L'SPACE MCA

Planetary Habitat Operations & ExploratioN Investigation eXpedition

MISSION CONCEPT REVIEW

TEAM 1 - P.H.O.E.N.I.X

Submission date - 6/15/2025

P.H.O.E.N.I.X

To mars and beyond

Table of Contents

Table of Figures and Tables

Table of Acronyms

Abbreviation	Definition
MCR	Mission Concept Review
SMD	Science Mission Directorate
STM	Science Traceability Matrix
ESDMD	Exploration Systems Development Mission Directorate
RTG	Radioisotope Thermoelectric Generator
ISRU	In-Situ Resource Utilization
MLI	Multi-Layered Insulation
GNC	Guidance, Navigation, and Control
IMU	Inertial Measurement Unit
GNSS	Global Navigation Satellite System
SWIM	Subsurface Water Ice Mapping
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars
JMARS	Java Mission Planning and Analysis for Remote Sensing
JPL	Jet Propulsion Laboratory
ERE	Employee Related Expenses
LOX	Liquid Oxygen
CDH	Command and Data Handling
ConOps	Concept of Operations
PDR	Preliminary Design Review
CDR	Critical Design Review

1.0 Mission Concept Review

1.1 Mission Statement

P.H.O.E.N.I.X (Planetary Habitat Operations & Exploration InvestigatioN eXpedition) is a low-cost, unmanned rover mission conceptualized to land in the northern mid-latitudes of Mars. The primary goal is to explore the area and analyze geological indicators of subsurface water and ice. The mission will pay particular attention to debris aprons, stratigraphy, and mineralogical composition to gather the most crucial data, which will be useful for future Mars expeditions. This mission aims to expand scientific knowledge of Mars' climate and determine information about the history of planetary water sources. Following in the footsteps of the 2008 Phoenix Mission, the team is emerging from the shadows of prior research and venturing into a new environment to support future human exploration by assessing dust risks and in-situ resource utilization (ISRU) potential.

Additionally, the mission aims to enhance scientific understanding of Mars' geological and climatic history and lay the groundwork for future human exploration of the Red Planet. This mission aligns with the goals of NASA's Science Mission Directorate (SMD) and Exploration Systems Development Mission Directorate (ESDMD) by providing a means of assessment for dust hazards and evaluating the feasibility of oxygen production. The collected data will support the development and adaptation of site locations and life-support systems for future landings by identifying subsurface water conditions and characterizing geological and atmospheric conditions.

1.2 Science Traceability Matrix

The P.H.O.E.N.I.X mission concept is intended to lay the groundwork for future human exploration efforts by investigating the environment through its conditions of dust, gases on the surface, temperatures, and ice that may be on the subsurface of Mars. Investigating atmospheric conditions will enable the understanding of water sources on the Martian planet by identifying glacier locations and analyzing them for safe and efficient use. P.H.O.E.N.I.X is derived from the objectives of interpreting how the environment on Mars can impact organisms, as well as how much it has changed over time, and its effect on the existence of water sources. This further study serves to better prepare for future human exploration by ensuring safe interactions with resources on Mars.

Testing the ratio of particular gases, such as Deuterium and Hydrogen, which are found in hydrated volcanic rocks on the surface of Mars, serves to track possible locations of water. Locations of a high D/H ratio will be beneficial to know of the potentiality of water, while other varying ratios can be compared to Earth's ratios to determine if that water can support life [13] [15]. This investigation will also lead to clarification of located water’s history of where and how it was formed to trace past life and climate records.

Inspection of dust accumulation and characteristics of the Martian soil will give a perception of how accessible ice is to the surface for water extraction. Understanding the type of soil on Mars allows for efficient water extraction through the development and production of equipment that will accommodate easy access areas [1]. Comprehension of the behavior of dust storms on Mars will also aid in preventing hazards for the safety of astronauts and their equipment for long-term missions [2].

By examining the radiation effects on water samples taken with P.H.O.E.N.I.X on Mars, a rate of water conservation can be assured for astronauts through the use of a Radiation Assessment Detector [14]. With a variation of water samples, a deeper insight may be obtained into the best water system and water cycle for future Mars exploration and habitation efforts. Developing strategies and instrumentation for water recycling and preservation is critical to ensure astronauts' safety and ensure the crew is well-informed on how the effect of radiation on Mars will alter the chemical properties of water for precautionary use.

The impact between asteroids and subsurface ice on Mars can lead to the discovery of uniquely formed crystals that may contain water, which further motivates the goal of locating water. When an asteroid comes into strong contact with possible areas of ice, water may be heated or trapped within the crystal rocks formed from this interaction [13]. This investigation explores the geological history of Mars and its evolution to the present state through the interaction between the dynamic internal and external forces on planet Mars that have formed and reshaped its surface through time. These interactions are evident to have changed the movement, stability, and distribution of water and can further give insight into how to locate preserved water life to select future landing sites for human missions.

