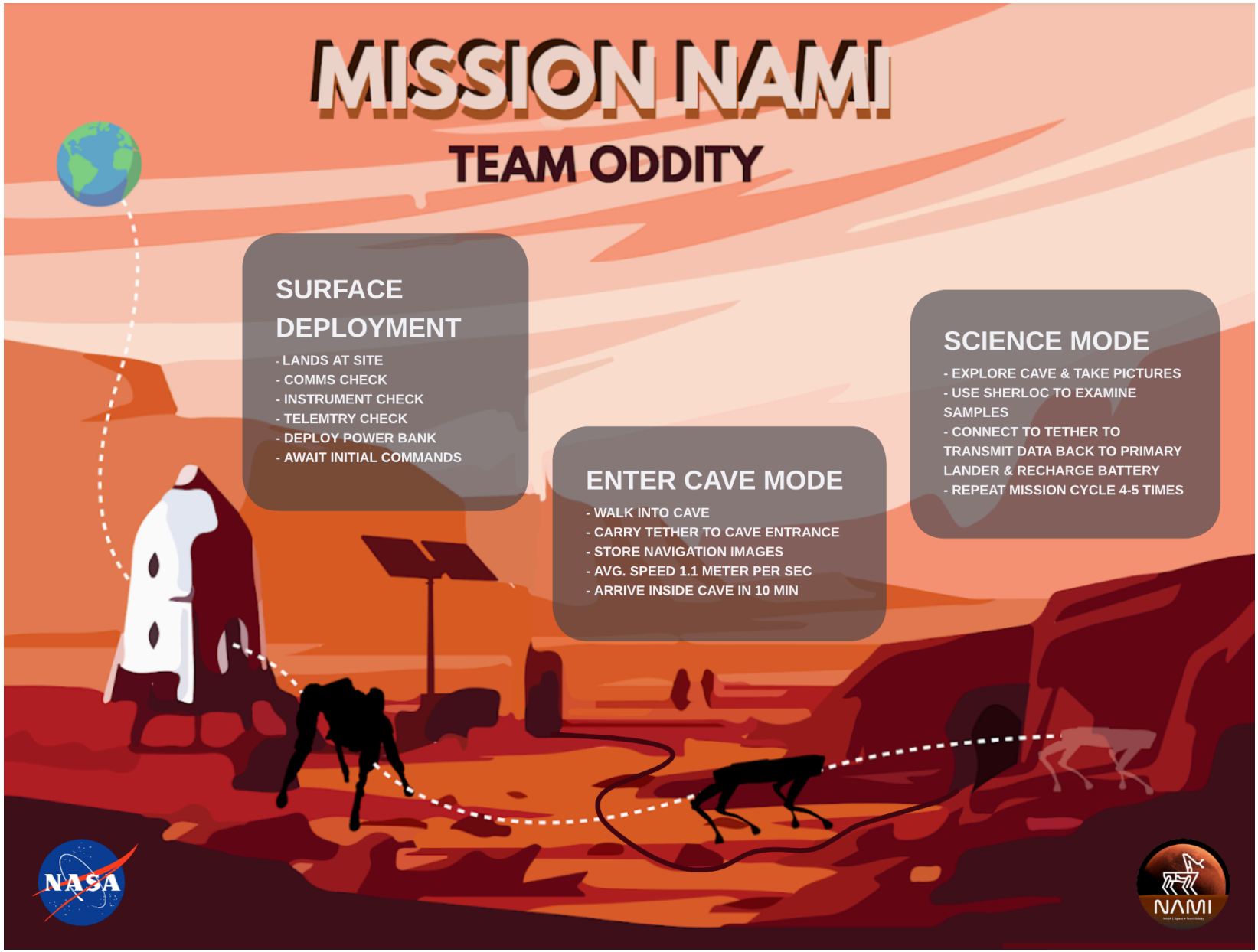
Mission NAMI is a data-collecting project geared for detecting biosignatures in Martian caves. The mission is executed using Spot, a quadruped robot designed by Boston Dynamics, as well as a series of instruments and sensors that are retrofitted on the robot's body. These upgrades include an external power station, a LiDAR-based navigation system, and a science instrument for collecting spectrometry-based data.

The following chart shows an overall timeline of mission NAMI in the operation stage. In other words, these events are critical to evaluating mission success.



The ConOps chart below summarizes Phase E of the mission cycle. The mission begins with the assumption that the primary lander transports Spot to the edge of the chosen cave entrance in nominal condition. Spot will then deploy a stowed charging station on the surface and carry a tether into the cave to use for power resupply and data transfer. The power station will be powered by solar panels deployed on the surface.

Spot will enter the cave and examine the cave for organic compounds and signs of speleothem formations. Ideal conditions call for a smooth terrain that Spot can safely maneuver, with minimal chance of fall damage. Upon successful data collection, Spot will export the data to the primary lander and recharge using the power station tether. This process will be repeated for 4-5 cycles, or as long as Spot is operational.


MISSION NAMI
TEAM ODDITY
SURFACE DEPLOYMENT
- LANDS AT SITE
- COMMS CHECK
- INSTRUMENT CHECK
- TELEMTRY CHECK
- DEPLOY POWER BANK
- AWAIT INITIAL COMMANDS
ENTER CAVE MODE
- WALK INTO CAVE
- CARRY TETHER TO CAVE ENTRANCE
- STORE NAVIGATION IMAGES
- AVG. SPEED 1.1 METER PER SEC
- ARRIVE INSIDE CAVE IN 10 MIN
SCIENCE MODE
- EXPLORE CAVE & TAKE PICTURES
- USE SHERLOC TO EXAMINE SAMPLES
- CONNECT TO TETHER TO TRANSMIT DATA BACK TO PRIMARY LANDER & RECHARGE BATTERY
- REPEAT MISSION CYCLE 4-5 TIMES
NASA
NAMI

1.2.5. Major Milestones Schedule

Mission NAMI is expected to have a five-year life cycle, from the beginning of concept formulation to the mission end of life (EOL) and decommissioning. A set of milestones have been identified to track the mission development, and distinguish the progression through each project phase.

Phase	Milestone	Dates
End of Pre-Phase A	★ MCRR Submission	6/20/2022
Phase A	★ Preliminary Designing	7/1/2022
End of Phase B	★ PDR Presentation	9/2/2022
Phase C	★ Material Purchase Completion	11/5/2022
	★ Product Design Management (PDM) Configuration	2/5/2023
	★ Instrument Testing	5/30/2023
End of Phase C	★ CDR Presentation	7/22/2023
Phase D	★ Manufacturing Completion	10/11/2025
	★ Integration Completion	5/10/2026
	★ Testing Completion	8/30/2026
Phase E	★ Launch	11/24/2026
	★ Payload Arrival on Mars	7/6/2027
	★ Mission EOL	8/14/2027
Begin Phase F	★ Decommissioning	9/20/2027

NOTE: This is a high-level overview of key checkpoints. To see a more comprehensive list of tasks, see the detailed schedule in section 6.2.

1.3. Vehicle Design Summary

Mission NAMI primarily uses a quadruped robot called Spot, designed and manufactured by Boston Dynamics. While Spot was initially designed for defense and commercial applications, it has also been tested and deemed capable of surveying operations. Several current NASA projects like NeBula have also indicated interest in using Spot for cave exploration on Mars. Spot's original specifications make it an attractive candidate for autonomous data collection and exploration missions. While they do not meet the constraints and requirements of mission NAMI, there are reasonable upgrades that can be made to deem Spot as mission-ready. The trade study included in section 2.2 shows the evolution of the robot design and retrofitting options considered while finalizing this vehicle design.

As part of the mission task, the customer requirements for mission NAMI require that the system have a maximum mass of 50kg, and fit within a 1.5m x 1.5m x 1.5m cube. This size requirement must be met to transport the vehicle as a secondary payload accompanying the primary spacecraft. An overview of the mass, volume, and power metrics for NAMI's Spot is given in the table below. The power is based on an extreme 100% charge to 0% charge, not the typical 80%-15% NAMI will operate at.

NAMI Subsystems Overview			
	Mass (Kilograms)	**Volume (cubic meters)**	**Power consumed (Watt hours)**
Maximum amount	50.00	3.3750	650
Spot Robot	26.95	0.1051	500
EAP	2.80	0.0092	8.00
Arm	5.10	0.0937	50.0
SHERLOC	4.71	0.0035	48.8
Power Station	10.29	0.2600	660.0
Total	**49.85**	**0.4715**	**606.8**
Available:	**0.15**	**2.9035**	**43.2**

Factory specifications indicate that the quadruped robot weighs 31.7kg. This weight will be reduced by eliminating unnecessary hardware and substituting materials contributing to the body of the robot. Ideally, this will yield a weight reduction of 15-25%, ranging between 23.8-26.9 kilograms. Spot is rated to carry 14kg of instrumentation, which leaves an additional 10 kg to mount a power resupply station on the body and increase the operational capacity of the robot. Weight distribution specifications can also be

found in section 3.1.2. In addition, Spot has a base volume of 0.462 cubic meters, leaving 1.038 cubic meters available for science instruments and any additional attachments.

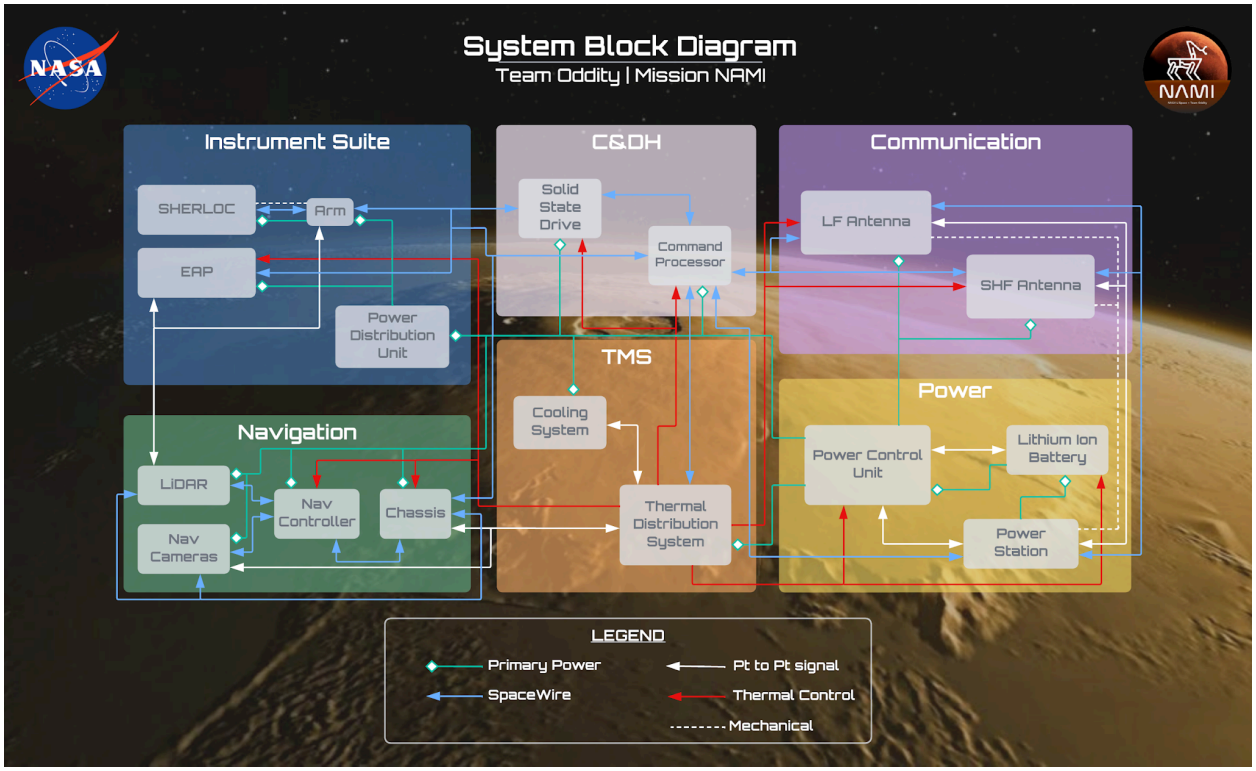
Unaltered, market versions of the Spot robot are susceptible to damage caused by radiation or temperature extremes. Therefore, components like electrolytic capacitors must be removed, as the incredibly thin martian atmosphere will weaken them. Electronics will be replaced with more temperature resistant versions where possible. Interfaces will be covered with Nitronic 50 or Inconel alloy 725 to be corrosion resistant. Finally, Spot will be covered with thermal coatings to mitigate the risk of operational failures.

Spot will be deployed with a immobile power station. This station will be stowed within the mass and volume constraints of mission NAMI. There will be a solar panel capable of generating at least 660W at the cave entrance. Details on communication from the power station to the primary lander were considered beyond the scope of this PDR by the L'SPACE academy mentors. For communicating inside the cave, it will have an antenna capable of communicating with the Spot using Low-Frequency (LF) band waves. LF band waves will be used due to a compromise between data transmission rates and maximum range inside the cave. The station will be deployed outside the cave entrance, and used as a means of charging and data communication. Spot will have the ability to recharge within two hours when docked to the station, and complete more trips inside the cave. Deploying the power station outside the cave will result in a 7-10kg payload capacity on Spot to pick up and analyze any samples in the cave. Spot can output 300W of power for payloads, they will use 200W of this operating normally, with 100W of margin. Spot has a maximum battery capacity of 605Wh, of which 70% (or 423.5Wh) will be usable for reliability purposes. Power consumption will be split equally between providing adequate heating and powering all other systems.

Spot's cameras and various processors will be upgraded with radiation resistant equivalents where possible. According to the customer, Spot will be transported to the cave entrance in perfect condition. Because of this, the need for radiation-hardened equipment will be dramatically reduced. All of Spot's equipment will be able to survive in the Martian surface radiation environment for 12 hours with 99.9% reliability. While major modifications will not need to be made due to the low radiation inside the cave, NAMI may need to be modified in the future if this changes. One way to achieve this will be cameras with more pixels than necessary. Pixels will fail, and the data will be downsampled to account for this. Processors will be substituted for either radiation-hardened processors, or a minimum of two processors will run in parallel. Two

processors will provide ample redundancy to account for Single Event Upsets. Another possible method is to have software determine which sections of the processors might be damaged, and reroute processing around it.

The following block diagram summarizes the subsystem interfaces and how they interact for mission NAMI's exploration vehicle.

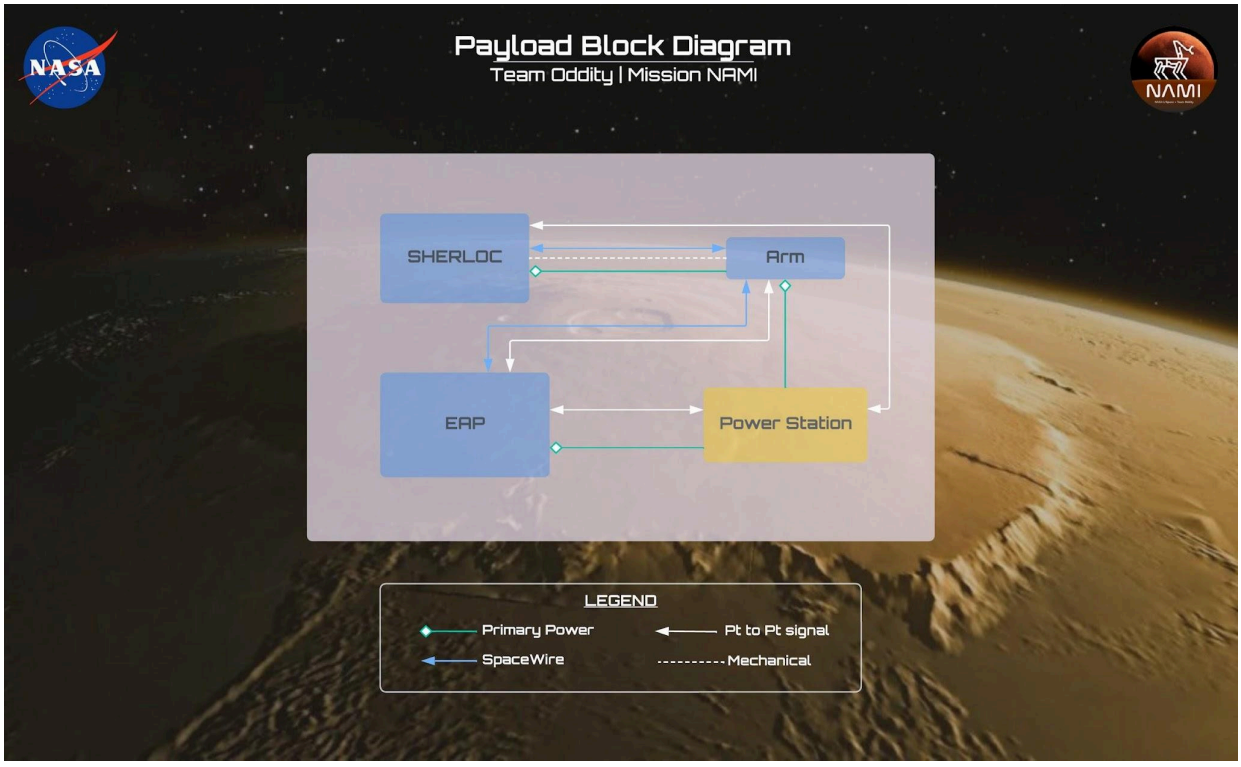


1.4. Payload and Science Instrumentation Summary

Due to the autonomous mode of operation required by the mission, Spot will require a LiDAR sensor in order to maneuver through the unknown terrain in the cave. A navigation package called the Enhanced Autonomy Payload (EAP) will be installed on the robot to fulfill this requirement. Furthermore, additional navigation cameras on the robot's body will also be used for cave mapping and as a measure of redundancy.

Like NASA's Perseverance rover, Spot will be equipped with the instrument Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC). SHERLOC uses cameras, spectrometers, and a laser to search for organics and minerals. This will tackle both mission success criterias and help detect numerous gasses and isotopes in carbon, hydrogen and oxygen.

The following block diagram summarizes the payload-specific interfaces and how they interact for mission NAMI's exploration vehicle.



2. Evolution of Project

2.1. Evolution of Mission Experiment Plan

Scientific objectives initially revolved around surveying and collecting reconnaissance data that can be used for scientific return. Eventually, individual members of the team began analyzing specific attributes of cave systems like speleothems and the possibility of identifying complex compounds like amino acids and extremophiles for bioindicators, which contain clues for deciphering Martian history. The following is a list of initially brainstormed science goals and objectives.

Initial Science Goals & Objectives
Determine if and how caves could sustain human life easier than the surface.
Are radiation levels in caves substantially lower than the surface?
Do caves have the structural integrity to support a colony?
Is martial soil in caves fertile?
Is there subsurface ice?
Determine the geological and biological history of Mars.
Do martian caves have features we see on Earth, like stalagmites, stalactites, flowstone, and helictite?
What kind of materials do Martian caves have?
Is the methane spike on the Martian surface subterranean? Methane spikes during the winter and summer, and it's a universal indicator for life.
Determine whether current or past biosignatures are present in Martian caves.
Do Martian Caves provide enough shelter for life to emerge? Mass spectrometry can potentially identify complex molecules and organic structures.
Determine how Martian caves were formed.
On Earth, rainwater mixing with carbon dioxide is responsible for the formation of many caves. The moving water dissolves away the rocks. This can further indicate the historic presence of water on Mars.
Examine the nature of the cave rocks and their shape/texture
Prepare for human exploration.
Did life exist or does it currently still exist? If so, follow protocols for planetary protection.
Are the martian caves elaborate and/or strenuous for human exploration? If so, devise a strategy, gather data, and safely execute exploration following planetary protocols.

These ideas were discussed as a team and evolved into their final iteration for mission NAMI, focusing on detecting and analyzing any mineral and chemical biological activity, if present, in Martian caves:

Final Science Goals & Objectives
Do Martian caves provide sufficient shelter to sustain primitive life, or protect fossilized biomarkers denoting past life?
Determine if chemical biosignatures are present in Martian lava tubes.
Detect the presence of water ice directly, or through the existence of speleothems.

The expectations for the experiment plan evolved from a surveying mission that focused heavily on broad camera usage, radiation detection, and thermal analysis to biochemical detection with onboard spectrometry and onboard cameras with spectrography features. The use of spectrometry and an onboard heritage technology containing a Raman spectroscopy instrument, infrared sensors with thermal imagery, and instruments with environmental particle analysis capabilities allow the team to not only determine the chemical and mineral composition of a Martian cave, but also allows NAMI to preserve the site for future missions. Areas of interest that subterranean spectrometry discovers will provide vital data that paves the way for future sampling and habitation missions.

2.2. Evolution of Vehicle Design

Team Oddity brainstormed a variety of vehicle designs for the mission. The first factor considered was the chassis of the robot, since the driving base is a crucial component in delivering an operational robot. Because skylights and caves on Mars are completely unknown territory, the robot needs to reliably traverse through and complete the mission tasks. Therefore, a trade study was conducted to assess the best chassis design between legs, wheels, and an aerial system like rockets.

The trade study below indicates that legs are the most reliable form of movement to fulfill the goals and criteria for mission NAMI, with a 72% rating compared to 59% and 56% for rockets and wheels, respectively. They provide the most reliability, longevity, and are advantageous for navigating rough terrains.

Vehicle Chassis Trade Study						
Criteria	**Explanation**	**Grade**	**Weight**	**Legs**	**Rockets**	**Wheels**
Support Systems	Vehicle systems need to be supported with other systems	1. Very complicated support system 4. Simple support system 5. No support system	15.0%	3	2	4
Reliability	The vehicle needs to have systems that will not break spontaneously	1. The system has a >5% chance of breaking during mission 3. The system has a 1-5% chance of breaking during mission 5. The system has a <1% chance of breaking during mission	30.0%	4	3	2
Longevity	The vehicle requires systems that will last the length of the mission	1. The system can only be used for less than 10 min 3. The system can be used 60-90 min 5. The system can be used for more than 120 min	25.0%	3	1	4
Mobility Functions	The vehicle must to be able to navigate the cave autonomously	1. The system can only move on flat terrain 4. The system can move as easily as a human 5. The system can move better than a human	30.0%	4	5	2
		TOTAL	**100%**	**72.0%**	**59.0%**	**56.0%**

After settling on a quadruped robot design, Team Oddity conducted another trade study to decide between using Spot or a proprietary robot as the primary exploration vehicle. Here, budget and control constraints were used to conclude that using a retrofitted Spot rather than designing and fabricating a vehicle would have high cost and time savings. Spot was given a rating of 80% as compared to 60% for the proprietary design.

Spot vs Proprietary Design Trade Study					
Criteria	**Explanation**	**Grade**	**Weight**	**Spot**	**Proprietary Design**
Cost	Lowering costs is critical, using already developed hardware where possible will help	1. Extremely expensive 5. Relatively cheap	50.0%	4	1
Control	Control over aspects of the vehicle's design will lead to the mission requirements being accomplished more efficiently, and with a higher success rate	1. Only minor modifications can be done 3. Major modifications possible 5. Every aspect of the vehicle can be modified	50.0%	4	5
		TOTAL	**100%**	**80.0%**	**60.0%**

The first interaction was simply using Spot with a larger battery, robot arm, spectrometer, and LiDAR. This was deemed impractical as the weight and power constraints were impossible to meet without making further changes to the design.

In developing a second iteration, the team considered rappelling Spot into the cave with a permanently attached tether to provide sufficient power. However, tether would present excessive risks concerning tangling or damage of the system. Similar to the first, this iteration was too heavy and would even limit the range at which the vehicle could travel.