Table 1.1

<table>
<tr><th rowspan="2">Science Goals</th><th rowspan="2">Science Objectives</th><th colspan="2">Science Measurement Requirements</th><th rowspan="2" colspan="2">Instrument Performance Requirements</th><th rowspan="2">Predicted Instrument Performance</th><th rowspan="2">Instrument</th><th rowspan="2">Mission Requirements</th></tr>
<tr><th>Physical Parameters</th><th>Observables</th></tr>
<tr><td rowspan="8">"HBS-1LM: Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants." — Moon to Mars Objectives, NASA</td><td rowspan="4">Assess the Martian environmental impacts on varied enclosed and protected Earth water models for astronaut internal use, heat dissipation, LOX and methane rocket propellant, and agricultural recycling.</td><td rowspan="4">Receive and monitor water cycle data for potential radioactive isotope presence, chemical reactions, and environmental contamination that bypasses protected storage, generating new developments in material science to help ensure astronaut safety across the wide spectrum of water applications.</td><td rowspan="4">Use gamma spectrometry to monitor for alpha, beta, and gamma radiation at twelve intervals over a one-year period, logging data for transmission back to Earth.</td><td>TBD</td><td>TBD</td><td>TBD</td><td rowspan="4">TBD</td><td rowspan="3">TBD</td></tr>
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<tr><td rowspan="4">Investigate the effects of Martian dust accumulation and regolith characteristics on the accessibility and stability of near-surface water ice to</td><td rowspan="4">Measure regolith grain size, porosity, dust layer thickness, and thermal conductivity over target region.</td><td rowspan="4">Use GPR reflection delays, thermal probe data, and surface albedo variation to infer dust cover and subsurface ice location within a 10 km traverse.</td><td>TBD</td><td>TBD</td><td>TBD</td><td rowspan="4">TBD</td></tr>
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<tr><td></td><td>support in-situ resource utilization and reduce environmental health risks for future human missions.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="8">“Q10.3b: What are the long-term endogenic and exogenic controls on the presence of liquid water on terrestrial planets?”—Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023–2032</td><td rowspan="4">Determine the Deuterium to Hydrogen (D/H) ratio in hydrated volcanic rock on Mars' surface.</td><td rowspan="4">Define the relative abundance of protium and deuterium within samples of hydrogen from hydrated volcanic rock.</td><td rowspan="4">Collect absorbance spectra in the 2500–25,000 nm range of H in selected hydrated volcanic rock samples at multiple surface sites.</td><td>TBD</td><td>TBD</td><td>TBD</td><td rowspan="4">TBD</td><td rowspan="3">TBD</td></tr>
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<tr><td rowspan="4">Determine the crystal structure of minerals formed by asteroid impacts interacting with exposed subsurface ice.</td><td rowspan="4">Identify chemical structure, crystal structure, and bond structure of Olivine from asteroids.</td><td rowspan="4">Collect raman spectra in the 11,111–33,333 nm range of Olivine in selected asteroid rocks at multiple surface sites.</td><td>TBD</td><td>TBD</td><td>TBD</td><td rowspan="4">TBD</td></tr>
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Table 1.1: Science Traceability Matrix

1.3 Summary of Mission Location

Mars is a terrestrial planet with a thin atmosphere composed mostly of carbon dioxide. Its surface, like other terrestrial planets, is covered with volcanoes, craters, and tectonic interactions. Mars has water in the form of ice at its poles and in glacial features. Dust storms and high radiation levels present challenges to future human expeditions. These features and challenges offer important data for missions such as P.H.O.E.N.I.X pertaining to human survival [17].

Erebus Montes, situated in Arcadia Planitia at approximately 39.0° N, 192.1° E, has been selected as the primary focus region for P.H.O.E.N.I.X. This selection for the mission location is determined by Erebus Montes' exceptional alignment with customer constraints, selected scientific objectives, and the need for terrain that offers a safe and feasible landing.

In alignment with customer location criteria, the mission location must be within a latitude of 60° North or South and may have any longitude, must be within a Potential High Priority Radar Targeting Zone, must be within 10 km of subsurface ice at a depth of 0-1m or within 5 km of an impact-exposed ice area. The data for this location shall be derived from SWIM maps, JMARS, and CRISM.

The Science Traceability Matrix (STM) focuses on several goals: investigating the stability and accessibility of near-surface water ice, characterizing Martian regolith and dust properties, determining the deuterium-to-hydrogen (D/H) ratio in hydrated volcanic rocks, and analyzing the mineralogy of asteroids that interacted with impact-exposed ice. Erebus Montes offers an excellent combination of features to address these goals [15].

Erebus Montes lies in the northern mid-latitudes, a zone repeatedly identified by NASA and the planetary science community as an attractive landing site to be further studied [24]. This region is shown to have abundant access to shallow, subsurface ice within the 0-1m depth and exposure of Hesperian-Noachian era terrain, an era marked by many asteroid impacts and volcanic activity [25] [26]. The exposure means Erebus Montes offers an abundance of impact craters that have exposed clean subsurface ice, with targets for mineralogical and crystal analysis and investigation into geological features such as lava tubes.

A few regions of interest in Erebus Montes align with the P.H.O.E.N.I.X. objectives include: 39.7° N, 190.6° E; 39.5° N, 194° E; 38.5° N, 192.8° E; 39.5° N, 191.5° E; and 37.9° N, 190.8° E. [25]. As a whole, these regions offer ice-rich lobate debris aprons, Amazonian-aged subsurface ice, recent ice-exposing impact craters, buried craters, lava tube caves, contact with Amazonian volcanism, contact with Amazonian lava flows, and evidence for glacial and periglacial processes [25] [27].

Erebus Montes is a fairly dusty region, shown in *Figure 1.2*; however, due to the relatively flat grade in the area, there are suitable landing options to avoid the high dust regions when communication is most pertinent. [25] Therefore, Erebus Montes is the best option for P.H.O.E.N.I.X to reach a good balance between safety and the science objectives, while conforming to the customer requirements.

Figure 1.1: SWIM Map

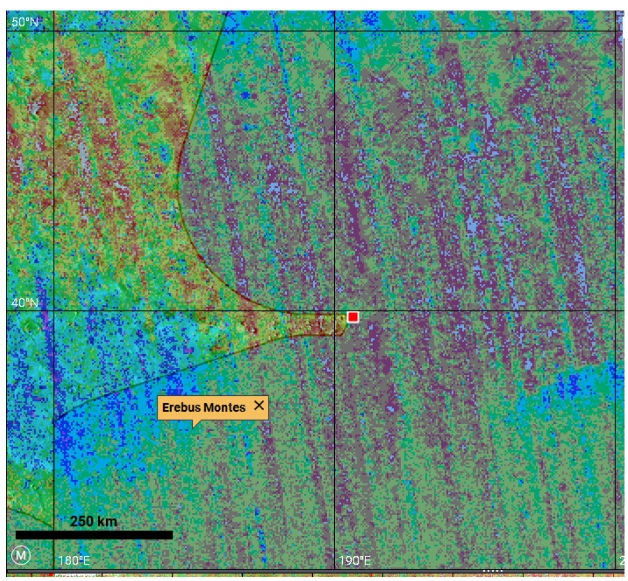

Figure 1.2: TES Dust Cover Index + SWIM Map

1.4 Mission Requirements

Customer constraints are a key driver of mission architecture, which determines the high-level requirements concerning mass, volume, and budget. Team P.H.O.E.N.I.X seeks to meet the system constraints presented by NASA, serving as the funding agency for the Discovery-class mission.

The spacecraft shall not exceed a mass of 200 kg. In a stored configuration, the spacecraft shall not exceed the dimensions of 2.5 m x 2.5 m x 2.5 m. This volume will house all the electronics, instruments, and payload suite. The spacecraft shall maintain the stored configuration for the entirety of the launch, transit, and entry into the Martian atmosphere. In an expanded form, there is no volume or mass constraint placed on the spacecraft. The spacecraft shall demonstrate resistance to temperatures consistent with atmospheric entry and descent. The spacecraft shall incorporate a landing attenuation system capable of withstanding surface impact.

After deployment on the landing site selected, the spacecraft shall traverse the terrain effectively to travel a minimum of 10 km. The spacecraft shall demonstrate an ability to traverse various Martian terrains, including sandy regions, icy regions, and small, medium, and large-sized rocks. The spacecraft shall demonstrate the ability to endure fluctuations in Martian atmospheric conditions, including dust storms, diurnal temperature variations, and reduced atmospheric pressure.

The spacecraft shall carry a scientific payload containing all instrumentation to complete science objectives. The volume of the scientific payload shall not exceed a cube of dimensions 0.5 m x 0.5 m x 0.5 m, nor a mass of 15 kg. This is to ensure the mission satisfies the human exploration goal and gets samples from the Martian surface that can be transmitted back to Earth for research. Furthermore, this research will contribute a great deal to the future of sustainability on Mars and future manned missions.