The third iteration of Spot was designed to be deployed in a cave with minimal grade and vertical descent. Relevant science can still be gathered in a cave that isn't a skylight, and provides easier access. Finding a cave site with these conditions makes Spot a perfect exploration vehicle for data collection and surveying. To counter the power consuming constraint of the small stock battery on Spot, a portable power station was proposed to replace the idea of a tether. Such a power station can also act as an antenna for relaying data to the primary lander, and offer an opportunity for Spot to execute multiple cycles of spelunking. The main obstacle with this design was that Spot would be exposed to extreme amounts of radiation every time it needed to exit the cave to recharge and export data, risking the possibility of successfully completing multiple cycles. Therefore, a combination of the second and third iterations was adopted for the final design: a power station with an attached tether. Spot could carry the tether into the cave and leave it at the entrance. This allows the power station to charge using solar energy, and Spot can connect to the tether for data export or battery recharge from the safety of the cave.

2.3. Evolution of Payload and Science Instrumentation

Payload and science instruments evolved largely with the science objectives. While the first objectives for mission NAMI were focused on reconnaissance and cave survey, the initial interactions included a variety of cameras mounted to the front and back surfaces of Spot to provide accurate mapping data. This created volume implications that overstepped the limitations of the mission constraints.

The objectives of mission NAMI were eventually evolved to focus on the search for biosignatures to support or refute the possibility of microbial life. Using thermometers or spectrometry was determined as the primary method of scientific data collection, but determining the most appropriate instruments required the use of a second trade study. The trade study below shows the criteria considered in finalizing an instrument for mission NAMI:

Science Instrument Trade Study						
Criteria	**Explanation**	**Grade**	**Weight**	**IC Thermometers**	**TLS**	**SHERLOC**
Operating Temperature	Instruments need to operate in extreme temperature and harsh conditions	1. Small temperature range, 0 to 32°C 3. Moderate temperature range, -25 to 75°C 5. Extremely high temp range, -75 to 100°C	50.0%	3	3	3
Biosignature identification	Instruments need to accurately detect biosignature by analyzing samples	1. Yield results with 0-25% accuracy 3. Yield results with 50-75% accuracy 5. Yield results with 100% accuracy	30.0%	3	3	4
Quality	Instruments need to be durable and reliable for the length of the mission	1. Highly susceptible to damage 5. High quality and extremely robust	20.0%	2	4	5
		TOTAL	**100%**	**56.0%**	**64.0%**	**74.0%**

The first sensor considered was an IC thermometer, similar to electrical BJT components in appearance. Due to the cheap and reliable design, multiple thermometers together would produce accurate measurements and sufficient redundancy for the mission. The primary drawback of this design was the insufficient temperature range, as the maximum cold range was -55℃.

The second interaction incorporated cameras with tunable laser spectrometry (TLS), using a specific wavelength to identify samples. A combination of the two is an efficient method for identifying chemical compounds in the images of subterranean caves.

Replacing the IC thermometer with a T-type thermocouple thermometer is more than sufficient for the Martian atmosphere, and increases the accuracy of the results.

The third iteration involves the inclusion of raman-based spectroscopy. Raman-based spectroscopy scatters photons to create the chemical structure of a target sample and allows for the identification of chemical compounds and potential microbial patterns in subterranean surfaces. To meet the mass and volume constraints for the mission while satisfying the need for the most accurate and reliable spectrometry-based instrument, the final iteration settled on using Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) as the primary science instrument for mission NAMI. SHERLOC is a heritage technology used previously on NASA's Perseverance rover. It uses Raman-based spectroscopy and is accompanied by a color-imaging camera called WATSON, making it highly capable for collecting accurate data from rock samples. Science instrumentation is further described within section 4.

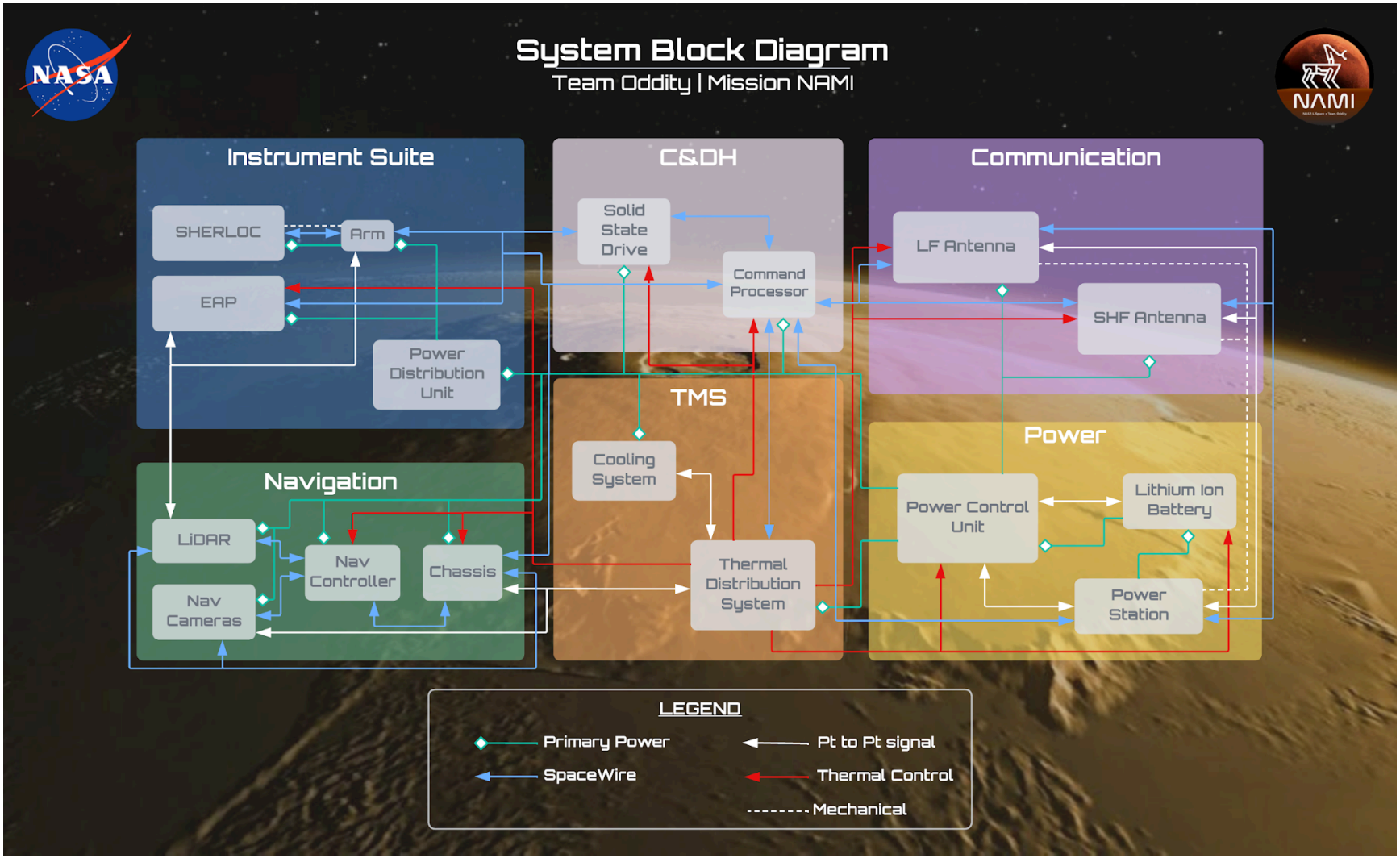
3. Overall Vehicle and System Design

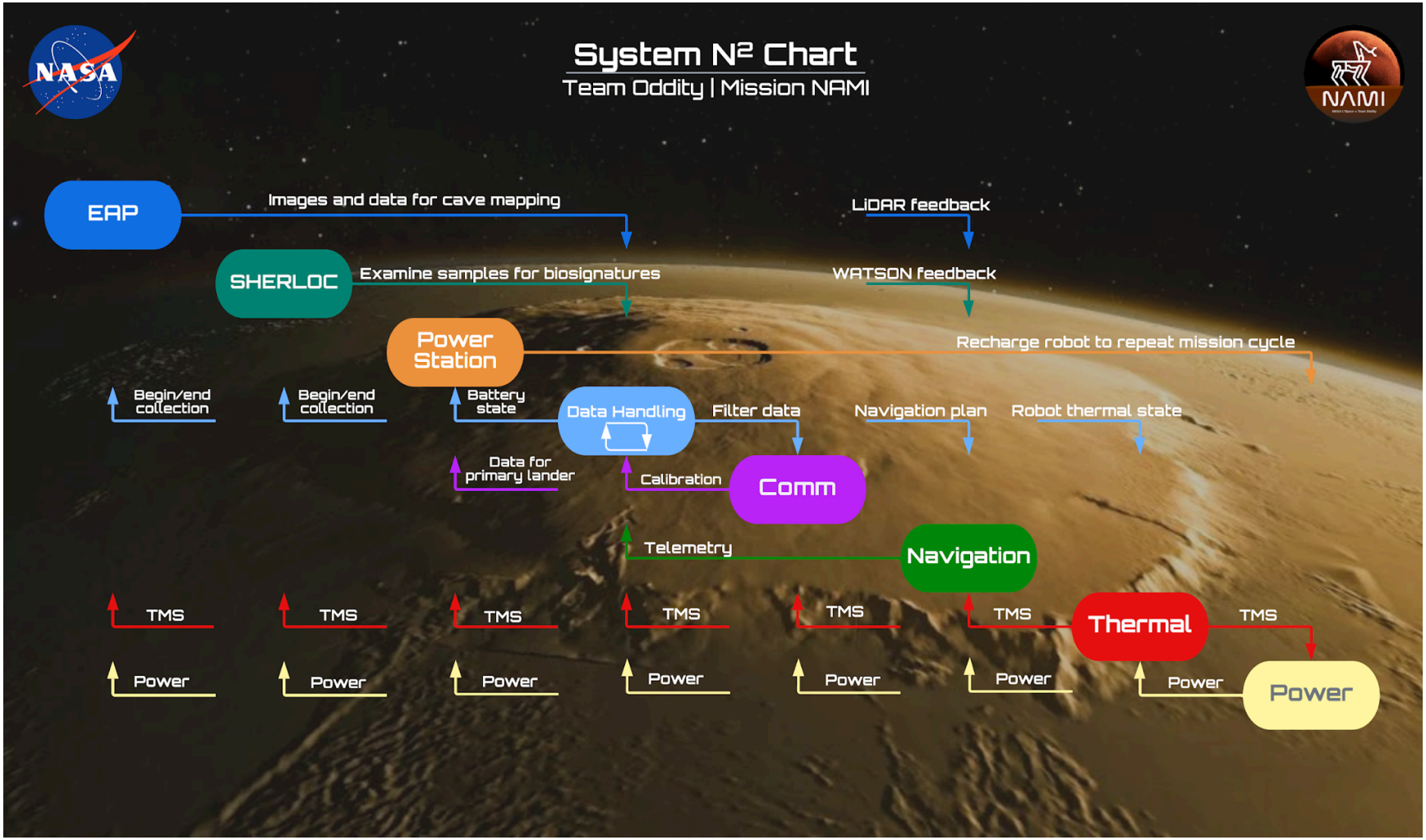
3.1. Selection, Design, and Verification

3.1.1. System Overview

Mission NAMI is dedicated to the exploration of Martian cave sites to investigate any biosignatures that may provide evidence of previous or present microbial life. To do so, NAMI uses a heavily modified version of Spot, a quadruped robot manufactured by Boston Dynamics. The robot will be retrofitted with relevant science instruments and navigation systems to autonomously maneuver through a cave, and relay data analysis back to a primary lander. These instruments include an Enhanced Autonomy Payload (EAP), the Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC), a power station, and multiple flash-equipped navigation cameras.

The following block diagram and N^2 chart represent the necessary interfaces and relationships between the different subsystems of the Spot vehicle:




System N² Chart
Team Oddity | Mission NAMI
EAP
Images and data for cave mapping
LiDAR feedback
SHERLOC
Examine samples for biosignatures
WATSON feedback
Power Station
Recharge robot to repeat mission cycle
Begin/end collection
Begin/end collection
Battery state
Data Handling
Filter data
Navigation plan
Robot thermal state
Data for primary lander
Calibration
Comm
Telemetry
Navigation
TMS
TMS
TMS
TMS
TMS
TMS
Thermal
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Power
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3.1.2. Mechanical System Overview

Requirements

SYS.2: System should be able to operate in Martian environment

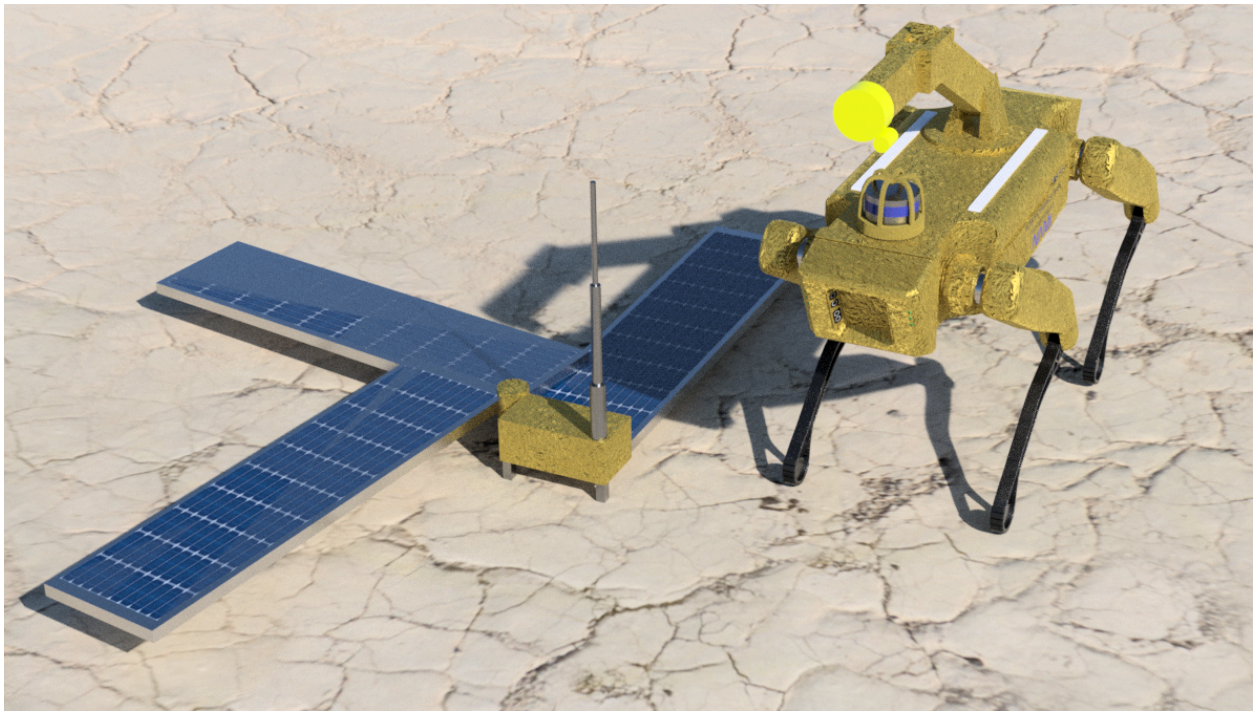
SYS.2.3: System shall be able to operate in low light environments where a light source may not readily be available

SYS.2.4:System shall be capable of tolerating shock and impacts

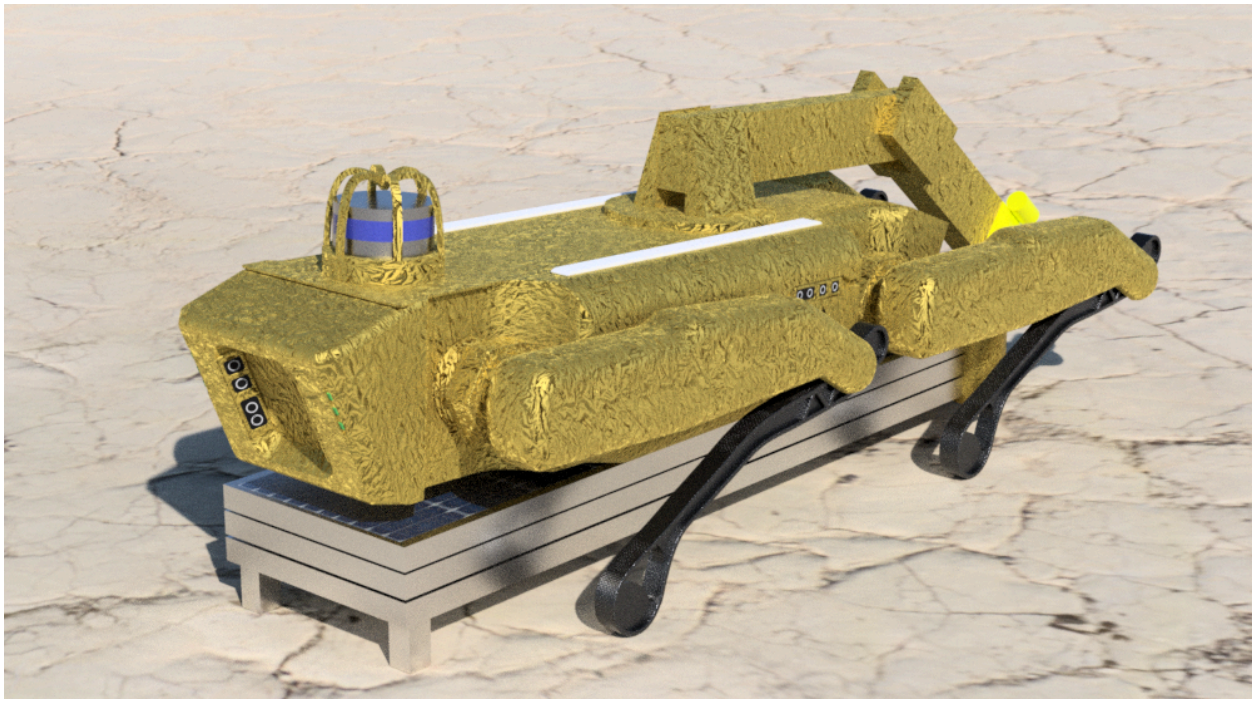
Overview

A high-level CAD model rendered below shows Spot with multiple payloads and instruments necessary for meeting mission NAMI's science objectives. In order to successfully complete this mission with a 99.9% reliability, Spot will be upgraded to withstand the environmental conditions on Mars, and equipped with multiple subsystems. It will use an EAP equipped with a LiDAR assembly for navigation. The EAP subsystem will also be utilized for pattern recognition in detecting speleothem formations. Furthermore, Spot will be equipped with SHERLOC, an arm-mounted ‘heritage’ technology used to search for organic materials and biosignatures. Lastly, Spot will be deployed along with a removable power station. The power station will be solar powered and have a tether that can reach the cave and offer secure recharging and data transferring capabilities.

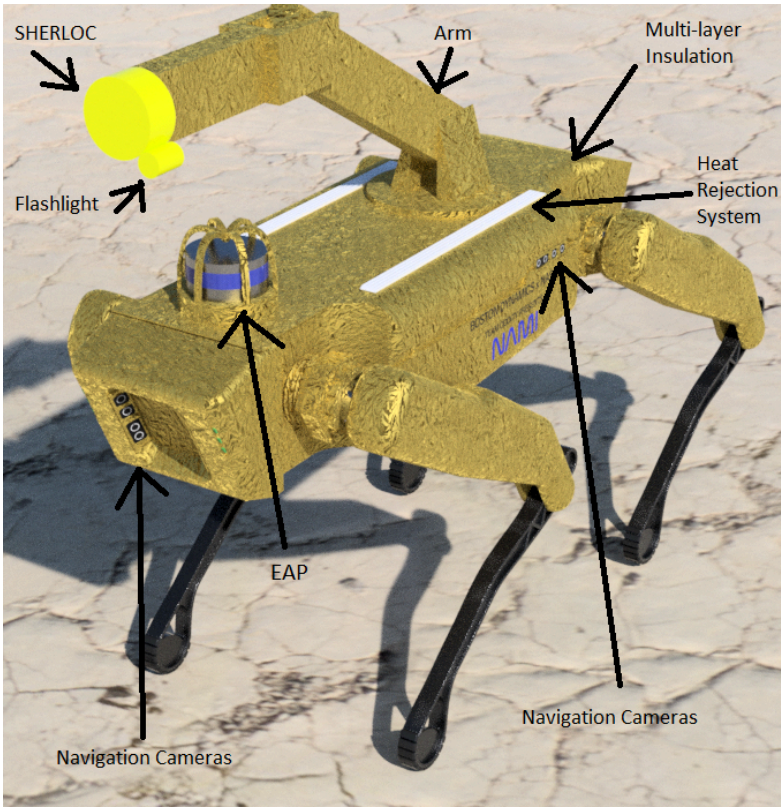
Deployed



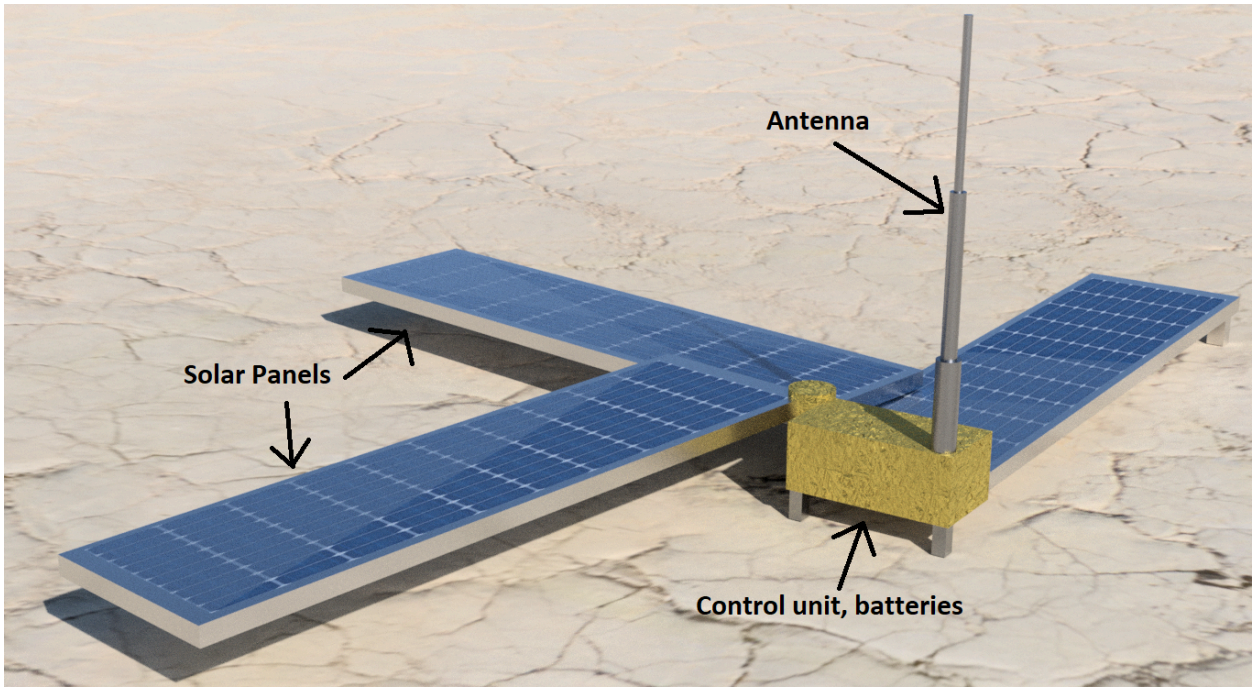
Pre-deployment



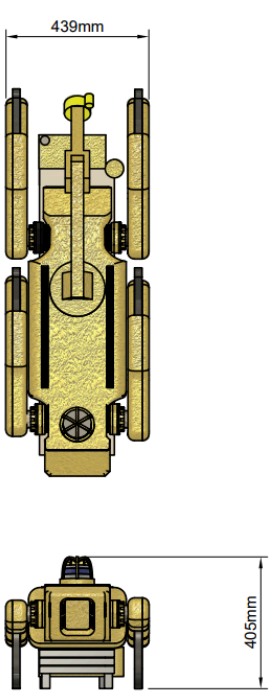
Spot Overview

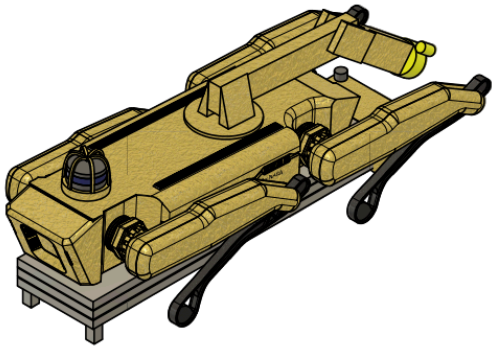


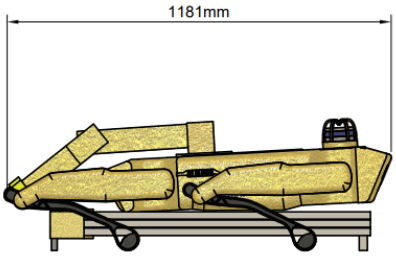
Power Station Overview



Dimensioned Model







Manufacturing Plans

In base form, Spot is unlikely to survive the harsh environmental conditions present on Mars. The extreme fluctuation in temperatures, harmful radiation, and unknown terrain must be accounted for in modifying Spot to function as needed. The following is a list of necessary modifications that will be made:

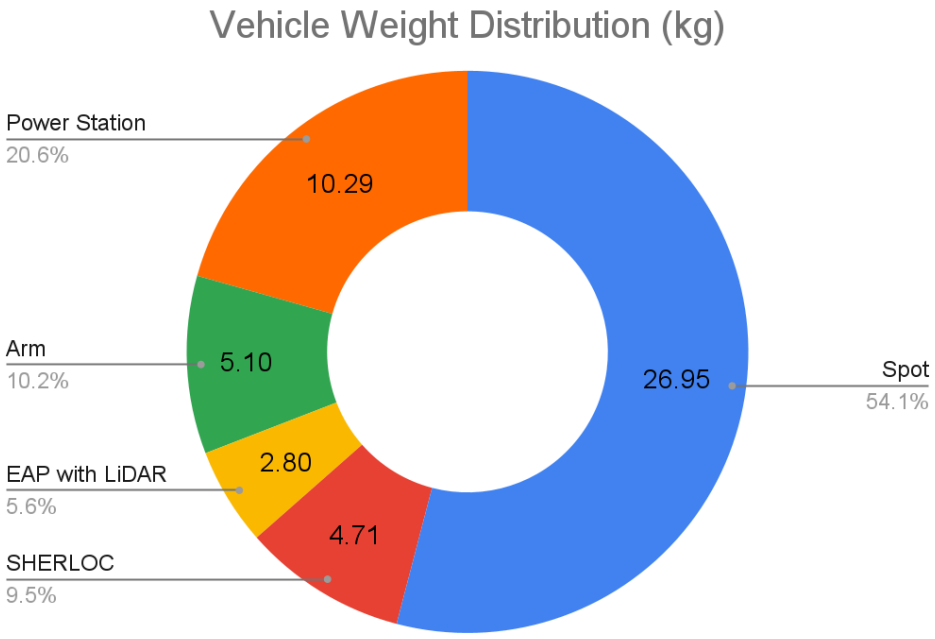
- Martian dust is likely to populate and corrode surfaces that require lubricants. Joints where lubricants are used will need to be completely sealed from the atmosphere. If this is not possible, Teflon™ (Polytetrafluoroethylene), a long lasting corrosion-proof, low friction material, will be used on mating surfaces instead of lubricants. >IP54
- Any included plastics that conduct outgassing or struggle in cold temperatures will need to be removed. The Martian environment is incredibly thin, and volatile vapors will evaporate and destroy most plastics.
- Spot will inevitably encounter extreme temperature swings on Mars. Since many different materials are to be included, Team Oddity also understands that there will be different resulting expansions. It is critical that a buffer is included where parts are met in order to prevent further internal stresses.

While increasing the structural integrity of Spot is crucial, it is also important to account for mass and volume constraints in order to meet mission requirements. Spot will require various weight reduction techniques to fit the allotted limit, as listed below:

- Areas utilizing fasteners will be replaced with singular parts machined from a billet block.
- Parts will be substituted with generatively designed parts that also contain lower weights where possible.
- Parts will have iso-grids machined into them to reduce weight where possible.
- Metals such as Grade 4 Titanium or 6061 Aluminum will be used where possible.
- Machinability is not a concern. If a 7-axis CNC machine is needed with a material that rapidly breaks tools, this is acceptable.
- Parts that do not directly contribute to mission success will be removed. An example of this is any buttons on Spot as they will never be able to be pressed.
- Carbon composites will be used primarily in the legs. Composites are very strong, lightweight, and don't conduct heat well which are all desirable properties. Testing can be complicated, which makes it very expensive and sometimes “unreliable” in the sense its properties will not be the same every time.
- Pre-impregnated carbon composites will be used as their behavior is more predictable and resistant to Foreign Object Debris (FOD) than wet layup parts.

Using these methods, NAMI is estimated to have a total mass of 49.84 kilograms. The table below summarizes the weight reduction and distribution of Spot and its different various components. An accompanying chart is given to visualize these metrics.

Component	Original weight (kg)	Weight Reduction	Final Weight (kg)	Reasoning
Spot Robot	31.70	15-25%	26.95	Lighter materials
SHERLOC	4.71	-	4.71	Legacy hardware
EAP with LiDAR	3.60	15-25%	2.80	Lighter materials
Arm	8.00	35-45%	5.10	Lighter materials; gripper replaced with SHERLOC + flashlight
Power Station	10.06	-	10.06	-



Verification and Validation Plans

Parts that are not critical to mission success will be tested using Finite Element Analysis (FEA) simulations to save time and money. Mission-critical parts, however, will be verified and validated extensively in the following ways:

- Thermal cycling more extreme than the Martian environment to be encountered
- Extensive shake tests on a vibration table
- Non-destructive inspection techniques such as thermography, electromagnetic testing, ultrasonic testing (Dye penetrant tests will not be used to ensure Foreign Object Debris (FOD) is limited as much as possible)
- Use of destructive testing will be minimized except for highly important mission critical parts
- Composite parts will be tested more thoroughly than their metal counterparts. Testing of such materials is extensive as standardized “grades” of carbon composites do not exist.

3.1.3. Power System Overview

Requirements

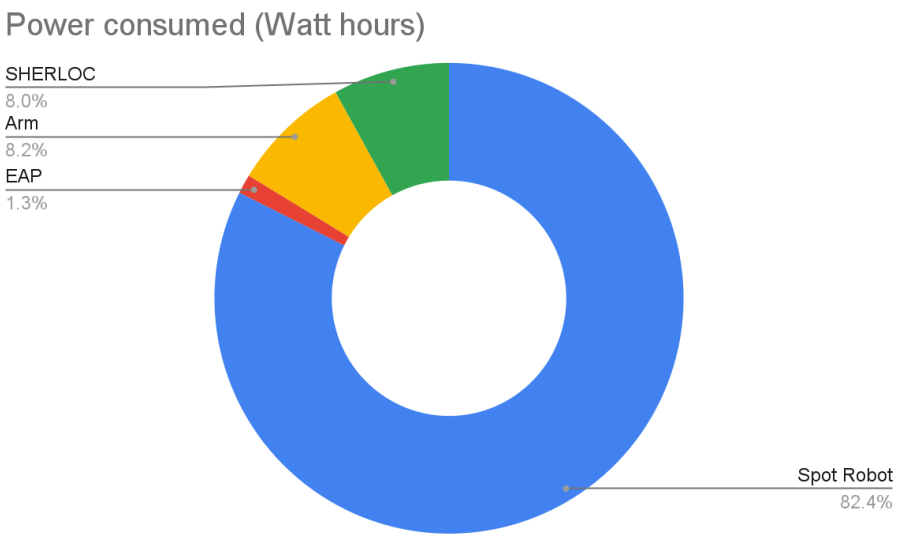
SYS.2: System should be able to operate in Martian environment

SYS.2.3: System shall provide needed electricity for systems

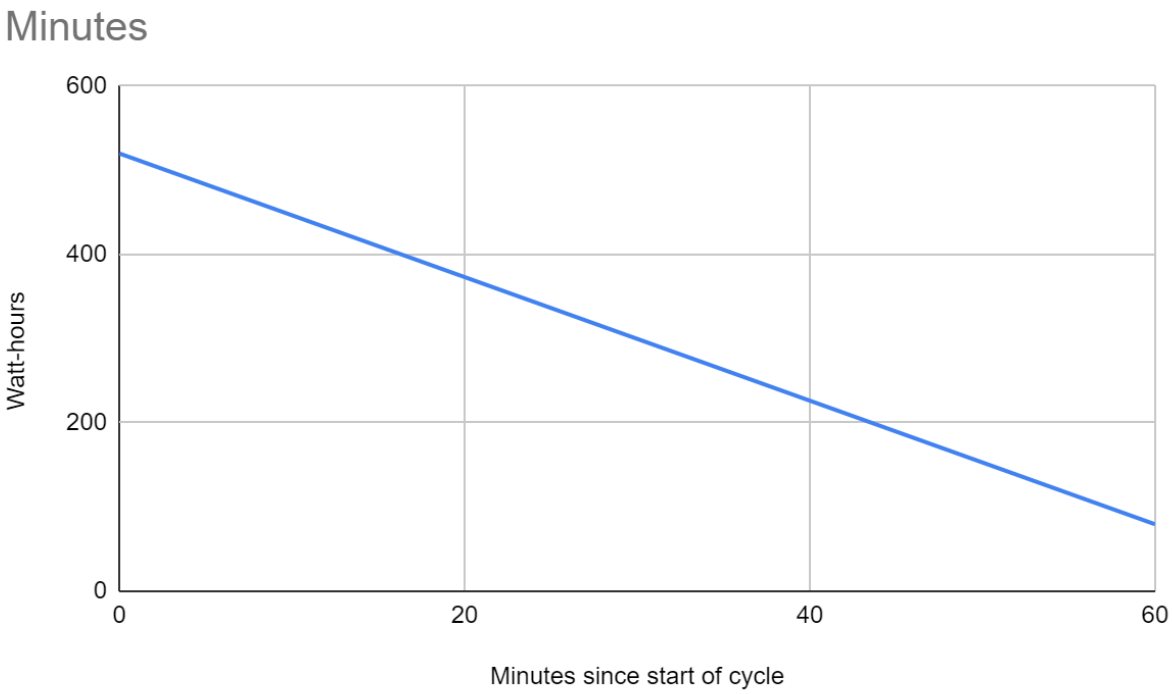
How Spot will use power

Spot will have a battery capacity of up to 660Wh, upgraded from 605Wh. This will be accomplished with higher quality batteries that will remain within 5% of the batteries initial weight. While Spot is rated to run for 90 minutes normally, it will only run for 60 minutes for battery integrity reasons & margin. This is because batteries degrade faster between 0-15% and 80-100%, so Spot will be kept within those ranges. 605Wh for 90 minutes gives Spot's systems without payload a power draw of 402W. After retrofits, Spot's systems besides payloads will not use any more than this, and should use ~10% less if possible for redundancy reasons. Payloads will use no more than a maximum of 150W at any time, unless special circumstances arise. As Spot explores the caves, it will have a programmable sequence to travel back to its charging port at a 35% of battery life to use the remaining energy for safe travel back to charge and prepare for its next exploration within the cave. During stand-by mode while charging or during the night, Spot will consume as little power as possible, and all heating will be done by radioactive decay discussed in section 3.1.5.

Below is a chart of where power will be consumed. All of the values are based on the average usage per mission cycle. A mission cycle is defined as the time spot is operating and not on standby/charging.



Below is a chart of power consumption over time. Spot will operate between 80%-15% of total battery capacity.



How Spot will obtain power

Spot will be deployed from the primary lander with a stowed power station. The robot will recharge from 30% to 75% within two sols. During charging, a worst case scenario will yield 660Wh in three sols. Assuming 24 hours of sunlight, this would result in 10-12W of power drawn during charging. Lithium-ion batteries charge at almost 100%

efficiency, so the assumed load will be 10W.

The stowed power station will detach from Spot and deploy solar panels upon landing on the surface. Spot will carry a 50m-tether to the cave entrance, which can be used to draw power from the power station and relay data from Spot to the power station. The tether allows Spot to utilize the station while being shielded from radiation in the cave. The cord will be magnetized at the end, so Spot can attach and detach itself easily. The cord will be dropped off somewhere level and safe when not in use. The cord will also be able to transfer data. Solar panels are between 18% efficient, and solar flux on the Martian surface is about 607.6 W/m^2. At 15% efficiency, that is approximately 91.1W of electricity per square meter. Three solar panels spanning half of a square meter will cover the power consumption of Spot, and will provide extra power consumption of 54Wh in case of dust storms. The power station will be equipped with 55Ah lithium-ion, rechargeable batteries that will provide the energy for NAMI. In situations where the power cable fails, Spot will be able to interface directly with the power station.

Verification and Validation Plans

The power station will be tested in a martian analogue environment. A light will be shined on it that has the same flux as the sun would at mars. If power generated is insufficient, more solar panel area will be added. If the solar panels expand past the weight or volume constraints, a new system will be developed based on the actual power needs of Spot. The solar panels will also be tested by how fast the batteries can be produced in one single cell. If batteries can’t be produced fast enough for Spot, solar panels will need to be larger to keep up with Spot’s cycles, making sure solar panels are within volume constraint.

3.1.4. Communications and Data Handling Overview

Requirements

SYS.1:System shall perform mission tasks autonomously

SYS.1.1:System shall be able to communicate to primary lander, from inside Martian caves

Overview

Low Frequency (LF) waves will be used to tell Spot what to move and what commands to execute. During initial landing, Spot will create a direct line to the charging station's mesh network by bringing in a tether. Due to data transfer rates, only commands will be sent and received using this method of asynchronous communication, no scientific data. All data will primarily be routed when Spot connects to the power station umbilical cord. The power station umbilical cord is a fiber optic line that will attach to Spot and send power and data. Fiber optic lines are considered optimal for their high data transfer rates and qualified for space flight since they are less at risk for interference through electromagnetic radiation.

In the event of communication failure, Spot will automatically route back to the station and dock with it, allowing the mission to continue. The power station umbilical cord will be attached to the power station, which will have two antennas attached to it. One of the antennas will transmit the LF waves to Spot, which will have an onboard antenna to receive the signal, and the other will transmit to the primary lander, assumed to be 5km away, using Super High Frequency (SHF) waves. The SHF antenna will be able to send and receive data and be powered by the solar panel that expands at the entrance of the target site with small space qualified lithium ion batteries. Due to this, communication will only be available at night.

For the storage of scientific data and



communication between the onboard instrumentation, NAMI intends to use an onboard processor called CORE for storage. Spot's CORE is 250 mm long, 190 mm wide, and 84 mm tall. CORE contains 512 gigabytes of primary storage at 2,666 mHz and runs on a 64 bit, Linux Ubuntu system. Nominal temperatures for Spot's CORE range from 0° to 50° Celsius. CORE's motherboard uses an i5 Intel 8th Generation (Whiskey lake-U) Core with a CCG Lifecycle and has a net weight of 2,000 grams in accordance with the specification sheet provided by Boston Dynamics.

Verification and Validation Plans

Radio frequency gain and loss will be tested between the transmitter and receiver on the charging station and Spot, which functions interchangeably as a transmitter and receiver. This will allow NAMI to determine the allowable path loss (lp), which is a range of communication through the volcanic basalt and other rocky materials present on Mars until communication is no longer possible. Furthermore, the visual data Spot gathers from its onboard equipment must be converted to numerical data, allowing it to be transferred from Spot to the charging station. The fiber optic cord, which functions as a hardwired relay that transfers power and small amounts of data, will serve as an alternate pathway in the event the communication between Spot and the charging station is obstructed.

3.1.5 Thermal Management System Overview

Requirements

SYS.2: System should be able to operate in Martian environment

SYS.2.1: System shall be able to withstand temperatures between 203K and 300K

Predicted Heat loss Calculations for Spot

Assuming Spot to be a rectangular prism with 500mm wide x 1100mm long x 200mm tall, the body loses heat via convection and radiation. The following table summarizes the equations applicable to different modes of heat transfer:

Radiative	Conduction	Convection
$Q = \varepsilon\sigma F A(T_1^4 - T_2^4)$ ε = Emissivity σ = Stefan - Boltzmann Constant F = View Factor A = Projected Area	$Q = \frac{kA(T_1 - T_2)}{L}$ k = Thermal Conductivity A = Area L = Length of Conduction Path	$Q = hA(T_1 - T_2)$ h = Connective Heat Transfer Coefficient A = Area

The operating temperature of Spot will be -30.15°C (243K), as its electronics are likely to die at more than 233°K. Mars temperature at night, on average, is -70.15°C (203K). Since Spot will be in a cave with no sunlight, this is a good approximation The surface area of Spot is 0.7075m^2. The effective emissivity of 20 layers of Multi-Layer Insulation is between 0.003 and 0.006. For purposes of calculation, 0.006 will be used. Plugging into the radiation equation, this gives a heat loss of 0.601W to radiation.

To simplify calculations, the legs will be assumed to be 600mm long, 70mm x 70mm cross section, made of high-grade carbon composites, and lose no heat to radiation or convection. Carbon composites have heat transfer coefficients of 5.28±0.42$\frac{W}{mK}$. To be conservative, 5.7$\frac{W}{mK}$ will be used, resulting in a conductive heat loss of 1.31W.

Because it is very hard to find convective heat transfer coefficients for an object sitting still in the incredibly thin Martian atmosphere, it will be approximated to around 1.5 times that of the radiation losses, at 0.902W. This brings the total heat loss to be 2.813W. Spot will not be exposed to solar radiation inside the cave, so those calculations need not be considered.

Predicted Heat loss Calculations for Power Station

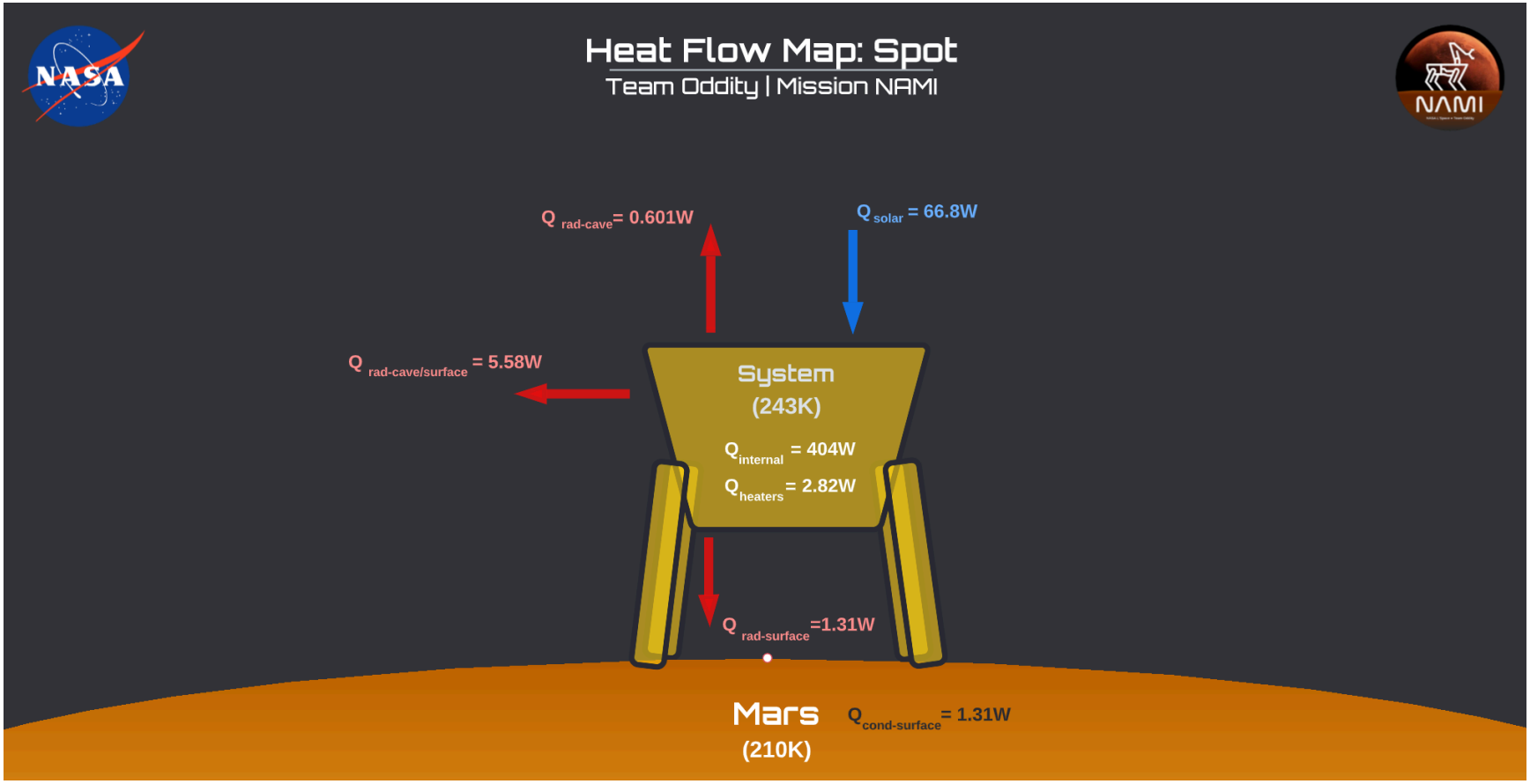
The power station, with the 3 solar panels stacked on top of one another will have a cube prism of 141mm wide x 238mm long x 186.5mm high. When the solar panels are now expanded to start its operation, the power station will lose heat via radiation and convection. The proper equations used are seen on the previous page.

Inside the power station will be the antenna used to communicate with Spot, as well as 5 rechargeable 55Ah lithium-Ion batteries that operate normally in the given temperature of 253K. As the three solar panels expand, the surface area is 0.1176m^2. Due to the CGM cover glass with an emissivity of 0.8 that protects the solar panels from radiation damage, the calculated amount of heat loss will be 66.1W of radiation.

The base of the power station is measured to be 141mm wide x 238mm long x 186.5mm high. Given that, the surface area from the base is 0.034m^2. With the multi-layer Insulation used for the power station, having an emissivity of 0.7, and heat conductivity of $10 \pm .5 \frac{W}{mK}$, the calculated heat conducting from the power station to the surface of Mars is 54.87W.

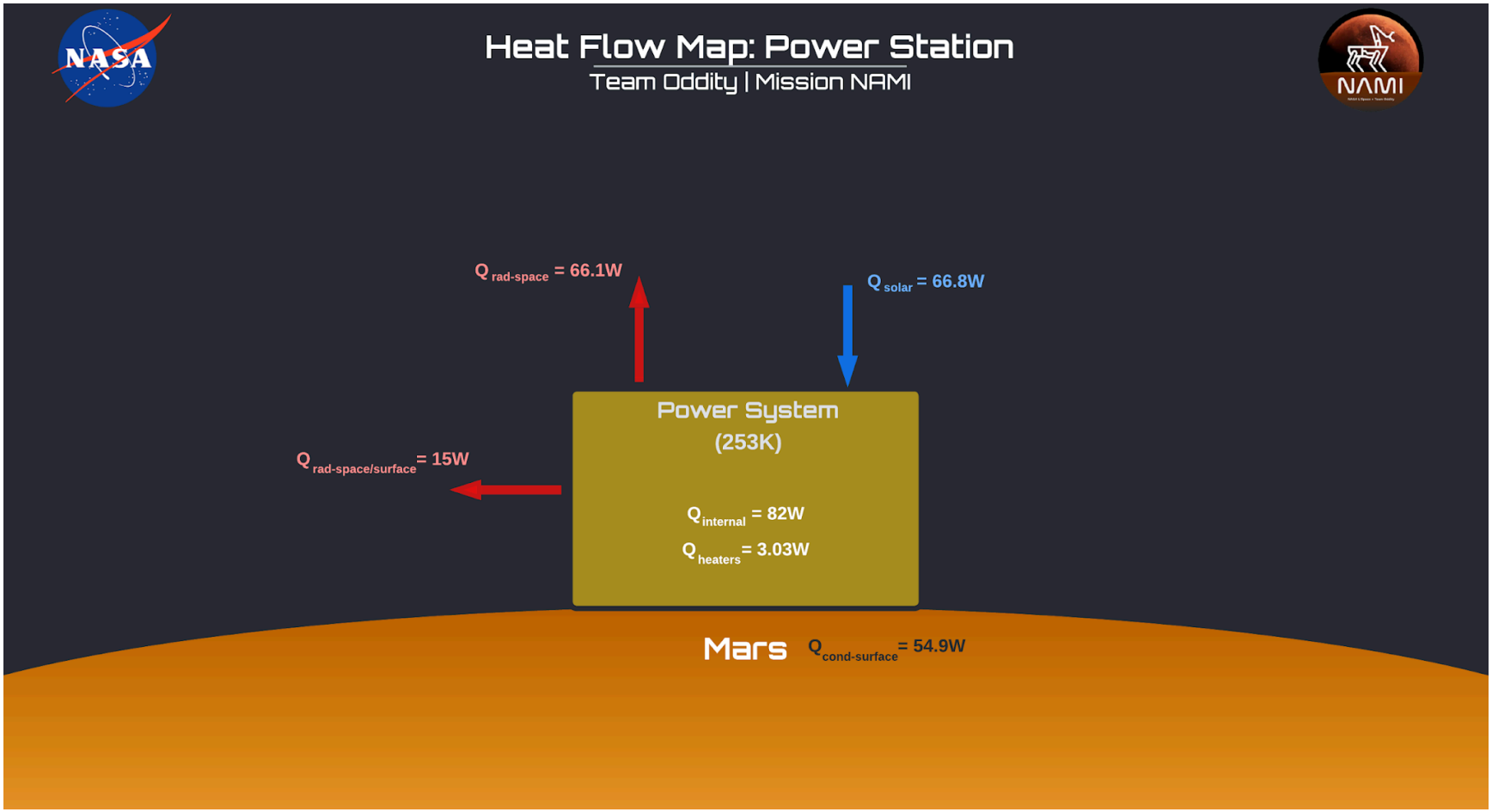
With the internal power being 82W and the heat from the solar is 66W, The power station will lose roughly 3W of heat.

The heat flow maps given below illustrate the thermal loss and gain of the system as well as the power station:



Heat Flow Map: Power Station

Team Oddity | Mission NAMI



Thermal Management System (TMS) Overview

To account for heat loss, Spot will use several pieces of radioactive material to keep itself warm. With the current heat calculations, Spot will use 2.813W to keep itself warm, with at least 5.84g of plutonium dioxide as a heat source. This was found by extrapolation from what the Perseverance rover uses. Perseverance has 4,103g of plutonium dioxide, which produces 1,975W of thermal energy. 4103/1975 makes 2.07g of plutonium dioxide per Watt. For our predicted heat loss of 2.813W, we would need 5.84g of plutonium. As this is extremely likely to change and very low, a more realistic estimate is 20g of plutonium dioxide. As it is likely Spot may produce more power than it radiates, a heat rejection system will be added, most likely in the form of radiators that can be turned off and on. No electrical power will be generated from the radioactive material, only thermal energy.

Manufacturing and Integration Plan for Thermal Management System

1. Radioactive Heating Units: Radioactive material will be acquired through NASA as a heating source for Spot. The material will be in the vehicle such that it can radiate heat to components that need power easily. This may be in the form of having several small blocks, or one big block with radiation shielding. The exact way this will be done will be found in the CDR that follows this PDR.

2. Multi-Layer Insulation (MLI): The exact way MLI will be attached to the vehicle will be found after extensive testing and consideration. Common ways MLI is attached to the vehicle is that they can be stacked and sewn together at the edges or affixed by other means such as plastic pins. Metal grommets may be placed at the corners to attach the blankets to space vehicles. Depending on various constraints at the time, TMS will be manufactured and integrated (budget, lead time, adaptability) the decision to whether to do those tasks in-house or via contractor will be determined then. The MLI is relatively thin and should be easy to integrate into the system. It must be the layer on the very exterior of the vehicle. The legs of Spot will also provide some insulation. The legs will be made of carbon fiber reinforced plastic, which provides low thermal conductivity, while maintaining low weight and high strength.

3. Heat Rejection System: A form of heat pump will be attached to the system. There will be a hole in the MLI where a fluid-cooled radiator will be. Fluids will be able to move or not move, depending on the needs of the TMS. The fluid moving through the radiator will heat it up, and that heat will be rejected.

4. Emergency Heaters: Emergency electrical heaters will be included in the TMS to provide heating if the MLI and radioactive heating units cannot keep up the temperature

Verification & Validation

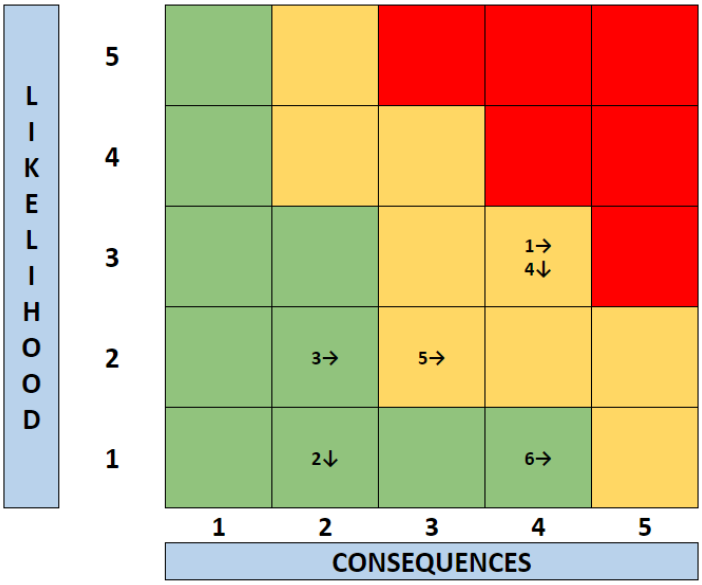
As the heat calculations made so far are very basic, testing will be done to determine the correct amount of material needed. How this will be done is subjecting Spot to the average Mars night temperature of 203K, and material will be added until Spot stays at 243K. Spot will be in “stand-by” mode, and will be consuming as little electrical power as reasonably possible - all heating should come from the radioactive material. Once the correct amount of material is found, 20% more will be added to account for material loss due to decay & extra in case of extreme cold conditions. The heat rejection system will be tested to ensure that it can reject heat when subjected up to temperatures of 300K.

3.1.6. FMEA and Risk Mitigation

In finalizing a vehicle design for mission NAMI, all subsystems were evaluated for possible risks and potential failures. Identifying risks and mitigation methods is important in increasing the probability of mission success. A broad overview is given below, and a Failure Modes and Effects Analysis (FMEA) table is attached for more in-depth analysis.

ID	Summary	L	C	Trend	Approach	Risk Statement
1	Vehicle is damaged or tipped over during activity	3	4	→	M	Narrow real-estate or rough terrain can cause damage to the vehicle
2	System has insufficient power to finish mission	1	2	↓	W	Power loss will stop data gathering, but can be resupplied from power station
3	One of Spot's legs break during operation	2	2	→	W	Possible material deterioration or contact with large rocks could break one of the legs
4	Systems exceeds temperature limits	3	4	↓	M	Exceeding temperature limits would damage the robot
5	Vehicle battery fails to recharge	2	3	→	R	Batteries not recharging would reduce the mission to one cycle
6	Software failure during run time causes the vehicle to lose data	1	4	→	M	Data loss can occur in the event an operation is interrupted or executed incorrectly.

L = Likelihood (1-5)	LxC Trend	Approach	Criticality
1 = not likely	↓ - Decreasing (improving)	A - accept	HIGH
5 = extremely likely	↑ - increasing (worsening)	M- mitigate	MED
C = Consequence (1-5)	→ - unchanged	W - watch	LOW
1 = low consequence	**NEW** - added this month	R - research	
5 = high consequence			



Function: What system or function of the spacecraft or instrument is being considered?	Failure Mode: How might this function fail?	Effects: How might this failure affect the mission?	Severity: On a scale of 1 (least) - 100 (most) how severe would be the consequences of this failure?	Cause: What might cause this failure to occur?	Occurrence: On a scale of 1 (least) - 100 (most) how likely is it that this failure would occur?	Prevention: What methods can be used to prevent this failure from happening?	Detection: On a scale of 1 (least) - 100 (most) how easily could this failure be detected?	Risk Priority Number (RPN): This is the product of the Severity, Occurrence, and Detection scores. The higher this number is, the more important it is.	Actions: What can be done if this failure continues?
Function	**Failure Mode**	**Effects**	**Severity**	**Cause**	**Occurrence**	**Prevention**	**Detection**	**RPN**	**Actions**
Radioactive Heat System	Heat system doesn't properly heat Spot.	Spot will become inoperable and electronic systems will freeze.	100	The radioactive material is placed inside of Spot and not secured properly causing it to fall out.	5	Only present Spot with the correct amount of radioactive material. This amount is 5.84 g of plutonium dioxide.	95	47500	Review the amount of material being presented to Spot and correctly determine how the material reacts with the instruments on Spot.
	Heat system overheats Spot.	Spot will become inoperable and electronic systems will start to melt.	100	The radioactive material is presented in a high quantity causing Spot to overheat.	5	Only present Spot with the correct amount of radioactive material. This amount is 5.84 g of plutonium dioxide.	95	47500	Review the amount of material being presented to Spot and correctly determine how the material reacts with the instruments on Spot.
Power Station	Power station does not charge Spot.	Spot will be unable to continue the mission resulting in a mission failure.	100	The power station is not properly set up or happens to get stuck to Spot where he is unable to release it at mission start.	10	Repeatedly test the power station to insure that Spot will be able to deploy it and that the power station successfully charges Spot.	95	95000	Find an alternate method for deploying the power station and attempt to deploy it safely.
	Power station is damaged.	Depending on the severity of the damage, Spot will be unable to continue the mission resulting in a mission failure.	80	The power station is deployed at an unsecure location that is vulnerable to falling debris or hazardous weather.	5	Only deploy the power station at a safe location that is safe from falling debris and extreme weather.	90	36000	Continue to research cave sites to determine which cave provides the best coverage from falling debris and extreme weather.
	Power station is covered by debris or dust.	Depending on the severity of the coverage of the power station, Spot will be unable to continue the mission resulting in a mission failure.	65	The power station is deployed without proper shielding from the elements.	5	Only deploy the power station at a safe location that is safe from falling debris and extreme weather.	90	29250	Continue to research cave sites to determine which cave provides the best coverage from falling debris and extreme weather.
Mechanical	Leg failure	Spot will lose control of one of its legs, if more than one leg fails, Spot cannot move, resulting in mission failure	60	Martian dust, general wear and tear	5	Better parts, limit movement	95	28500	Walk on 3 legs if one fails. If more than one leg fails, attempt to crawl if no other options.

	Arm fails	Spot will be unable to use its arm, resulting in the SHERLOC instrument being less effective to useless, depending on how bad failure is	50	Martian dust, general wear and tear, hitting something	5	Only move arm when strictly necessary, be cautious with moving it around as to not hit anything.	95	23750	Try to aim arm by moving Spot itself to where the arm needs to aim.
Communication	LF antenna fails	Spot cannot easily receive commands, leading to a more inefficient and failure prone communication method.	70	Radiation, command unit failure	2	Nothing	90	12600	Communicate using cable every time Spot needs a command.
	Cable connection to power station is broken	Spot cannot easily transmit science data. Using LF antenna will be very slow and will compromise science goals.	90	Snags, tangling, excessive strain	6	Be extremely sure to keep the cable untangled. Move cable as little as possible after deployment.	90	48600	Communicate using LF antenna, interface with power station directly as a last resort.

3.1.7. Performance Characteristics and Predictions

As previously described, Mission NAMI uses Spot, as well as several other instruments and sensors inspired by successful ‘heritage’ components of previous missions. The chosen instruments are built to endure the unforgiving atmosphere that exists on Mars.

Spot is expected to face conditions of -73.15°C to 16.85°C (200K to 290K). While Spot is expected to land on Mars near the end of summer, it will need to operate properly through temperature fluctuations. Radiation and harsh weather like dust storms will likely not impact Spot, as it will be protected by the cave and perform most of the mission objectives underground. In the case of dust storms, the power station solar panels will be built to withstand and operate in those conditions. Spot will maintain its nominal thermal range via decaying radioactive elements housed inside the body.

One of Spot’s best features is its navigation ability, which is a primary reason for using Spot as NAMI’s exploration vehicle. With a triple redundant system, the EAP, SHERLOC instrument, and onboard navigation cameras offer a fully autonomous mode of operation. Furthermore, Spot has been field tested and is capable of handling rough terrain.

SHERLOC has been tested on Mars and is proven to work. This brings a very high degree of confidence in predicting the possible success of NAMI. Spot can collect highly accurate data with SHERLOC as it is attached to a mechanical arm capable of assessing samples up close.

3.1.8. Confidence and Maturity of Design

Technological Readiness Levels

System	Spot Body	EAP	SHERLOC	Power Station
TRL	6	6	9	6

Justification for TRL Ratings

The category “Spot Body” includes the navigation, arm, legs, and all processing equipment. Essentially, everything the current consumer Spot robot has. Created by Boston Dynamics, Spot is a tested, proven, and capable robot for this mission. It is perfect for navigating through tough terrain with high autonomy. As such, the base manufacturing level of Spot has a TRL of 9, on Earth. The upgraded variant of Spot used for this mission will have a TRL of 6 once the testing phase is completed. Since we will not be able to test Spot on other planetary bodies, it will be impossible to bring it to a more attractive TRL before launch. Modification of the original model grants a much higher degree of confidence in the system and its ability to perform on Mars. Spot will be operating mostly within the limits of what it was designed & tested for, so it is likely to work without issue.

The EAP system has the same reasoning as the Spot body. It has been field tested and proven on Earth, where it works with a great deal of confidence. However, it has not been tested in the Martian environment, and it would be effectively impossible to do before the start of the mission.

The SHERLOC instrument has a TRL of 9 as it has been tested, and is flight proven on Mars. It is currently on the Perseverance rover and works as intended. The only change that would be made to the SHERLOC instrument is modifying the mounting hardware to fit the robot arm.

The power station has solar panels and batteries at a TRL of 6. After the successful exploration from Sojourner, the solar panels from Sojourner were used but have been multiplied in size and panels, as well as tested for proper operation. The batteries used to store the power for Spot were used for Perseverance’s back-up battery pack. Overall, the power station has been retrofitted, tested, and modified as many times as needed to bring it to TRL 6. The final test will be a Martian analog environment on earth.

3.2. Recovery/Redundancy System

Redundancy:

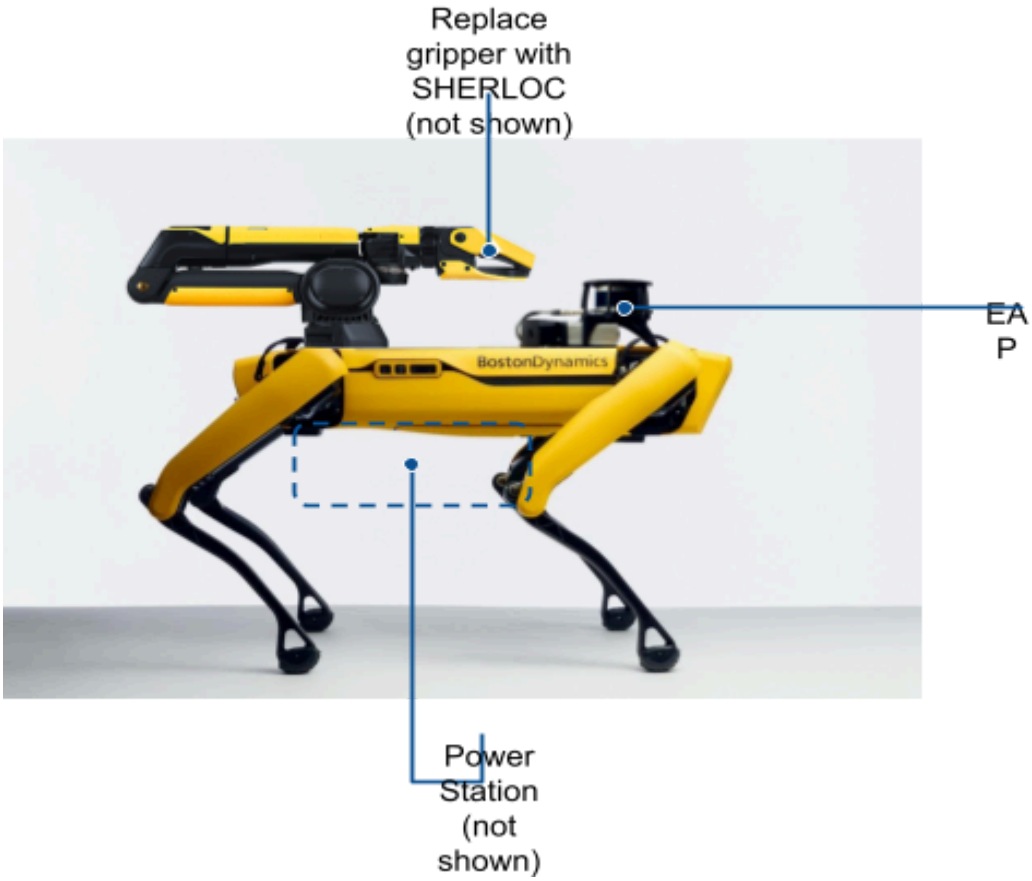
- Navigation
  - Spot can navigate if either the LiDAR, camera system, or SHERLOC fails. All three accomplish science and navigation goals. SHERLOC has a color camera which will work for navigation, but make it very slow. The camera system doesn't add much in weight and is proven to work as the old navigation aid, so that will be kept for redundancy.
  - If one leg fails, Spot can still move with 3 legs.
- Communication
  - If the antenna on Spot fails, it can still communicate via the power station umbilical cord.
- Thermal
  - If the Thermal Management System insulation & radioactive heating units fails to keep the vehicle hot enough, electric heaters can be used to aid it.
  - If Spot gets too hot, the MLI is fragile and can be removed by Spot rubbing its body against rocks.
- Power
  - Spot will be able to interface directly with the power station in emergencies, but this must be as limited as possible as the radiation will destroy Spot.
- Science
  - The EAP, SHERLOC, and onboard navigation cameras can all map the cave to determine the structure of it. SHERLOC and navigation cameras can both take pictures, but the navigation cameras can only see in black & white.

Reliability:

- All structural components will be built to withstand 200% of their expected load.
- Spot’s batteries are to be kept between 15%-80% of total charge to stop battery degradation. In emergency situations, Spot will be able to utilize the full potential of its batteries.
- Typical runtime for Spot is 90 minutes, within regular operating conditions Spot will run for 60 minutes at a time.

3.3. Payload Integration

Payloads will be directly integrated into Spot's body. The top of the body is capable of housing two payloads, with mounting rails available to secure the payload in place. The back mount will house the mechanical arm. The gripper on the arm will be replaced with the SHERLOC instrument to allow for close-up sample examination. The EAP subsystem will be installed on the front mount. The LiDAR and computer module will make Spot a fully-autonomous exploration vehicle, and counter the weight of the mechanical arm to provide a balanced center of gravity. Lastly, the power station will be stowed on the belly of the robot. Upon arrival at the cave site, the power station will be undocked and Spot will carry a tether into the cave, capable of charging the robot as well as transferring data back to the primary lander. Spot also comes packed with additional navigation cameras and sensors along the sides of the main body that can be used for navigation as well as any pattern recognition software. The cameras as well as the mechanical arm may be retrofitted with mini-LED flashlights to assist SHERLOC in getting clear images and experimental data from samples. The picture below directly identifies payload placements:



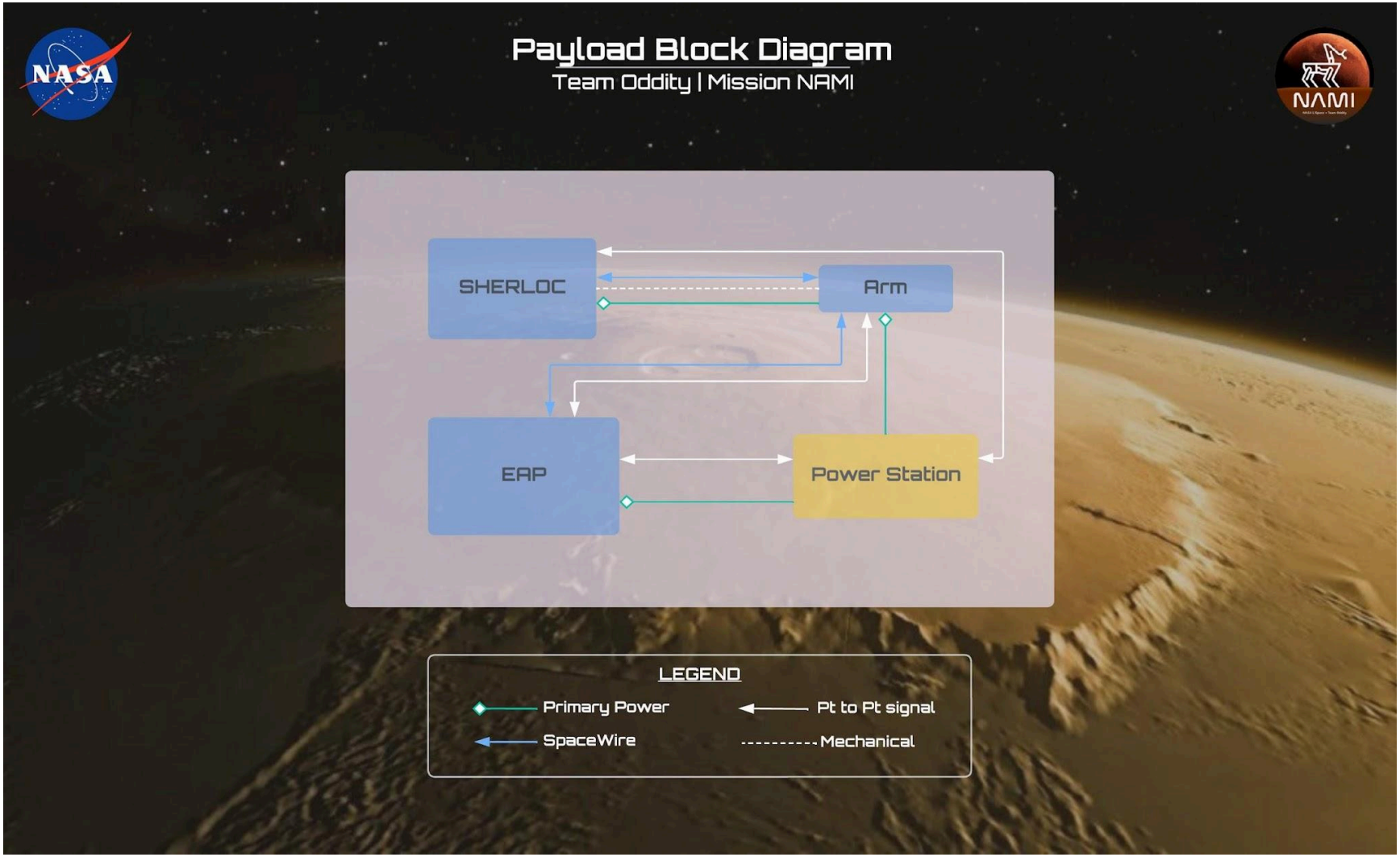
4. Payload Design and Science Instrumentation

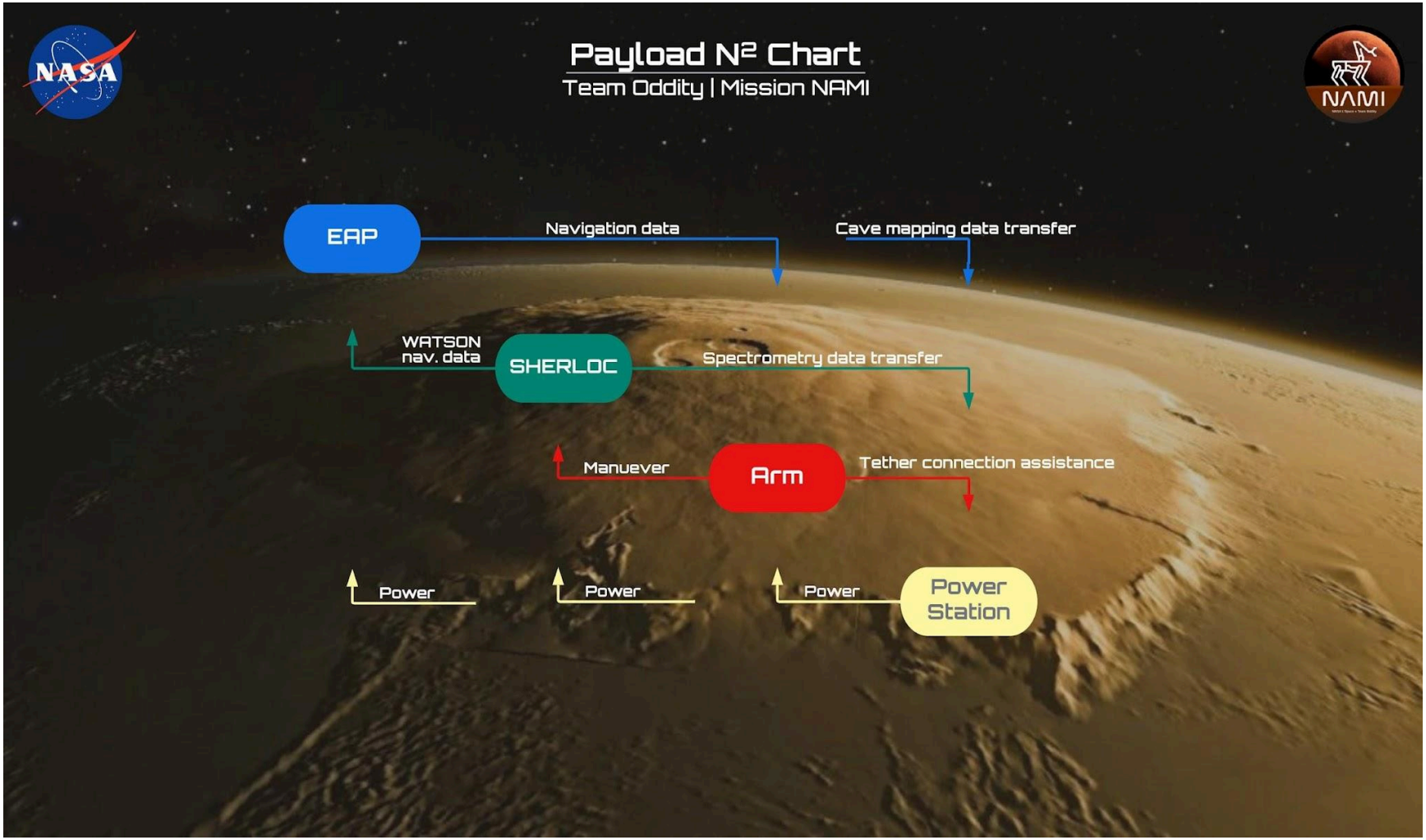
4.1. Selection, Design, and Verification

4.1.1. System Overview

NAMI will use an array of scientific instrumentation to navigate the cave site and search for biosignatures. NAMI will be equipped with two different subsystems, one being the EAP, primarily devoted to cave mapping and macroscopic imaging for primarily non-scientific consumption, while the other subsystem, SHERLOC, will analyze the geochemistry of the cave's interior, searching for biosignatures and enhancing NASA's understanding of past and present Martian caves.

The following block diagram and N^2 chart represent the payload-specific interfaces on the Spot vehicle:




Payload N² Chart
Team Oddity | Mission NAMI
EAP
Navigation data
Cave mapping data transfer
WATSON
nav. data
SHERLOC
Spectrometry data transfer
Manuever
Arm
Tether connection assistance
Power
Power
Power
Power
Station

4.1.2. Subsystem Overview

The Enhanced Autonomy Payload, or EAP, is a navigation-focused system equipped with LiDAR and multiple sensors that help Spot move through unknown terrain autonomously. The EAP paired with the cameras integrated into the main body of the robot offer a 360° view of the cave. The images and data from these can be used for cave mapping as well as running pattern recognition algorithms to detect speleothem formations that may be present.

SHERLOC is a technology used for detecting biosignatures with high efficiency and accuracy. The Raman spectrometry-based instrument is attached to a mechanical arm, allowing it to closely examine samples of Martian regolith and gather necessary scientific data. The mechanical arm will also be equipped with mini-LED flashlights to assist the cameras integrated in SHERLOC get a better visual of samples.

Spot's onboard computers will be capable of distributing power throughout the system. A majority of the supply will be dedicated to the EAP subsystem, as well as the main chassis that allows Spot to navigate through the cave. The rest of the power will be consumed by SHERLOC in gathering and analyzing appropriate data. The turret for SHERLOC consumes 32.2 watts of power while the camera itself utilizes 16.6 watts during active data gathering.

The power station deployed at the cave entrance will provide a source of solar power for Spot to recharge and conduct multiple cycles of exploration. It will also serve as a relay for exporting gathered data back to the primary lander. Spot will be able to tether to the power station to transfer data, and the power station will be equipped with antennae to communicate with the primary lander. More information regarding the power supply and communication systems can be found in sections 3.1.3 and 3.1.4, respectively.

To maintain a reasonable thermal homeostasis, Spot will be equipped with 20g of plutonium dioxide. Similar to the Perseverance rover, this will provide the vehicle with a heat source that can mitigate the extreme cold conditions and prevent hardware or electrical failure. The TMS described in section 3.1.5 will also help Spot remain functional and capable of conducting the mission. Regulation of SHERLOC’s thermal requirements of -40 to 50°C will be taken into consideration when using the thermal emissions of plutonium dioxide.

4.1.3. Manufacturing Plan

The manufacturing of the heritage SHERLOC instrument will be completed by NASA's Jet Propulsion Laboratory in Pasadena, California and managed by Arizona State University (ASU). ASU will consult the California Institute of Technology for manufacturing specifications to obtain data on the original SHERLOC component prior to construction. Any components of SHERLOC unable to be recreated by the Jet Propulsion Laboratory will be created and modified by an off-the-shelf commercial company in Irvine, California that specializes in spectroscopy components and shows background in Raman spectroscopy and custom scientific instrument design. To meet commercial needs, HORIBA's facility in the United States of America was selected for its background in creating customized instrumentation and its ability to fulfill NAMI's scientific objectives. All manufacturing completed by HORIBA will be completed in conjunction with the Jet Propulsion Laboratory to ensure that commercial components follow SHERLOC's specifications by May 31st, 2023.

The Jet Propulsion Laboratory will work in conjunction with Boston Dynamics under the management of Arizona State University (ASU) to make minor modifications SHERLOC. SHERLOC must be able to attach to Spot's mechanical arm and work in conjunction with the Enhanced Autonomy Payload (EAP). The EAP will contain minor structural and electrical modifications to transmit data to and from SHERLOC, and each modification requires Boston Dynamics to collaborate with the JPL to ensure the design integrity of the instrumentation prior to the end of May 31st, 2023.

4.1.4. Verification and Validation Plan

SHERLOC’s functionality is accounted for through its ability to calibrate and debug remotely for the duration of the mission, and it’s further enforced as a flight-proven piece of legacy hardware. In order to verify its functionality for this mission, it will be tested rigorously on different geological targets on Earth and calibrated using a slice of a Martian meteorite, a piece of aluminum gallium nitrate on a sapphire, and spacesuit materials. Geological structures containing target compounds in subterranean surfaces will be analyzed on Earth by SHERLOC to create a database with matchable data during the mission. If SHERLOC successfully matches the martian dataset with the sets acquired on Earth, the instrument will be properly verified. The arm for SHERLOC will be tested by moving in a 360° circle and by carrying 50% more than the expected load.

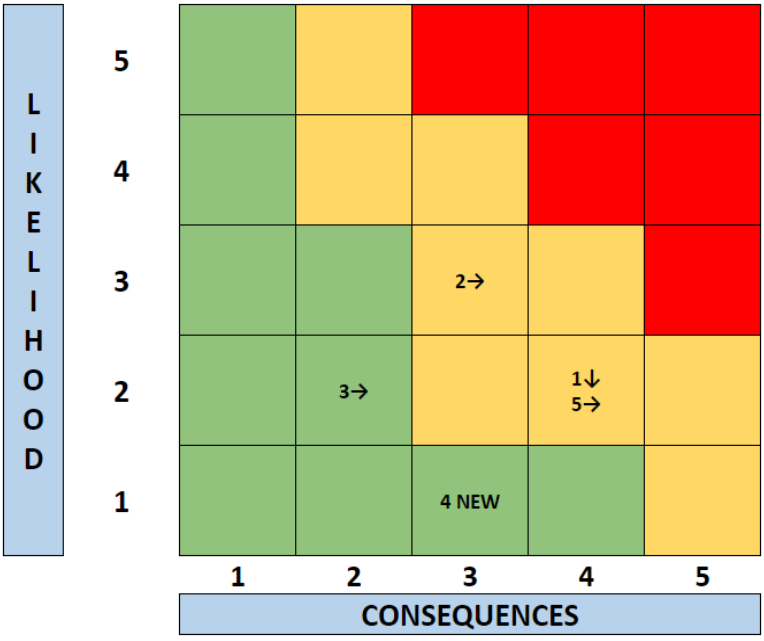
The EAP system, on the other hand, will be tested by being placed in a room with objects in it that have had their dimensions verified. If it can detect the object's size in complete darkness using its onboard light sources within a reasonable margin, Spot’s EAP system will be considered validated.

4.1.5. FMEA and Risk Mitigation

Risks and associated mitigation methods were identified for all science instruments and external payloads, similar to section 3.1.6. A summary of these risks is given below along with a risk matrix to evaluate the current trend, and a FMEA table is also attached for more in-depth analysis.

ID	Summary	L	C	Trend	Approach	Risk Statement
1	Instruments are damaged or malfunction	2	4	↓	M	SHERLOC or EAP could make contact with cave wall and be damaged
2	Mechanical arm is damaged and cannot move	3	3	→	M	Damage to the arm will prevent SHERLOC from getting close to samples for data collection
3	One of the navigation cameras fail to operate	2	2	→	W	Cameras may be damaged during cave exploration, but having backups provides redundancy measures
4	Instruments are not calibrated properly	1	3	**NEW**	M	Failure to calibrate instruments could result in skewed data
5	Power station is damaged	2	4	→	R	Dust storms could damage solar panels or other components of the power station

L = Likelihood (1-5)	LxC Trend	Approach	Criticality
1 = not likely	↓ - Decreasing (improving)	A - accept	**HIGH**
5 = extremely likely	↑ - increasing (worsening)	M- mitigate	**MED**
C = Consequence (1-5)	→ - unchanged	W - watch	**LOW**
1 = low consequence	**NEW** - added this month	R - research	
5 = high consequence			



Function: What system or function of the spacecraft or instrument is being considered?	Failure Mode: How might this function fail?	Effects: How might this failure affect the mission?	Severity: On a scale of 1 (least) - 100 (most) how severe would be the consequences of this failure?	Cause: What might cause this failure to occur?	Occurrence: On a scale of 1 (least) - 100 (most) how likely is it that this failure would occur?	Prevention: What methods can be used to prevent this failure from happening?	Detection: On a scale of 1 (least) - 100 (most) how easily could this failure be detected?	Risk Priority Number (RPN): This is the product of the Severity, Occurrence, and Detection scores. The higher this number is, the more important it is.	Actions: What can be done if this failure continues?
Function	**Failure Mode**	**Effects**	**Severity**	**Cause**	**Occurrence**	**Prevention**	**Detection**	**RPN**	**Actions**
Enhanced Autonomy Payload (EAP)	Bad weather causes LiDAR to be inoperable	Usage of LiDAR outside of the cave during a dust story could damage the sensor.	95	Improper usage of Spot in a bad weather location.	10	Spot can only be operated in a location that is deemed extreme weather free.	95	90250	Review weather patterns on Mars and only allow Spot to exit the cave during clear weather.
	Heavy debris could crush the LiDAR system.	Crushing of the LiDAR could result in mission failure.	95	Spot is used in a cave that is not properly navigable or thoroughly inspected.	10	Only navigate caves that are documented to be safe sites for exploration.	90	85500	Add a protective roll cage to the LiDAR system to prevent debris from denting it or crushing it.
	LiDAR uses a considerable amount of power which could kill Spots batteries.	The complete usage of Spots batteries could result in a mission failure.	100	Spot's batteries are not kept under close watch while using the LiDAR system.	10	Spot will not be able to operate the LiDAR system under a certain battery level.	95	95000	Limit the usage of the LiDAR system to insure that Spot returns to the charging dock with excess battery life.
Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC)	Insufficient power or battery to operate SHERLOC	Spot will be unable to gather data, possibly resulting in a mission failure.	90	Low battery or damage to on-board computer	5	Let Spot charge to full power before starting a mission	100	45000	Spot can recharge at the power station and operate as normal once sufficient power is obtained
	Mechanical arm becomes non-operational	SHERLOC can't be moved close to a sample for examination	60	Damage to the mechanical arm	30	Improved object detection so Spot can maneuver arm to avoid damage	95	171000	Samples can still be observed, but the accuracy of the data may be reduced if SHERLOC is not close enough to a sample
	Flashlight stops working	Spot will be unable to example samples for biosignatures	80	Low battery or damage to laser	10	Additional flashlight for redundancy and hard casing for SHERLOC to increase durability	100	80000	A backup flashlight should enable Spot to continue exploration and gather data to some capacity

4.1.6. Performance Characteristics

NAMI combines several types of instrumentation and technology from previous successful missions. Every component will be rigorously tested to ensure its ability to withstand conditions such as radiation, pressure changes, temperature changes at the end of the Martian summer in addition to the rapid changes in acceleration that will inevitably occur during the mission. To accomplish this, the Jet Propulsion Laboratory will perform a range of vibrational tests, pressure tests, and thermal tests to ensure that NAMI is capable of operating in a Martian environment.

SHERLOC has been developed since the conception of the Perseverance Rover in 2012. Its Raman spectroscope has been flight proven and engineered to survive the lengthy trip to Mars, endure the harsh EDL during the primary mission's descent, as well as endure severe weather conditions on Mars ranging from heavy dust storms and remain operational in temperatures as low as -80°C. Furthermore, SHERLOC is mounted on a hexapod arrangement of spring-loaded struts that help dampen the vibrations it might encounter during the duration of its mission. Several tests have also been conducted to ensure that the spectroscopy laser is able to fire the required voltage consistently at all operating temperatures and pressures by using a Spectroscopy State of Health Calibration mode, which analyzes the full range of spectra on the SHERLOC instrument.

4.2. Science Value

4.2.1. Science Payload Objectives

NAMI intends to assess an assortment of cave formations to identify their mineral and chemical composition. The use of onboard spectrometry-centric instruments, in addition to detection equipment to validate NAMI's findings, will allow NAMI to determine the chemical and mineral composition of a Martian cave. This data not only provides a baseline for future subterranean missions but also contains detailed records of the Martian climate, useful mineral deposits for future missions, and a detailed history of the presence of life.

NAMI is equipped to search for microbial life in targeted segments of 50.8 meters, providing a thorough assortment of data on targeted sites. These segments of data will be used to develop a subterranean map containing chemical distributions and mineral compositions. This data will be analyzed and interpreted to identify notable chemical compounds, allowing it to highlight the differences in mineral distribution across the subterranean surface. Chemical compounds such as organic carbonyl groups, are identifiable through NAMI's instrumentation suite. Furthermore, elevated levels of methane on the surface of Mars, as identified by the Curiosity rover, peaking during Martian northern summer and southern winter in the Gale Crater may be more present on the subterranean surface, indicating the presence of active life from an unidentified source. Sulfide oxidation has also been identified as a potential metabolic driving force for Martian life in the Noachian period, and molecules capable of sulfur redox reactions that occur with the oxygen and nitrogen in the Martian atmosphere have been taken under consideration. Complex structures like amino acids or lipids may also be present in subterranean Martian cave structures. Amino acids and lipids combine to form proteins, the building blocks of cellular material, and may even determine the presence of cellular membranes. NAMI is equipped to identify all of these materials on the Martian subsurface to meet the goal of identifying minerals and biosignatures on Mars.

Evaluating data provided by these biosignatures allows NAMI to assess the following: whether life is already present, whether life has thrived in Mars in the past, and whether Martian caves are a suitable location for in-situ resource utilization and shelter in the future. Providing thorough, in-depth molecular data on these resources paves the way for Martian missions that intend to build upon NAMI's data, using the data extracted from the Martian subsurface. Overall, NAMI creates an important baseline for the presence of biosignatures and mineral deposits on the Martian subsurface.

4.2.2. Science Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Instrument	Mission Requirements
		Physical Parameters	Observables				
Do Martian caves provide sufficient shelter to sustain primitive life, or protect fossilized biomarkers denoting past life?	Determine if chemical biosignatures are present in Martian lava tubes	Identify complex organic compounds and minerals like various levels of carbon (C), hydrogen (H), oxygen (O), Sulfur (S), and nitrogen (N) and their percent concentration by evaluating a <100 micron area.	Produce spectral data greater than 270 nm and identify spectral rings in the sample area, indicating high organic content.	Wavelength range:	250-600 nm	Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC)	System shall investigate biosignatures in Martian caves
				Integration time	1 sec		
				Sensitivity:	10-2 to below 10-4 w/w		
				Spatial resolution:	<100 µm		System will operate inside a Martian cave at -51.4°C
	Detect the presence of water ice directly, or through the existence of speleothems	Identify the many minerals that make up speleothems such as Stalactite, Helictites, and Stalagmites.	Identify significant cave features in a 20-50 meter area of subterranean cave using the LiDAR subsystem in a spectral range of 250-360 nm.	Measurement range:	100 m	Enhanced Autonomy Payload (EAP)	System will analyze surface materials in martian caves
				Field of view:	15° to -15° (vertical); 360° (horizontal)		
				Laser Wavelength:	903 nm		
				Rotation Rate:	5-20 Hz		

4.2.3. Payload Success Criteria

Criteria 1:

As described in 1.2.3, the identification of known biomarker(s) or complex organic compounds and minerals containing various levels of Carbon (C), Hydrogen (H), etc. will grant a successful mission. With that being said, NAMI will have Raman, fluorescence spectrometers, and a laser on SHERLOC to search for organics and minerals such as Carbon, hydrogen, Sulfur, etc. SHERLOC will measure mineralogy and the distribution, as well as the types of organic preserved within the cave and correlate them to textual features. Discovering minerals within Mars subsurface will provide the various ways to research further, such as if the minerals have been altered in any way relating to a watery environment, resulting in signs of past microbial life. This criteria is considered fulfilled if numerous organic bioindicators are identified in the mineralogy of the subterranean surface.

Criteria 2:

NAMI will not only possess a built-in WATSON camera on SHERLOC for science imaging, but will also have a mounted LiDAR sensor within EAP for navigation. If the selected cave site was once below a water table of saturation before reaching a level of aeration, speleothems are likely to have formed. A discovery of speleothem formations would directly confirm that Mars has contained water in its past life and additional spectral analysis of its chemical composition, capable of identifying the carbon dioxide (CO_2) present in water ice, will fulfill this criteria if abundant levels of CO_2 are identified. In order to confirm the structure and related formations inside the cave, NAMI shall identify carbon and various other minerals that make up speleothems with SHERLOC's UV-induced fluorescence. Its Raman spectrometer is sensitive to aromatic organics which enables the detection and classification of minerals with grain sizes below 20μm grains so minerals and organics can be detected.

4.2.4. Experimental Logic, Approach, and Method of Investigation

Biosignatures may be detectable in subterranean environments. To confirm this hypothesis, NAMI uses a suite of scientific instruments, which are used to identify the molecular and mineral components of the martian subsurface through spectroscopy. More specifically, the payload acquires scientific deliverables by using a method called Raman spectroscopy. This process uses the scattering of fluorescent light to determine the presence of organic materials and identify the mineralogy of the Martian surface. NAMI will be used to search areas greater than 270 nm containing spectral rings, which indicate an area of high organic content. The molecules will be differentiated by using a deep UV laser to generate photons, which will identify the mineralogy of the Martian subsurface.

The experimental procedure alternates between three processes: surveying, data transfer, and spectral sampling. To collect a sample, a target sight will be identified based on the LiDAR data provided by Spot during its first survey into a martian cave, allowing Team Oddity to identify significant features in the cave's interior. Once Spot autonomously constructs a three dimensional model of the interior cave every 25-50 meters, the team will analyze the data from the first cave segment and determine areas of interest. Areas consisting of better terrain will have a larger 50 meter analysis, while more treacherous terrain will have a smaller region of 25 meters. The team will also direct Spot to obtain LiDAR data of another 25-50 meter area within the subsurface while performing their analysis. Spot will use SHERLOC on the first site before conducting its second survey. When spectral analysis begins for the first time, Spot will return immediately with this spectral data to verify that equipment is operational, and this data will be distributed to the team as points on the LiDAR map generated by Spot.

When Spot returns from its preliminary investigation, it will receive commands from Team Oddity to perform an analysis on more cave features while Spot uploads spectral data from the first site. Spot will also receive its next two sites to survey before moving out to perform one analysis and survey two more 25-50 meter segments. NAMI will continue to alternate between surveying and spectral analysis to provide as much data on the martian subsurface as possible in a small operational window.

The target cave site was determined by analyzing elevation, minimum and maximum temperature, average temperature, the availability of hydrogen in that particular area of the martian surface, and slope. Each piece of data comes from a combination of orbiters and equipment including HiRISE, CTX, HEND maps, and elevation and thermal

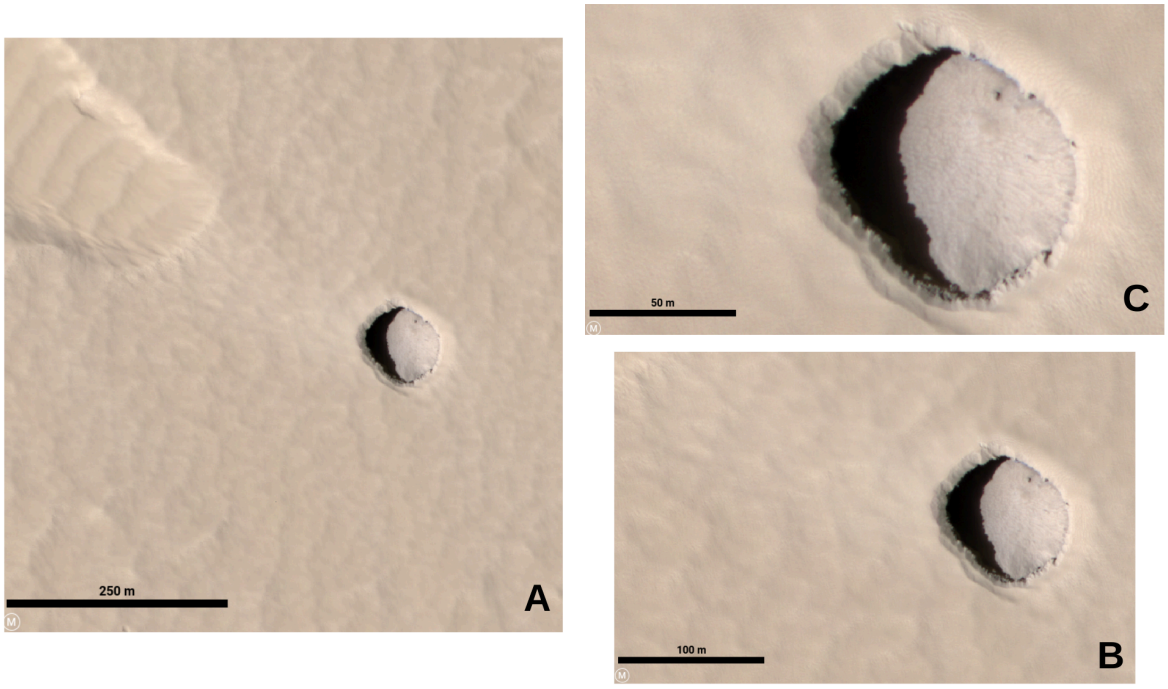
data maps using MOLA and HRSC tools available on the Java Mission-planning and Analysis for Remote Sensing (JMARS) application. Each site was identified by Jung et al. (2014) in an investigation of data from CTX and HiRISE.

The following table summarizes the cave site candidates for NAMI. Team Oddity assessed these caves to determine the most optimal option for Spot to enter and exit the cave without exceeding a 30-degree slope limit.

	Site A	Site B	Site C	Site D	Site E
Elevation:	approx. 7,470 m	7,463-7,488 m	approx. 7,444 m	6,795-6,801 m	8,195-8,203 m
Maximum Surface Temp:	22.6°C (296K)	22.3°C (295K)	22.°3C (295K)	22.5°C (296K)	22.4°C (296K)
Minimum Surface Temp:	-120.6°C (153K)	-119.6°C (154K)	-119.6°C (154K)	-119.5°C (154K)	-113.6°C (160K)
Average Surface Temp:	-52.2°C (221K)	-51.2°C (222K)	-51.2°C (222K)	-51.4°C (222K)	-48.6°C (225K)
Hydrogen Distribution:	0.68 - Medial	0.68 - Medial	0.68 - Medial	0.673 - Medial	0.58 to 0.72 - Low
Slope	0.896 (Instrument: HRSC MOLA Blended DEM Slope (200m) V2 - Inspect Tool;) - Likely Meets Parameters	Data Points - 0.833 (cave entrance, south end of the cave), 0.781 (central point) (Instrument: HRSC MOLA Blended DEM Slope (200m) V2 - Inspect Tool;) - Possibly Meets Parameters [Note: Despite the numerical data provided, usage of this sight increases risk because the visual scope of the slope is limited.]	0.561 (Instrument: HRSC MOLA Blended DEM Slope (200m) V2 - Inspect Tool;) - Possibly Meets Parameters [Note: Despite the numerical data provided, usage of this sight increases risk because the visual scope of the slope is limited.]	0.39 (edge of the cave), 4.23 (edge of shadowed area), 4.84 (shadowed region) (Instrument: HRSC MOLA Blended DEM Slope (200m) V2 - Inspect Tool;) - Likely Meets Parameters	Data Points - 3.07 degrees (cave entrance, end of the green line), 2.83 degrees (central converging point), 2.75 degrees (cave interior) (Instrument: HRSC MOLA Blended DEM Slope (200m) V2 - Inspect Tool;) - Likely Meets Parameters

Site A is located at a longitude of 244.26° and -1.29° with a 50 meter width. Site B is located at a longitude of 244.28° and a latitude of -1.09° and also has a 50 meter width. Site C is located near Site B at a longitude of 244.27° and a latitude of -1.09°. Site D, a primary candidate for NAMI, is located at a 241.58° longitude and a -1.86° latitude with an 80 meter width. Finally, Site E is located at a longitude of 249.21° and a latitude of 0.33° with a 100 meter width. Other sides remained outside of our range of consideration, positioned either too far away from the equator, identified beyond the scope 10 to 10° latitude, or identified to be in a hazardous region that would not be optimal for a mission.

After reviewing the data, Team Oddity determined that Site D is the ideal candidate for our mission. Due to vehicle constraints, the area needed to have a slope less than 30°, a medial to high hydrogen distribution to maximize the detection of potential biosignatures, a stable temperature for optimal operation, and an area of intermediate elevation, which has been previously identified to be optimal for life. Site D contains the best elevation level, making the area to reach. It also provides the most visible data of the cave site in addition to a medial hydrogen count. It also has the second warmest temperatures out of all the cave sites.



This image shows different resolutions of Cave Site D using JMARS. A evaluates data at 6,636 pixels. B evaluates data at 131,072 pixels. C evaluates data at 262,144 pixels.

Imagery of Cave Site D allows Team Oddity to determine the potential path of NAMI and its entry point during descent. After examining the site and varying resolutions, entry will most likely occur to the east of the cave site and follow a path Northwest. Spot will egress the cave simply by walking in as the slope is within the vehicle's tolerance level.

4.2.5. Testing and Calibration Measurements

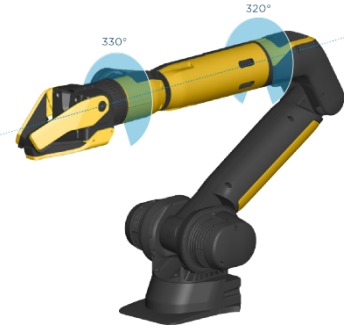
SHERLOC will use the same calibration method it uses normally. For the Perseverance mission, the calibration target carried pieces of spacesuit material. This will be discarded, as the test has already been conducted on Perseverance. The LiDAR will be tested by NAMI scanning itself, and the power station immediately after landing. This process will be quick as NAMI cannot stay on the surface, and the data will be processed once inside. The power station size is known to a high degree of accuracy, so it will be used as a scanning target. The charging cable will be striped with visual markers spaced apart at regular intervals, the LiDAR will also scan this. In the event that the scans start to drift, NAMI will compare current scan data with previous data and adjust so the current scan matches the previous scan.

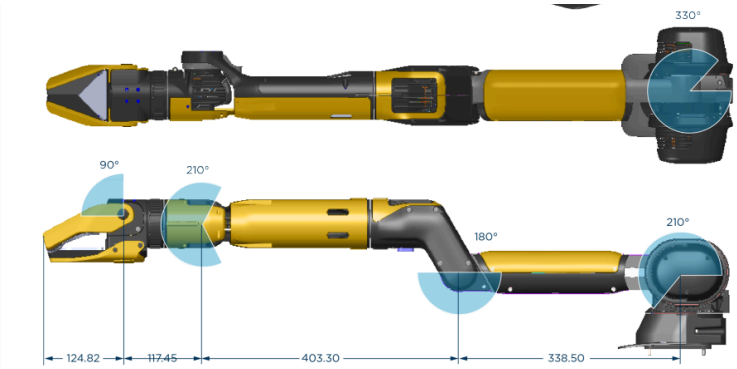
4.2.6. Precision and Accuracy of Instrumentation

- **EAP LiDAR:**
  - The LiDAR model is Velodyne VLP-16 which is preloaded in Spot CORE.
  - 16 sensor channels.
  - LiDAR has a measurement range of 100m and an accuracy of +/-3cm.
  - Its laser wavelength is 903 nanometers (nm).
  - Ingress Protection of IP67.
  - Vertical field of view is 30° (-15° to 15°) and an angular resolution of 2°.
  - Horizontal field of view is 360° with an angular resolution of 0.1°-0.4°.

- **SHERLOC:**
  - SHERLOC has Deep UV (DUV) resonance Raman and fluorescence spectrometer utilizing a 248.6 nanometers (nm) DUV.
  - <100 micron spot size.
  - autofocusing /scanning optical system with spatial resolution of 30 micrometers (µm).
  - SHERLOC operates over a 7x7mm area through use of an internal scanning mirror.
  - 500 micron depth of view.
  - DUV fluorescence enables detection at or below 10-6 weight-for-weight (w/w) at <100 micrometers (µm) spatial scales.
  - DUV Raman enables detection below 20 micrometers (µm) grains.
  - SHERLOC creates a fluorescence region from 250-270 nanometers (nm).

- **Spot Arm:**
  - Max Reach height of 1800 mm (70.9 in).
  - Max Drag Capacity of 25 kg (55.1 lbs).
  - Max Lift Capacity of 5 kg (11 lbs).
  - Max endpoint speed of 10 m/s.
  - Spot Joint ranges:





4.2.7. Expected Data & Analysis

NAMI is expected to collect point-cloud data from the LiDAR scanner. For the detection of biosignatures, Team Oddity intends to use images from the WATSON camera on SHERLOC and spectroscopy data from SHERLOC to detect bioindicators. The LiDAR data will be processed into the physical structure of the cave in addition to the colorized images provided by the WATSON camera on SHERLOC. The spectra from the SHERLOC data will be analyzed with this in mind:

- Deep UV-Induced Florence is very sensitive to condensed carbon and aromatic organics.
- Deep UV Raman enables detection and classification of minerals relevant to aqueous chemistry.
- If the sample fluoresces and produces spectral rings, it likely has organic compounds.
- Organic compounds are detected at greater than 270 nm.

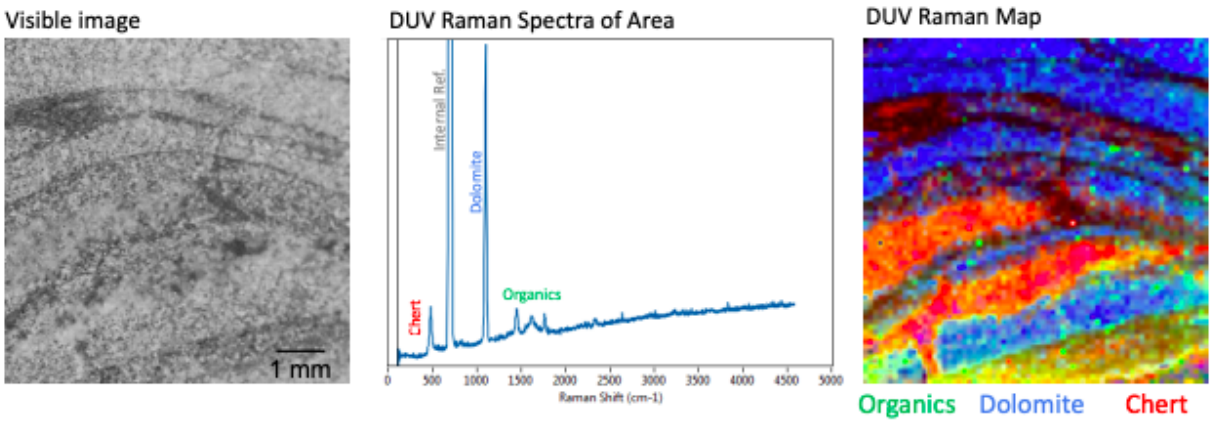


Figure 4 Example of SHERLOC science on the Stelley Pool Stromatolite using the lab breadboard MOBIUS instrument [2][5].

The Sherloc sample data is provided by the Software Interface Specification provided by the Jet Propulsion Laboratory (JPL) for the Mars 2022 mission and will be used by NAMI to identify biomarkers in the subterranean surface. Manual verification and validation will be performed by random tests during the mission and general tests on the system. Automated test will examine NAMI's scientific instrumentation consistency against the data product, NAMI's database, and ensuring that the data is adjusted for the time it's received on Earth.

5. Safety

5.1. Personnel Safety

5.1.1. Safety Officer

The safety officer for this mission is Aidan Byrne. Aidan Byrne has completed 21 hours of OSHA safety training. The safety officer's first priority is to keep all personnel safe and unharmed. Furthermore, the safety officer is responsible for making sure that the materials and equipment are not damaged. Due to the large number of hazards present during the construction and testing of the payload, all tasks must be executed and handled with care at the safety officer's discretion.

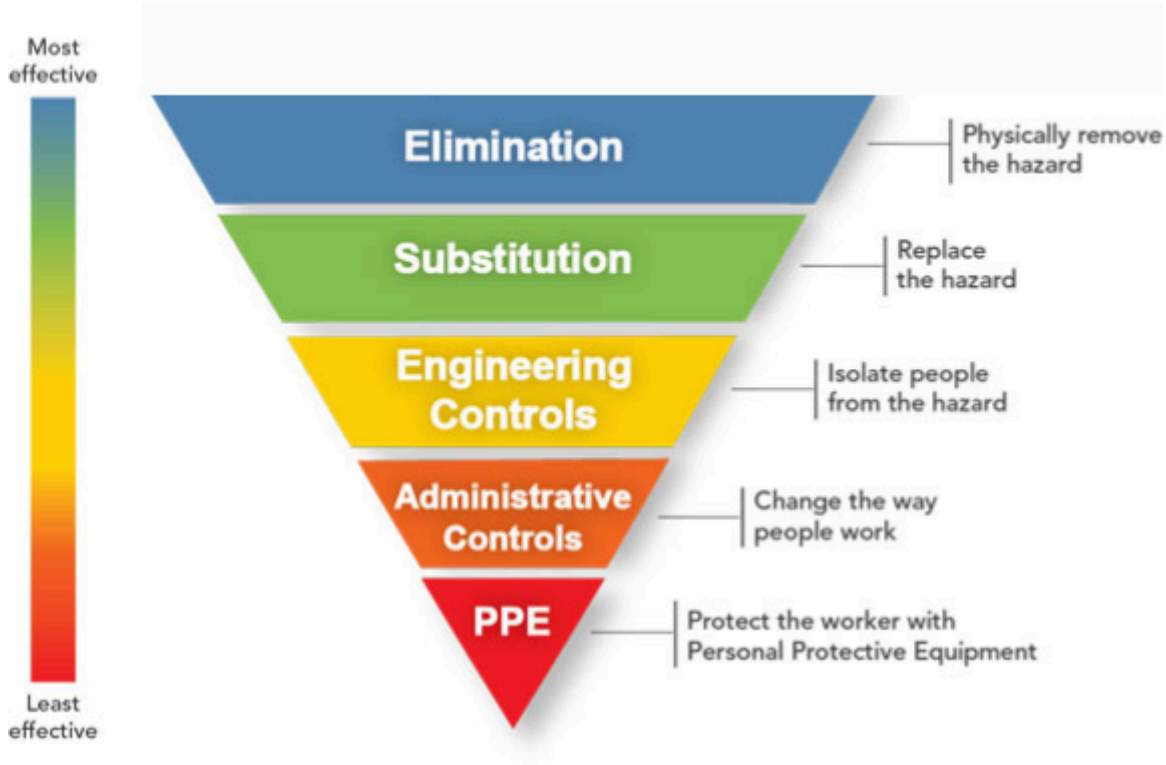
5.1.2. Personnel Hazards

The main hazards personnel will face are in the manufacturing, integration, and testing phases of the mission. The following table highlights the avoidable safety hazards associated with each phase of the mission and their possible causes.

Phase	Cuts	Falls	Shocks	Burns	Internal	Collisions	Radiation
Manufacturing	Burrs from machining	Slick surfaces or spills	Loose wire connections	Chemical exposure	Chemical exposure	Truck operation	From heating chucks
	Blades	Tripping on wires	Conductive liquids	Flammables/ volatiles	Dust inhalation	Forklift operation	-
	Power tools	Falling off equipment	Faulty equipment	Welding injury	Fiber inhalation	-	-
	Composite production	-	Short circuits	-	Gaseous exposure	-	-
Integration	Power tools	Slick surfaces or spills	Loose wire connections	Chemical exposure	Chemical exposure	Truck operation	From heating chucks
	Wire Insulation	Tripping on wires	Flammable materials	Welding injury	Dust inhalation	Forklift operation	-
	-	Falling off equipment	Faulty equipment	-	Fiber inhalation	-	-
	-	-	Short circuits	-	Gaseous exposure	-	-
Testing	Scrapes	-	Loose wire connections	-	-	Transportation	From heating chucks
	-	-	Short circuits	-	-	-	Fluorescence testing

5.1.3. Hazard Mitigation

These hazards are dangerous, but can be avoided. To keep all team members as safe as possible, a plan must be followed. The industry standard for hazard mitigation is called the “Hierarchy of Controls” and will be followed when assessing risks & hazards. The following is the order of mitigation methods from most effective to least effective:



As the safety of team members is important, using the most effective technique is paramount. Where possible, hazard mitigation methods on the higher end of effectiveness (such as elimination and substitution) will be used, unless absolutely necessary.

The most dangerous manufacturing hazards are cuts and crushes. These are especially relevant with machining. PPE is not an option for either, wearing PPE can hinder these. While cut-proof gloves might stop you from getting cut with a knife, a lathe will pull them off along with your hand. A hard-hat might lessen the blow of a tool falling on your head, but will do nothing to stop a 2 ton block of steel. As these hazards are necessary and must be there to have work done, elimination and substitution are not possible. Engineering and administrative controls are the only effective, practical solution in this case, and must be implemented. Moving heavy objects in certain lanes is a good way to get people away from the hazard, and making employees aware of when heavy objects

are moving is a great way to mitigate that hazard. Where possible, CNC mills should be substituted for manual mills. CNC mills get employees away from hazardous rotating objects, and protects employees' physical guard between them and the machine.

In the integration phase, the biggest hazards are crushes and shocks. Crushes will be dealt with in the same manner described in the manufacturing hazard mitigation above. Shocks are especially prevalent when assembling due to electrical systems. There can be live wires, and it is critical employees do not hurt themselves with them. Implementing administrative control methods and PPE is the best way to deal with this. Informing employees that electrical systems are hot is critical and must be done every time. Class E hard-hats and electrician’s gloves should be worn when assembling electrical equipment.

The testing phase has multiple big hazards, such as crushes, extreme environments, and radiation/chemical hazards. Crushes will be dealt with in the same manner described in the manufacturing hazard mitigation above. Some test methods put areas big enough for a human to fit in extreme environments, such as a vacuum or very high/low temperatures. It is important that employees do not get stuck in these areas, as often they are environments where employees are required to go in order to complete their work. An engineering control method such as the lock-out tag-out method is an effective way to combat this. Any employees venturing into such areas must take with them a key that physically stops the testing equipment from starting. After tests are completed, items being tested may be very hot or cold and should not be touched until a thermometer says they are in a safe temperature range. A hand near the object and trying to “feel” the radiant heat/cold is not an effective method of determining temperature. Radiation and chemical hazards also exist, and inspection methods can utilize radiation and chemical hazards. Employees will be kept away from radiation hazards during tests. Often, it is impossible to implement anything but PPE measures when using chemical inspection methods, so Tyvek® suits will be worn when using such methods.

6. Activity Plan

6.1. Budget

With a projected mission life span of approximately five years, NAMI has an estimated budget of **$180,447,536.13**. This quote meets the necessary budget requirement and categorizes NAMI as a discovery-class mission. A narrative of how the mission budget is allocated is given below. A complete budget summary can be found at the end of this section.

Personnel

The personnel requirements for mission NAMI vary as the mission progresses through the design and fabrication stages. During the first year, the team's main focus will be on completing the Critical Design Review (CDR). A large team is not required to fulfill this deliverable. The second and third year will heavily transition into manufacturing and fabrication. Therefore, a large engineering team will be required, along with more management staff to oversee the various operations happening simultaneously. The fourth and fifth year of mission NAMI will consist of integration and testing, as well as the mission execution itself. In other words, there will be a heavy emphasis on completing science-related milestones during the fourth year, which will require a large team of scientists. The fifth year will have smaller science and engineering teams as mission launch and decommissioning will not require a lot of personnel.

The specific number of team members, along with related costs is given below. Note that this estimate is determined assuming a full-time commitment from all hired personnel and also includes a 28% margin for salaries and employee related expenses (ERE).

# of Team Members	FY 1	FY 2	FY 3	FY 4	FY 5
Science Personnel:	15	10	10	25	15
Engineering Personnel:	10	25	25	15	10
Administration Personnel:	5	5	5	5	5
Management Personnel:	3	5	5	5	3

	Yr1 Total	Yr2 Total	Yr3 Total	Yr4 Total	Yr5 Total	Total
PERSONNEL						
Science Personnel	$ 1,200,000.00	$ 800,000.00	$ 800,000.00	$ 2,000,000.00	$ 1,200,000.00	**$ 6,000,000.00**
Engineering Personnel	$ 800,000.00	$ 2,000,000.00	$ 2,000,000.00	$ 1,200,000.00	$ 800,000.00	**$ 6,800,000.00**
Administration Personnel	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	**$ 2,000,000.00**
Project Management:	$ 750,000.00	$ 750,000.00	$ 750,000.00	$ 750,000.00	$ 750,000.00	**$ 3,750,000.00**
Total Salaries	$ 3,150,000.00	$ 3,950,000.00	$ 3,950,000.00	$ 4,350,000.00	$ 3,150,000.00	**$ 18,550,000.00**
Total ERE	$ 879,165.00	$ 1,102,445.00	$ 1,102,445.00	$ 1,214,085.00	$ 879,165.00	**$ 5,177,305.00**
TOTAL PERSONNEL	$ 4,029,165.00	$ 5,052,445.00	$ 5,052,445.00	$ 5,564,085.00	$ 4,029,165.00	**$ 23,727,305.00**

Travel

Any necessary travel related to mission NAMI will be funded through the project budget. The first year will have minimal travel related to outreach events, conferences, and promoting any marketing related to mission NAMI. The second year will be completely focused on manufacturing, and will not require any travel. It is possible that meetings with Subject Matter Experts (SMEs) are crucial to the manufacturing of the vehicle, or to train engineers for certain scopes of work. Therefore, a travel budget will be set aside for the third year of the project. The last of the travel-related expenses will not be used until the fifth and final year of the mission, when the team will commute to the launch site for mission execution. There will be additional costs related to more conferences as well as outreach at K-12 school districts to spark interest in mission NAMI's launch and significance. A summary of travel-related costs is given below:

Year	Yr1 Total	Yr2 Total	Yr3 Total	Yr4 Total	Yr5 Total	Total
TRAVEL						
Flight Costs	$ 75,000.00	$ -	$ 75,000.00	$ -	$ 250,000.00	**$ 400,000.00**
Hotel Costs	$ 50,000.00	$ -	$ 50,000.00	$ -	$ 150,000.00	**$ 250,000.00**
Transportation Cost	$ 25,000.00	$ -	$ 25,000.00	$ -	$ 75,000.00	**$ 125,000.00**
Per Diem Cost	$ 10,000.00	$ -	$ 10,000.00	$ -	$ 50,000.00	**$ 70,000.00**
Total Travel Costs	$ 160,000.00	$ -	$ 160,000.00	$ -	$ 525,000.00	**$ 845,000.00**

Outreach

Outreach is essential in promoting mission NAMI and gaining public-traction. The goal is to use social media, conference and K-12 school presentations, and well-designed merch to make mission NAMI visible to the public and garner support for related Mars-exploration missions.

The first year of the mission will require a heavy focus on social media presence, conference presentations, and merchandise distribution. For example, designing a website for mission NAMI will be an informative way for the general public to learn about the mission objectives and get up to date information about its progress and development. Buying a website domain, materials for merchandise, and renting venues for conferences will require an allocated budget. The second and third year will be primarily focused on social media and website updates of the building stages. During the fourth year, mission NAMI will need more outreach to promote the upcoming launch with similar measures as the first year. There will be additional costs related to K-12 school scholarships and presentations. Lastly, the final year of the mission will have a livestream for the mission launch, and more social media updates upon arrival at the cave site. A cost summary for this scope is given below, and a more detailed outreach plan can be found in section 6.3.

Year	Yr1 Total	Yr2 Total	Yr3 Total	Yr4 Total	Yr5 Total	Total
OUTREACH						
Outreach Material Costs	$ 100,000.00	$ 25,000.00	$ 25,000.00	$ 200,000.00	$ 50,000.00	**$ 400,000.00**
Outreach Venue Costs	$ 250,000.00	$ -	$ -	$ 500,000.00	$ -	**$ 750,000.00**
Total Outreach Costs	$ 350,000.00	$ 25,000.00	$ 25,000.00	$ 700,000.00	$ 50,000.00	**$ 1,150,000.00**

Direct Costs

The majority of the budget for mission NAMI is invested in the direct costs associated with manufacturing and testing. These are split by payload and subsystem, and also include margin costs to provide a healthy buffer in case of unforeseen hiccups in the schedule.

Costs associated with science instruments and all subsystems are derived using the NASA Instrument Cost Model (NICM), and divided into 50%, 33%, and 17% between the first three years. This is primarily the cost of purchasing materials for each sub

category. Because the fourth and fifth years should be primarily focused on integration and testing, there is no predicted need for material purchase. Manufacturing facility costs are evenly divided between the second and third year of mission NAMI. These two years focus on the building stages of the vehicle, whereas the fourth and fifth years focus on required testing. Therefore, 33% of the testing facilities budget is allocated for the fourth year, and 67% for the fifth year. It may be noted that testing facility costs calculated using Cost-Estimating Relationships (CERs) were given per unit. It is assumed that each unit will be tested twice, once during prototyping, and again after final assembly is complete. A run down of direct costs specific to each science instrument and subsystem is given in the Appendix, and a summary of direct costs is included below.

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Cumulative Total
DIRECT COSTS						
|> Science Instrumentation	$ 3,135,847.51	$ 2,090,565.01	$ 1,045,282.50	$ -	$ -	**$ 6,271,695.03**
|> Other Payload Costs	$ 153,524.00	$ 102,349.33	$ 51,174.67	$ -	$ -	**$ 307,048.00**
Total Payload Costs	$ 3,289,371.51	$ 2,192,914.34	$ 1,096,457.17	$ -	$ -	**$ 6,578,743.03**
|> Mechanical Subsystem	$ 6,341,890.18	$ 4,227,926.79	$ 2,113,963.39	$ -	$ -	**$ 12,683,780.36**
|> Power Subsystem	$ 150,000.00	$ 100,000.00	$ 50,000.00	$ -	$ -	**$ 300,000.00**
|> Thermal Control Subsystem	$ 724,893.08	$ 483,262.06	$ 241,631.03	$ -	$ -	**$ 1,449,786.17**
|> Comms/Data Handling Subsystem	$ 1,811,100.71	$ 1,207,400.48	$ 603,700.24	$ -	$ -	**$ 3,622,201.43**
Total Vehicle Costs	$ 9,027,883.98	$ 6,018,589.32	$ 3,009,294.66	$ -	$ -	**$ 18,055,767.95**
|> Manufacturing Facility Cost	$ -	$ 16,000,000.00	$ 16,000,000.00	$ -	$ -	**$ 32,000,000.00**
|> Test Facility Cost	$ -	$ -	$ -	$ 5,133,333.33	$ 12,800,000.00	**$ 17,933,333.33**
Total Facilities Costs	$ -	$ 16,000,000.00	$ 16,000,000.00	$ 5,133,333.33	$ 12,800,000.00	**$ 49,933,333.33**

Margins & Final Costs

Before calculating the final costs for mission NAMI, a considerable amount of margin was applied for various categories. This includes a 10% margin for Facilities and Administrative Costs (F&A), 50% for manufacturing, and 30% for total cost. ERE margin is already accounted for in Personnel costs. Accounting for these margins along with each category listed above, the final cost for mission NAMI is evaluated at $180,447,536.13 as shown in the table below. This may be subject to change as more research is done during the critical design review (CDR) process.

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Cumulative Total
Manufacturing Margin	$ 6,158,627.75	$ 12,105,751.83	$ 10,052,875.92	$ 2,566,666.67	$ 6,400,000.00	**$ 37,283,922.16**
Total Direct Costs	$ 18,475,883.24	$ 36,317,255.49	$ 30,158,627.75	$ 7,700,000.00	$ 19,200,000.00	**$ 111,851,766.48**
Total MTDC	$ 6,158,627.75	$ 4,105,751.83	$ 2,052,875.92	$ -	$ -	**$ 12,317,255.49**
FINAL COST CALCULATIONS						
Total F&A	$ 615,862.77	$ 410,575.18	$ 205,287.59	$ -	$ -	**$ 1,231,725.55**
Total Projected Cost	$ 23,630,911.01	$ 41,805,275.67	$ 35,601,360.34	$ 13,964,085.00	$ 23,804,165.00	**$ 138,805,797.02**
Total Cost Margin	$ 7,089,273.30	$ 12,541,582.70	$ 10,680,408.10	$ 4,189,225.50	$ 7,141,249.50	**$ 41,641,739.11**
Total Project Cost	$ 30,720,184.32	$ 54,346,858.38	$ 46,281,768.44	$ 18,153,310.50	$ 30,945,414.50	**$ 180,447,536.13**

With a total project cost of $180,447,536.13, mission NAMI falls well within the $300 million budget requirement for the given mission task with $119,552,463.87 to spare. This is primarily thanks to the high-TRL technology and components used. For instance, using heritage science technology like SHERLOC allows for higher confidence and success probability while driving the costs lower. Furthermore, using Spot allows the engineering team to focus on upgrading an existing chassis to match the thermal and power constraints of the mission rather than engineering an expensive and time-consuming design from scratch.

The following table offers a justification summary for how each cost was determined in evaluating the final budget for mission NAMI. A complete budget summary is also included in the Appendix for reference.

PERSONNEL					
Science Personnel	10	15	15	25	10
Engineering Personnel	10	25	25	15	10
Administration Personnel	5	5	5	5	5
Project Management:	3	5	5	5	3
TRAVEL					
How much expected travel?	low	none	low	none	high
Reason for travel	outreach	-	SME meetings	-	launch, outreach
OUTREACH					
Outreach Plans?	Introduce Mission NAMI	Update on fabrication development	Update on fabrication development	Promote NAMI and upcoming launch	Updates about launch and mission execution
Materials?	Social media, posters, presentations, swag	Social Medial Ads	Social Medial Ads	Social media, posters, presentations, swag	Social Medial Ads
Venue Cost	yes	no	no	yes	no
DIRECT COSTS					
|> Science Instrumentation	high	mid	low	none	none
|> Mechanical Subsystem	high	mid	low	none	none
|> Power Subsystem	high	mid	low	none	none
|> Thermal Control Subsystem	high	mid	low	none	none
|> C&DH Subsystem	high	mid	low	none	none
|> Manufacturing Facility Cost	none	high	high	none	none
|> Test Facility Cost	none	none	none	low	high

6.2. Schedule

The full five-year mission schedule for NAMI offers a timeline of key milestones for the development and execution of the mission. These include the submission of the mission concepts and requirements review (MCRR), presentation of the preliminary design review (PDR), the critical design review (CDR), Phases C&D, launch, arrival, mission activities, and decommissioning. The Gantt chart in the Appendix is used to illustrate this schedule, with margins included for the completion of each task.

The schedule is broken down into 11 tasks. The first two tasks are focused on the completion of the Mission Concept and Requirements Review (MCRR) and the PDR. These tasks are part of Phases A & B of mission NAMI, and are allotted a total of 94 days for completion.

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
1	**Completion of Mission Concept and Requirements Review (MCRR)**		100%	5/31/22	6/20/22	21	3
1.1	Brainstorm mission statement	All	Complete	5/31/22	6/10/22	11	
1.2	Create Science Traceability Matrix (STM)	All	Complete	6/10/22	6/18/22	9	
1.3	Establish Requirements and Risks	All	Complete	6/10/22	6/18/22	9	
1.4	Determine Mission Name	All	Complete	6/14/22	6/18/22	5	
1.5	Schedule Margin			6/18/22	6/20/22	3	
1.6	◆ Submission of MCRR Final Draft		Complete	6/20/22	6/20/22	1	
2	**Completion of Preliminary Design Review (PDR) Presentation**		13%	6/22/22	9/2/22	73	8
2.1	Establish Safety Measures	Safety Officer	Complete	6/22/22	7/4/22	13	
2.2	Establish Preliminary Budget and Schedule	Business Officer	In Progress	6/22/22	7/4/22	13	
2.3	Develop an Outreach Plan and Create Required Media	Outreach Officer	In Progress	6/22/22	7/4/22	13	
2.4	Establish Vehicle & System Design	Engineering	In Progress	6/30/22	7/11/22	12	
2.5	Select of Science Instrumentation	Science	In Progress	6/30/22	7/11/22	12	
2.6	Implement MCRR FRAs in PDR	All	Not complete	7/11/22	7/24/22	14	
2.7	Revise and Submit final draft of PDR	All	Not complete	7/24/22	8/15/22	23	
2.8	Schedule Margin			8/15/22	8/22/22	8	
2.9	◆ PDR Presentation		Not complete	8/22/22	9/2/22	12	

Tasks 3-6 involve the completion of a Bill of Materials (BOM) that can be used to purchase any necessary materials for manufacturing. Finalized CAD models will also be prepared for any finite element analysis (FEA) as well as simulations. Overall instrument functionality and compatibility will also be tested using this simulation software. With a more concrete and finalized design, Phase C will be concluded with the CDR.

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
3	**Completion of Bill of Materials (BOM)**		0%	9/2/22	11/5/22	65	17
3.1	Determine vehicle manufacturing material	Engineering	Not complete	9/2/22	9/25/22	24	
3.2	Determine sensors and tools needed	Science, Engineering	Not complete	9/25/22	10/10/22	16	
3.3	Draft BOM	Business Officer	Not complete	10/10/22	10/20/22	11	
3.4	Schedule Margin			10/20/22	11/5/22	17	
3.5	◆ Completion of Material Purchase		Not complete	11/5/22	11/5/22	1	
4	**Completion of Final Vehicle Design**		0%	11/5/22	2/5/23	93	6
4.1	Draft first CAD model	Engineering	Not complete	11/5/22	11/30/22	26	
4.2	Conduct FEA and simulation-based testing	Engineering	Not complete	11/30/22	12/28/22	29	
4.3	Revise and Finalize Design	Engineering	Not complete	12/28/22	1/31/23	35	
4.4	Schedule Margin			1/31/23	2/5/23	6	
4.5	◆ Completion of PDM and Software set-up		Not complete	2/5/23	2/5/23	1	
5	**Instrument Functionality Testing**		0%	2/5/23	5/31/23	116	25
5.1	Perform EAP LIDAR Sensor Tests	Science	Not complete	2/5/23	3/7/23	31	
5.2	Perform SHERLOC Spectrometer Tests	Science	Not complete	3/7/23	4/6/23	31	
5.3	Perform Navigation Cameras and Sensor Tests	Science, Thermal Engineer	Not complete	4/6/23	5/6/23	31	
5.4	Schedule Margin			5/6/23	5/30/23	25	
5.5	◆ Completion of Instrument Testing		Not complete	5/30/23	5/31/23	2	
6	**Completion of Critical Design Review (CDR) Presentation**		0%	5/31/23	7/22/23	53	16
6.1	Revise any budget and schedule changes	Business Officer	Not complete	5/31/23	6/2/23	3	
6.2	Update old documentation	PM, DPM	Not complete	6/2/23	6/9/23	8	
6.3	First draft of CDR	All	Not complete	6/9/23	6/25/23	17	
6.4	Revise and write final draft of CDR	All	Not complete	6/25/23	7/5/23	11	
6.5	Schedule Margin			7/5/23	7/20/23	16	
6.6	◆ CDR Presentation		Not complete	7/20/23	7/22/23	3	

Once the CDR is completed, the mission will transition into Phase D. This includes the bulk of the system manufacturing, integration, and testing phases. System manufacturing has more than two years allotted to the fabrication of the chassis, as well as the assembly and installation of instruments and sensors. In reference to the Schedule Estimating Relationship (SERs) given for each subsystem instrument in the Appendix, most estimated time frames average approximately 36 months. Taking into account that this includes the PDR and earlier phases of the mission, the 36-month time estimate is knocked down by 10-12 months. Another reason for this accelerated timeline is to eliminate the assumption that all components need to be manufactured from scratch. By using high-TRL components and heritage science instruments like SHERLOC, most of the manufacturing time can be dedicated to installation rather than base-assembly operations.

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
7	**Completion of System Manufacturing**		0%	7/22/23	10/11/25	813	127
7.1	Manufacture / Upgrade Robot Chassis	Engineering	Not complete	7/22/23	4/20/24	274	
7.2	Install Power Systems	Engineering	Not complete	4/20/24	12/20/24	245	
7.3	Install Sensors	Science, Engineering	Not complete	10/20/24	6/1/25	225	
7.5	Schedule Margin			6/1/25	10/5/25	127	
7.6	◆ Final Assembly of System		Not complete	9/20/25	10/11/25	22	
8	**Execution of Software Integration**		0%	10/11/25	5/10/26	212	14
8.1	Write program for sensor detection	Engineering	Not complete	10/11/25	12/15/25	66	
8.2	Write program for maneuverability	Engineering	Not complete	12/15/25	2/18/26	66	
8.3	Write program for communication and navigation	Engineering	Not complete	2/18/26	4/25/26	67	
8.4	Schedule Margin			4/25/26	5/8/26	14	
8.5	◆ Completion of System Integration		Not complete	5/8/26	5/10/26	3	
9	**Test Final System**		0%	5/10/26	8/30/26	113	18
9.1	Perform Robot Movement Tests	Engineering	Not complete	5/10/26	6/9/26	31	
9.2	Perform Instrument & Sensor Tests	Science	Not complete	6/9/26	7/10/26	32	
9.3	Perform Power Tests	Engineering	Not complete	7/10/26	8/10/26	32	
9.4	Schedule Margin			8/10/26	8/27/26	18	

9.5	◆ Completion of Final Testing		Not complete	8/27/26	8/30/26	4	

Once the vehicle is completely manufactured and all subsystems and instruments are installed, the vehicle will be transported to the launch site and integrated into the primary payload. Mission launch is determined using data for available launch windows and slated for 11/24/2026, which will commence Phase E of mission NAMI.

Upon arrival at the cave site, all systems will be calibrated and be given a final check. Spot will be deployed along with the power station, and begin spelunking activities. Data will be transmitted back to the primary lander via the power station, and eventually back to mission control on Earth. Spot will use the power station in order to recharge and repeat numerous cycles of data collection and transfer before mission end of life. Decommissioning will begin shortly after, with margin for any necessary timeline adjustments.

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
10	**Installation of System**		0%	8/30/26	11/24/26	87	14
10.1	Install System onto Primary Payload	Engineering	Not complete	8/30/26	10/15/26	47	
10.2	Verify Mission Constraints are Met	PM, DPM	Not complete	10/15/26	11/1/26	18	
10.3	Transportation of Final Payload to Launch Site	All	Not complete	11/1/26	11/11/26	11	
10.4	Schedule Margin			11/11/26	11/24/26	14	
10.5	◆ MISSION LAUNCH		Not complete	11/24/26	11/24/26	1	
11	**Execution of Mission**		0%	11/24/26	9/21/27	302	38
11.1	Observe launch performance	All	Not complete	11/24/26	11/24/26	1	
11.2	Confirm Payload Arrival at Cave-site	All	Not complete	11/24/26	7/6/27	225	
11.3	Calibrate System	All	Not complete	7/6/27	8/5/27	31	
11.4	Deploy for cave-exploration activity	All	Not complete	8/5/27	8/7/27	3	
11.5	Retrieve data	All	Not complete	8/7/27	8/14/27	8	
11.6	Schedule Margin			8/14/27	9/20/27	38	
11.7	◆ Begin Decommissioning Process		Not complete	9/20/27	9/21/27	2	

6.3. Outreach Summary

To increase public awareness, NAMI will provide the public with a fixed website containing detailed information about the mission, social media platforms with regularly scheduled posts and outreach events, and regularly scheduled presentations to public areas of interest. NAMI's website will feature some basic information about the mission, the crew, and upcoming events. The design of the website will take the World Wide Web Consortium (W3C) standards for accessibility and multimedia configuration into account. This mission intends to have social media platforms on Twitter, Facebook, and Instagram to provide outreach. NAMI plans to increase outreach by regularly engaging with each platform during peak social media times, and regular presentations will be scheduled at underrepresented schools in rural and urban communities.

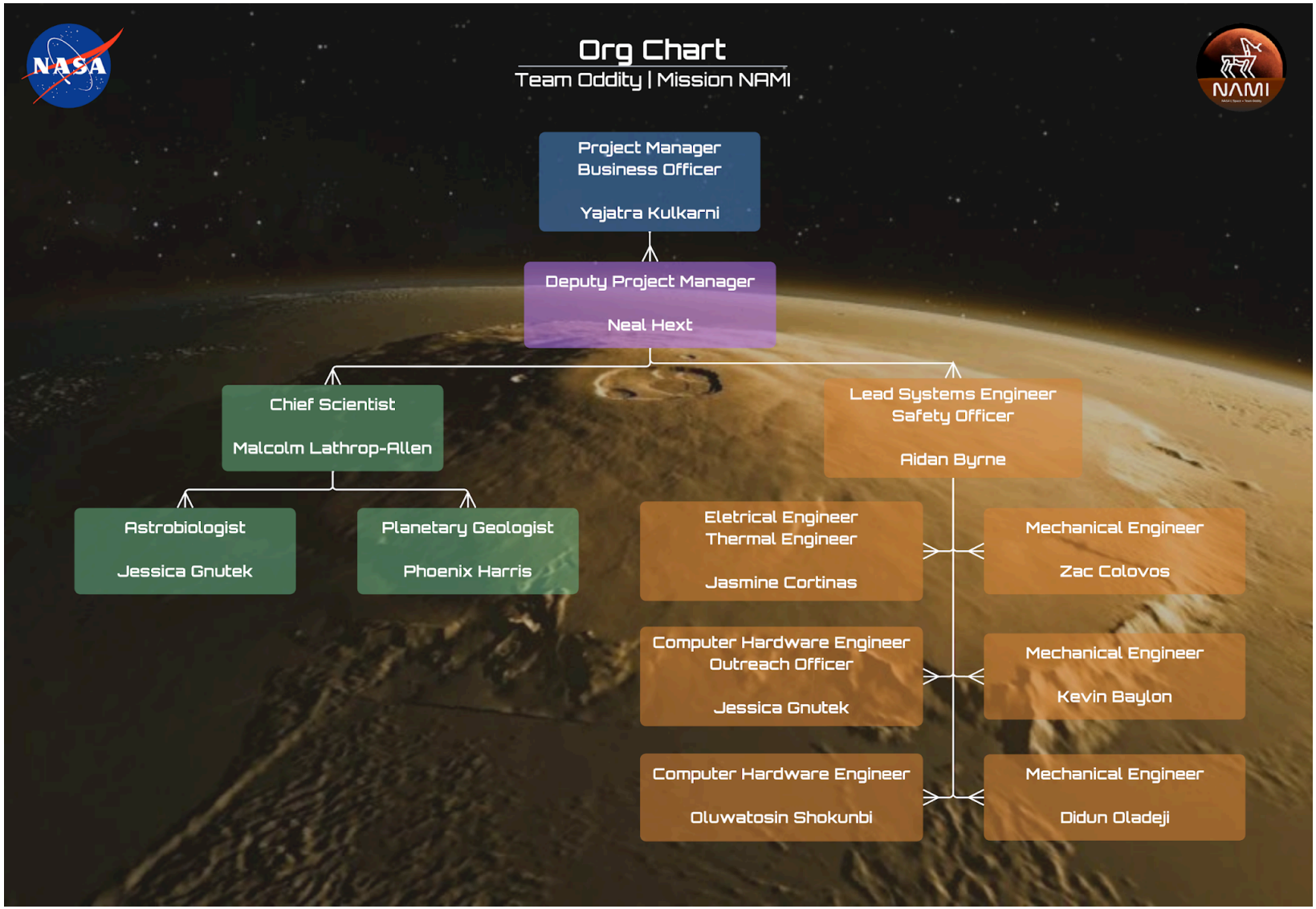
Priority will be given to institutions that have never had a speaker from previous NASA missions, institutions that represent underrepresented communities, and museums and libraries across the country.. NAMI will hold an essay competition to name the various tools available on NAMI, which will be flown on the rover during flight. Winners will be deliberated and determined at the beginning of August. Scholarships ranging from $2,000-$5,000 amount will be awarded to the winner of each grade level by the end of August 30th, 2023. The selected essays will be featured in Arizona State University for public display from September 15th, 2023 to December 2023.

6.4. Program Management Approach

Team Oddity's is composed of 11 team members, and organized with a traditional hierarchical structure. Project Manager Yajatra Kulkarni and Deputy Project Manager Neal Next were chosen as a result of a team election, while other leadership roles were assigned based on expressed interest and the assistance of team mentor Haile Brown.

The team members worked independently to research the project and write various sections of the PDR. A discord team server functioned as the primary form of communication between all members and the mentor. It was used to update all members on upcoming deadlines and newly added ideas. The server was also used as a form of democratic or consultative decision making when necessary. For example, a vote was taken on naming the mission and electing team leaders. On the other hand, autocratic decisions were made for formatting changes or administrative tasks that didn't impact the crux of the project. In cases of disputes, weekly meetings helped crease out any disagreements, and trade studies were used to determine best options for technical decisions regarding instrument or vehicle design selection.

An organization chart of the team below offers a more detailed overview of the roles of each member:



7. Conclusion

The goal of NAMI is to detect biosignatures by surveying a Martian cave site, as any current and or past life would be essential to proving that life is sustainable for future manned missions. NAMI uses Spot, a quadruped robot, developed by Boston Dynamics. NAMI will work to autonomously construct a 3D model of the subterranean environment and the collected data will be relayed back to the primary payload. This data will be used to confirm or refute the possibility of microbial life on Mars either pre-existing and/or current. NAMI will have a mass of 49.85 kilograms, a volume of 0.4715 cubic meters, and consume a total power of 606.8 watts per hour. NAMI will be equipped with an initial payload consisting of an EAP, a LiDAR sensor, SHERLOC, an arm, and an immobile power station which will be deployed outside of the cave entrance.

In the future Critical Design Review, radiation hardening for Spot will have to be more seriously considered. According to the customer, radiation would not be an issue as it was beyond the scope of this PDR. In the real world, this is unlikely and it is likely a significant amount of NAMI’s budget will have to be spent on radiation hardening. Spot's Runtime and recharge time should be considered during its exploration in the Martian caves due the amount of solar energy each solar panel can produce per sol. Generating more solar energy will lengthen its time in cave exploration and further its science discovery. Due to the charging station's loss in induction. The charging station will need further calculations on the loss during its mission time.

8. Work Cited

Spot Specs:

1. https://dev.bostondynamics.com/docs/concepts/about_Spot.html?highlight=Spot%20specifications

Carbon composites:

1. Personal experience from Aidan Byrne gained from the San Jacinto EDGE Center Composites Technician training program
2. https://hal.archives-ouvertes.fr/hal-02285958/document

Safety

1. Personal experience from Aidan Byrne gained from the San Jacinto EDGE Center Composites Technician training program
2. https://www.cdc.gov/niosh/topics/hierarchy/default.html

Mars specific environment details:

1. https://www.researchgate.net/publication/312171303_Mars_methane_detection_and_variability_at_Gale_crater
2. https://www.nature.com/articles/s41598-020-67815-8
3. Jung, Jongil & yi, yu & Kim, Eojin. (2014). Identification of Martian Cave Skylights Using the Temperature Change During Day and Night. Journal of Astronomy and Space Sciences. 31. 141-144. 10.5140/JASS.2014.31.2.141. https://www.researchgate.net/figure/Seven-cave-candidates-around-Tharsis-Montes-on-Mars-AG-Using-Context-Camera-CTX-on_fig1_274552048

Identifying life signs

1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7591378/

SHERLOC Instrument

1. https://mars.nasa.gov/mars2020/spacecraft/instruments/sherloc/for-scientists/
2. https://www.hou.usra.edu/meetings/lpsc2020/pdf/2081.pdf

Subject Matter Experts:

1. Joseph Kissling, Nanoracks
2. Georg Laupretch, Nanoracks
3. Anwar Abdalla, SpaceX
4. Robert Shackleford, Axiom Space
5. Robert McComb, Intuitive Machines

9. Appendix

The following are CERs used to evaluate the direct cost of each science instrument and subsystem for mission NAMI:

SHERLOC Direct Costs

Arm/Mast Mounted In-Situ Instruments	1,363 * TotalMass^0.42 * TotalMaxPwr^0.35
SHERLOC TotalMass	4.71
SHERLOC TotalMaxPower	48.8
Enter the number you received from the CER formula	10188.53108
Estimated cost in 2022 dollars (Without Wraps)	$4,815,099.79
Wrap Costs	**Cost Estimate**
Management Costs	$250,000.00
Systems Engineering Costs	$210,000.00
Product Assurance Costs	$220,000.00
Integration & Test Costs	$780,000.00
Final manufacturing cost per unit	**$6,300,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$950,000.00
EMI	$470,000.00
VIBE	$240,000.00
Ambient	$240,000.00
Final testing facility cost per unit	**$1,900,000.00**
Schedule Estimate Relation (SER)	**Time in months**
Planetary, Remote Sensing Instruments (Optical and Microwave)	36.9
Planetary, Remote Sensing Instruments (Fields and Particles)	48.4
Planetary, in situ Instruments	36.3

Enhanced Autonomy Payload (EAP) Direct Costs

Body Mounted In-Situ Instruments	652 * TotalMass^0.62 * TotalMaxPwr^0.44
EAP TotalMass	2.8
EAP TotalMaxPower	8
Enter the number you received from the CER formula	3082.088957
Estimated cost in 2022 dollars (Without Wraps)	$1,456,595.24
Wrap Costs	**Cost Estimate**
Management Costs	$80,000.00
Systems Engineering Costs	$70,000.00
Product Assurance Costs	$60,000.00
Integration & Test Costs	$210,000.00
Final manufacturing cost per unit	**$1,900,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$290,000.00
EMI	$140,000.00
VIBE	$70,000.00
Ambient	$70,000.00
Final testing facility cost per unit	**$600,000.00**
Schedule Estimate Relation (SER)	**Time in months**
Planetary, Remote Sensing Instruments (Optical and Microwave)	24.6
Planetary, Remote Sensing Instruments (Fields and Particles)	32.2
Planetary, in situ Instruments	30.4

Mechanical Subsystem Direct Costs

Mechanical/Structures Subsystem	219 * MechMass^0.41 * TotalMaxPwr^0.52
MechMass	29.91
Mech TotalMaxPower	711.8
Enter the number you received from the CER formula	26838.29954
Estimated cost in 2022 dollars (Without Wraps)	$12,683,780.36
Wrap Costs	**Cost Estimate**
Management Costs	$620,000.00
Systems Engineering Costs	$500,000.00
Product Assurance Costs	$650,000.00
Integration & Test Costs	$2,300,000.00
Final manufacturing cost per unit	**$16,800,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$2,520,000.00
EMI	$1,260,000.00
VIBE	$630,000.00
Ambient	$630,000.00
Final testing facility cost per unit	**$5,000,000.00**
Schedule Estimate Relation (SER)	**Time in months**
Planetary, Remote Sensing Instruments (Optical and Microwave)	51.3
Planetary, Remote Sensing Instruments (Fields and Particles)	67.3
Planetary, in situ Instruments	42.0
Spot Body cost (CAD est. from Xometry)	$288,372.00
Power Station cost (CAD est. from Xometry)	$18,676.00

Thermal Subsystem Direct Costs

Thermal/Fluids Subsystem	642 * ThermMass^0.62
ThermMass	12.4625
Enter the number you received from the CER formula	3067.681267
Estimated cost in 2022 dollars (Without Wraps)	$1,449,786.17
Wrap Costs	**Cost Estimate**
Management Costs	$80,000.00
Systems Engineering Costs	$70,000.00
Product Assurance Costs	$60,000.00
Integration & Test Costs	$210,000.00
Final manufacturing cost per unit	**$1,900,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$290,000.00
EMI	$140,000.00
VIBE	$70,000.00
Ambient	$70,000.00
Final testing facility cost per unit	**$600,000.00**
Schedule Estimate Relation (SER)	**Time in months**
Planetary, Remote Sensing Instruments (Optical and Microwave)	24.5
Planetary, Remote Sensing Instruments (Fields and Particles)	32.2
Planetary, in situ Instruments	30.3

Power Subsystem Direct Costs

Estimated COTS cost in 2022 dollars (Without Wraps)	$300,000.00
Wrap Costs	**Cost Estimate**
Management Costs	$20,000.00
Systems Engineering Costs	$20,000.00
Product Assurance Costs	$10,000.00
Integration & Test Costs	$40,000.00
Final manufacturing cost per unit	**$400,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$60,000.00
EMI	$30,000.00
VIBE	$20,000.00
Ambient	$20,000.00
Final testing facility cost per unit	**$100,000.00**

Electronics Subsystem Direct Costs

Electronics Subsystem	1516 * ElecMass^0.74
ElecMass	7.4775
Enter the number you received from the CER formula	6718.602595
Estimated cost in 2022 dollars (Without Wraps)	$3,175,211.59
Wrap Costs	**Cost Estimate**
Management Costs	$170,000.00
Systems Engineering Costs	$150,000.00
Product Assurance Costs	$140,000.00
Integration & Test Costs	$490,000.00
Final manufacturing cost per unit	**$4,100,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$620,000.00
EMI	$310,000.00
VIBE	$150,000.00
Ambient	$150,000.00
Final testing facility cost per unit	**$1,200,000.00**
Schedule Estimate Relation (SER)	**Time in months**
Planetary, Remote Sensing Instruments (Optical and Microwave)	32.0
Planetary, Remote Sensing Instruments (Fields and Particles)	42.0
Planetary, in situ Instruments	34.1

Software Subsystem Direct Costs

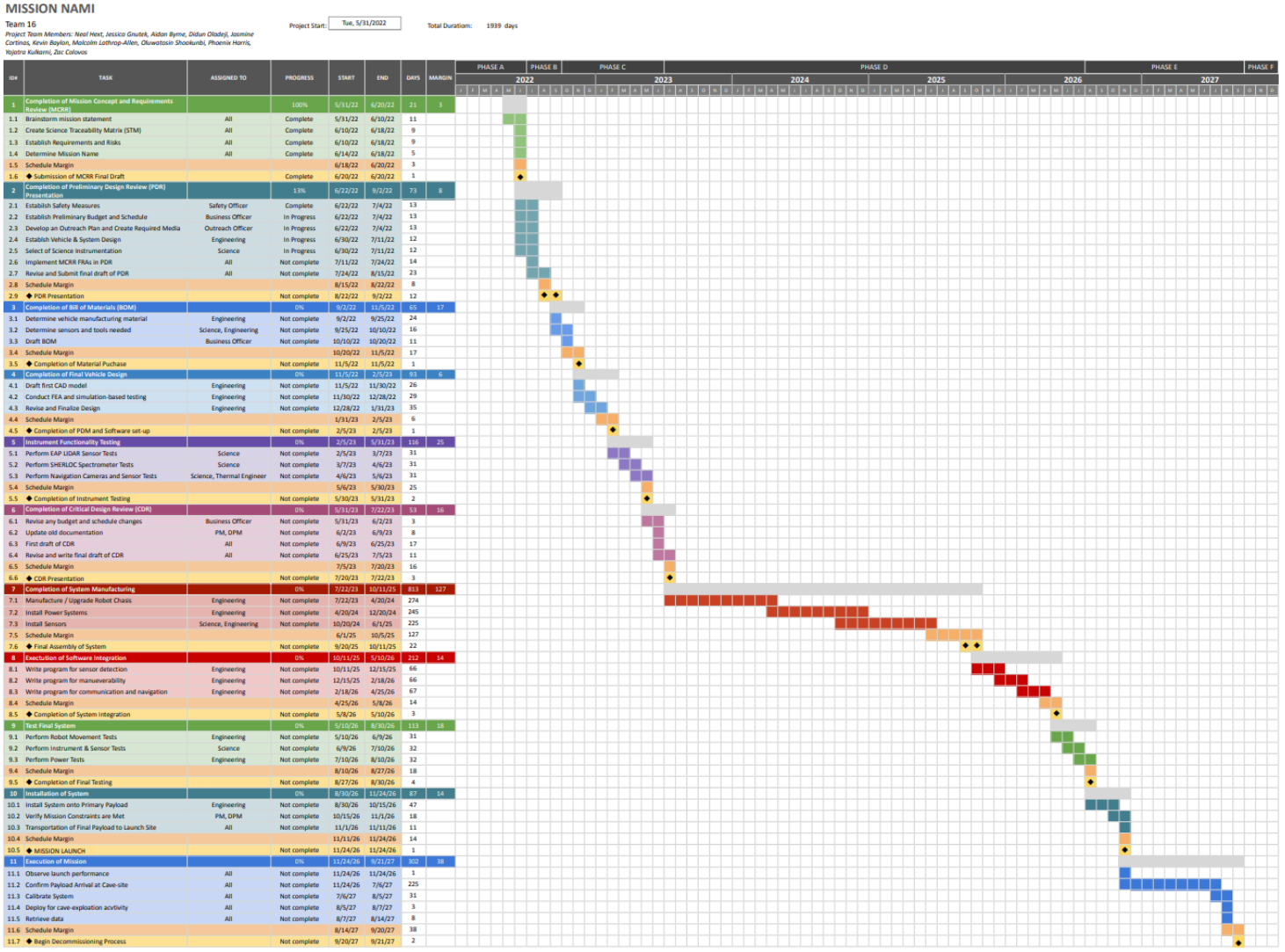
Software Subsystem	236 * ElecMass^0.69
ElecMass	7.4775
Enter the number you received from the CER formula	945.8100707
Estimated cost in 2022 dollars (Without Wraps)	$446,989.84
Wrap Costs	**Cost Estimate**
Management Costs	$30,000.00
Systems Engineering Costs	$30,000.00
Product Assurance Costs	$20,000.00
Integration & Test Costs	$60,000.00
Final manufacturing cost per unit	**$600,000.00**
Test Facility Cost	**Cost Estimate**
TVAC	$90,000.00
EMI	$50,000.00
VIBE	$20,000.00
Ambient	$20,000.00
Final testing facility cost per unit	**$200,000.00**
Schedule Estimate Relation (SER)	**Time in months**
Planetary, Remote Sensing Instruments (Optical and Microwave)	16.4
Planetary, Remote Sensing Instruments (Fields and Particles)	21.6
Planetary, in situ Instruments	25.4

The following is the overall summary of the budget for this mission:

NASA L'SPACE Mission Concept Academy Budget - *MISSION NAMI*

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Cumulative Total
PERSONNEL						
Science Personnel	$ 1,200,000.00	$ 800,000.00	$ 800,000.00	$ 2,000,000.00	$ 1,200,000.00	$ 6,000,000.00
Engineering Personnel	$ 800,000.00	$ 2,000,000.00	$ 2,000,000.00	$ 1,200,000.00	$ 800,000.00	$ 6,800,000.00
Administration Personnel	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 400,000.00	$ 2,000,000.00
Project Management:	$ 750,000.00	$ 750,000.00	$ 750,000.00	$ 750,000.00	$ 750,000.00	$ 3,750,000.00
Total Salaries	$ 3,150,000.00	$ 3,950,000.00	$ 3,950,000.00	$ 4,350,000.00	$ 3,150,000.00	$ 18,550,000.00
Total ERE	$ 879,165.00	$ 1,102,445.00	$ 1,102,445.00	$ 1,214,085.00	$ 879,165.00	$ 5,177,305.00
TOTAL PERSONNEL	$ 4,029,165.00	$ 5,052,445.00	$ 5,052,445.00	$ 5,564,085.00	$ 4,029,165.00	$ 23,727,305.00
TRAVEL						
Total Flights Cost	$ 75,000.00	$ -	$ 75,000.00	$ -	$ 250,000.00	$ 400,000.00
Total Hotel Cost	$ 50,000.00	$ -	$ 50,000.00	$ -	$ 150,000.00	$ 250,000.00
Total Transportation Cost	$ 25,000.00	$ -	$ 25,000.00	$ -	$ 75,000.00	$ 125,000.00
Total Per Diem Cost	$ 10,000.00	$ -	$ 10,000.00	$ -	$ 50,000.00	$ 70,000.00
Total Travel Costs	$ 160,000.00	$ -	$ 160,000.00	$ -	$ 525,000.00	$ 845,000.00
OUTREACH						
Total Outreach Materials	$ 100,000.00	$ 25,000.00	$ 25,000.00	$ 200,000.00	$ 50,000.00	$ 400,000.00
Total Outreach Venue Costs	$ 250,000.00	$ -	$ -	$ 500,000.00	$ -	$ 750,000.00
Total Outreach Costs	$ 350,000.00	$ 25,000.00	$ 25,000.00	$ 700,000.00	$ 50,000.00	$ 1,150,000.00
DIRECT COSTS						
|> Science Instrumentation	$ 3,135,847.51	$ 2,090,565.01	$ 1,045,282.50	$ -	$ -	$ 6,271,695.03
|> Other Payload Costs	$ 153,524.00	$ 102,349.33	$ 51,174.67	$ -	$ -	$ 307,048.00
Total Payload Costs	$ 3,289,371.51	$ 2,192,914.34	$ 1,096,457.17	$ -	$ -	$ 6,578,743.03
|> Mechanical Subsystem	$ 6,341,890.18	$ 4,227,926.79	$ 2,113,963.39	$ -	$ -	$ 12,683,780.36
|> Power Subsystem	$ 150,000.00	$ 100,000.00	$ 50,000.00	$ -	$ -	$ 300,000.00
|> Thermal Control Subsystem	$ 724,893.08	$ 483,262.06	$ 241,631.03	$ -	$ -	$ 1,449,786.17
|> Comms/Data Handling Subsystem	$ 1,811,100.71	$ 1,207,400.48	$ 603,700.24	$ -	$ -	$ 3,622,201.43
Total Vehicle Costs	$ 9,027,883.98	$ 6,018,589.32	$ 3,009,294.66	$ -	$ -	$ 18,055,767.95
|> Manufacturing Facility Cost	$ -	$ 16,000,000.00	$ 16,000,000.00	$ -	$ -	$ 32,000,000.00
|> Test Facility Cost	$ -	$ -	$ -	$ 5,133,333.33	$ 12,800,000.00	$ 17,933,333.33
Total Facilities Costs	$ -	$ 16,000,000.00	$ 16,000,000.00	$ 5,133,333.33	$ 12,800,000.00	$ 49,933,333.33
Manufacturing Margin	$ 6,158,627.75	$ 12,105,751.83	$ 10,052,875.92	$ 2,566,666.67	$ 6,400,000.00	$ 37,283,922.16
Total Direct Costs	$ 18,475,883.24	$ 36,317,255.49	$ 30,158,627.75	$ 7,700,000.00	$ 19,200,000.00	$ 111,851,766.48
Total MTDC	$ 6,158,627.75	$ 4,105,751.83	$ 2,052,875.92	$ -	$ -	$ 12,317,255.49
FINAL COST CALCULATIONS						
Total F&A	$ 615,862.77	$ 410,575.18	$ 205,287.59	$ -	$ -	$ 1,231,725.55
Total Projected Cost	$ 23,630,911.01	$ 41,805,275.67	$ 35,601,360.34	$ 13,964,085.00	$ 23,804,165.00	$ 138,805,797.02
Total Cost Margin	$ 7,089,273.30	$ 12,541,582.70	$ 10,680,408.10	$ 4,189,225.50	$ 7,141,249.50	$ 41,641,739.11
Total Project Cost	$ 30,720,184.32	$ 54,346,858.38	$ 46,281,768.44	$ 18,153,310.50	$ 30,945,414.50	$ 180,447,536.13

The following is a full-view of the Gantt chart associated with mission NAMI:



MISSION NAMI

Team 16

Project Team Members: Neal Hext, Jessica Gnutek, Aidan Byrne, Didun Oladeji, Jasmine Cortinas, Kevin Boylon, Malcolm Lathrop-Allen, Oluwatosin Shoukunbi, Phoenix Harris, Yajatro Kulkarni, Zac Colavas

Project Start: Tue, 5/31/2022 — Total Duration: 1939 days

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
1	Completion of Mission Concept and Requirements Review (MCRR)		100%	5/31/22	6/20/22	21	3
1.1	Brainstorm mission statement	All	Complete	5/31/22	6/10/22	11	
1.2	Create Science Traceability Matrix (STM)	All	Complete	6/10/22	6/18/22	9	
1.3	Establish Requirements and Risks	All	Complete	6/10/22	6/18/22	9	
1.4	Determine Mission Name	All	Complete	6/14/22	6/18/22	5	
1.5	Schedule Margin			6/18/22	6/20/22	3	
1.6	◆ Submission of MCRR Final Draft		Complete	6/20/22	6/20/22	1	
2	Completion of Preliminary Design Review (PDR) Presentation		13%	6/22/22	9/2/22	73	8
2.1	Establish Safety Measures	Safety Officer	Complete	6/22/22	7/4/22	13	
2.2	Establish Preliminary Budget and Schedule	Business Officer	In Progress	6/22/22	7/4/22	13	
2.3	Develop an Outreach Plan and Create Required Media	Outreach Officer	In Progress	6/22/22	7/4/22	13	
2.4	Establish Vehicle & System Design	Engineering	In Progress	6/30/22	7/11/22	12	
2.5	Select of Science Instrumentation	Science	In Progress	6/30/22	7/11/22	12	
2.6	Implement MCRR FRAs in PDR	All	Not complete	7/11/22	7/24/22	14	
2.7	Revise and Submit final draft of PDR	All	Not complete	7/24/22	8/15/22	23	
2.8	Schedule Margin			8/15/22	8/22/22	8	
2.9	◆ PDR Presentation		Not complete	8/22/22	9/2/22	12	
3	Completion of Bill of Materials (BOM)		0%	9/2/22	11/5/22	65	17
3.1	Determine vehicle manufacturing material	Engineering	Not complete	9/2/22	9/25/22	24	
3.2	Determine sensors and tools needed	Science, Engineering	Not complete	9/25/22	10/10/22	16	
3.3	Draft BOM	Business Officer	Not complete	10/10/22	10/20/22	11	
3.4	Schedule Margin			10/20/22	11/5/22	17	
3.5	◆ Completion of Material Puchase		Not complete	11/5/22	11/5/22	1	
4	Completion of Final Vehicle Design		0%	11/5/22	2/5/23	93	6
4.1	Draft first CAD model	Engineering	Not complete	11/5/22	11/30/22	26	
4.2	Conduct FEA and simulation-based testing	Engineering	Not complete	11/30/22	12/28/22	29	
4.3	Revise and Finalize Design	Engineering	Not complete	12/28/22	1/31/23	35	
4.4	Schedule Margin			1/31/23	2/5/23	6	
4.5	◆ Completion of PDM and Software set-up		Not complete	2/5/23	2/5/23	1	
5	Instrument Functionality Testing		0%	2/5/23	5/31/23	116	25
5.1	Perform EAP LIDAR Sensor Tests	Science	Not complete	2/5/23	3/7/23	31	
5.2	Perform SHERLOC Spectrometer Tests	Science	Not complete	3/7/23	4/6/23	31	
5.3	Perform Navigation Cameras and Sensor Tests	Science, Thermal Engineer	Not complete	4/6/23	5/6/23	31	
5.4	Schedule Margin			5/6/23	5/30/23	25	
5.5	◆ Completion of Instrument Testing		Not complete	5/30/23	5/31/23	2	
6	Completion of Critical Design Review (CDR)		0%	5/31/23	7/22/23	53	16
6.1	Revise any budget and schedule changes	Business Officer	Not complete	5/31/23	6/2/23	3	
6.2	Update old documentation	PM, DPM	Not complete	6/2/23	6/9/23	8	
6.3	First draft of CDR	All	Not complete	6/9/23	6/25/23	17	
6.4	Revise and write final draft of CDR	All	Not complete	6/25/23	7/5/23	11	
6.5	Schedule Margin			7/5/23	7/20/23	16	
6.6	◆ CDR Presentation		Not complete	7/20/23	7/22/23	3	
7	Completion of System Manufacturing		0%	7/22/23	10/11/25	813	127
7.1	Manufacture / Upgrade Robot Chasis	Engineering	Not complete	7/22/23	4/20/24	274	
7.2	Install Power Systems	Engineering	Not complete	4/20/24	12/20/24	245	
7.3	Install Sensors	Science, Engineering	Not complete	10/20/24	6/1/25	225	
7.5	Schedule Margin			6/1/25	10/5/25	127	
7.6	◆ Final Assembly of System		Not complete	9/20/25	10/11/25	22	
8	Exectution of Software Integration		0%	10/11/25	5/10/26	212	14
8.1	Write program for sensor detection	Engineering	Not complete	10/11/25	12/15/25	66	
8.2	Write program for manueverability	Engineering	Not complete	12/15/25	2/18/26	66	
8.3	Write program for communication and navigation	Engineering	Not complete	2/18/26	4/25/26	67	
8.4	Schedule Margin			4/25/26	5/8/26	14	
8.5	◆ Completion of System Integration		Not complete	5/8/26	5/10/26	3	
9	Test Final System		0%	5/10/26	8/30/26	113	18
9.1	Perform Robot Movement Tests	Engineering	Not complete	5/10/26	6/9/26	31	
9.2	Perform Instrument & Sensor Tests	Science	Not complete	6/9/26	7/10/26	32	
9.3	Perform Power Tests	Engineering	Not complete	7/10/26	8/10/26	32	
9.4	Schedule Margin			8/10/26	8/27/26	18	
9.5	◆ Completion of Final Testing		Not complete	8/27/26	8/30/26	4	
10	Installation of System		0%	8/30/26	11/24/26	87	14
10.1	Install System onto Primary Payload	Engineering	Not complete	8/30/26	10/15/26	47	
10.2	Verify Mission Constraints are Met	PM, DPM	Not complete	10/15/26	11/1/26	18	
10.3	Transportation of Final Payload to Launch Site	All	Not complete	11/1/26	11/11/26	11	
10.4	Schedule Margin			11/11/26	11/24/26	14	
10.5	◆ MISSION LAUNCH		Not complete	11/24/26	11/24/26	1	
11	Execution of Mission		0%	11/24/26	9/21/27	302	38
11.1	Observe launch performance	All	Not complete	11/24/26	11/24/26	1	
11.2	Confirm Payload Arrival at Cave-site	All	Not complete	11/24/26	7/6/27	225	
11.3	Calibrate System	All	Not complete	7/6/27	8/5/27	31	
11.4	Deploy for cave-exploation acvtivity	All	Not complete	8/5/27	8/7/27	3	
11.5	Retrieve data	All	Not complete	8/7/27	8/14/27	8	
11.6	Schedule Margin			8/14/27	9/20/27	38	
11.7	◆ Begin Decommissioning Process		Not complete	9/20/27	9/21/27	2	

PHASE A | PHASE B | PHASE C | PHASE D | PHASE E | PHASE F

2022 | 2023 | 2024 | 2025 | 2026 | 2027