P.H.O.E.N.I.X is a discovery mission and not a flagship mission; hence, the budget allocated to this mission is 450 million USD and shall be used effectively for the manufacturing of the spacecraft, its components, employee-related expenses (ERE), and testing of the spacecraft. The Spacecraft system shall not have a Radioisotope Thermoelectric Generator (RTG) or any similar power generation system. Furthermore, any radioactive material is allowed for use on other spacecraft subsystems, but cannot exceed a cumulative mass of 5kg of radioactive material on all subsystems. The spacecraft must be ready for integration with the other systems by October 1st, 2029, and must be ready for launch on December 1st, 2029. The launch site shall be in Cape Canaveral in Florida.

Req #	Requirement	Rationale	Parent Req.	Child Req.	Verification Method
0.1	System shall survive the Martian environment for TBD years	The system must be able to survive the Martian environment to fulfill its purpose and send data back to earth ground station and potentially return Martian samples		SYS.02	Demonstration
0.2	Shall investigate the presence of ice glaciers on Mars for future missions and sustainability	Foundational science driver for the mission	Customer	SYS.01 SYS.03 SYS.05 SYS.06 SYS.07 SYS.08	Scientific Review
SYS.01	The system shall have sufficient power to carry out the objectives for the duration of its mission	System needs power to operate, communicate back to earth and carry out its objectives	0.1, 0.2		Test
SYS.02	System shall maintain operating temperatures and survive the harsh thermal environment on the Martian surface	The system and its scientific instrumentation must be kept in operating temperature ranges in order to function properly	0.1		Test
SYS.03	System shall traverse the Martian surface smoothly and reach the required science points of interest	Points of interests are marked across potential high priority Radar targeting zones on Mars that are defined by the thickness of the atmosphere to allow for easy landing and research point	0.2		Test
SYS.04	System shall not exceed a total mass of 200 kg	Constraints provided by NASA for the mission	Customer		Inspection
SYS.05	Critical systems including power shall have a backup capable of complete operation	In the case of failure, if a critical system fails, the backup can takeover and still carry out the mission	0.1		Analysis

SYS.06	System must withstand the solar winds for the duration of its mission	All components on the rover must be strong enough to withstand the strong solar winds on mars	0.1		Test
SYS.07	System shall send and receive data collected with the science instrumentation back to the earth ground station	Data sent back to the earth ground station about Mars will be essential to future scientific research for sustainability on mars	0.2		Analysis
SYS.08	System shall comply with all applicable planetary protocol regulations	NPR 8020.12D *Planetary Protection Provisions for Robotic Extraterrestrial Missions*	0.2		Analysis

Table 1.2: Requirements Matrix

1.5 Physical Environmental Hazards

Mars’s harsh environment presents a myriad of challenges and potential setbacks for exploration. Using remotely operated spacecraft has its challenges, with a successful exploration mission being an undertaking that requires years of work and coordination. The challenges the red planet poses range from planet-wide dust storms at a magnitude unseen on Earth. Due to the thin atmosphere, temperatures are so variable that the surface temperature can be up to 24 degrees Celsius hotter than the atmospheric temperature, less than two meters from the surface [9].

One of the most notable hazards is dust storms and the damage inflicted by the dust. Mars is no stranger to planet-wide dust storms [1] [2], which ended Opportunity’s mission [1]. While planet-wide dust storms are relatively rare, regional dust storms are a more regular occurrence [2]. These dust storms can prevent sunlight from reaching the rover, compromising solar power and potentially the mission itself. This also presents unknowns in the form of their impact on surface radiation and atmospheric circulation [3] and possibly affects the thermal systems via dust accumulation acting as insulation [1]. Dust accumulation could also potentially block or coat lenses on the science instruments and navigation cameras, presenting a risk to data collection and navigation.

The dust itself also poses a hazard as it is fine and abrasive, with an average radius of 1.5 μm [2]. The nature of the dust poses a wear and tear risk, especially around more delicate or exposed systems like joints [1]. These dust particles, which come in a wide range of sizes and shapes and can even get down to .1 μm in size [1], pose a threat to hardware if they were to penetrate the instruments.

Mars's temperature range also poses a hazard for a rover mission, with temperatures hitting as low as -153 degrees Celsius [4], and as such, this presents a challenge with keeping all electronic components within operational temperatures. At incredibly low temperatures, metals can become brittle [5], and any liquid components, such as lubricants, can freeze [1]. Moreover, the temperatures on Mars vary over a wide range, hitting highs of 21 degrees Celsius during the day in equatorial regions [6] and varying significantly a few feet off the surface from ground temperature [6]. Due to this, contraction and expansion due to temperature variation must be taken into account [1], and that could introduce stresses along the rover’s body. This all speaks to how carefully a thermal system will have to be designed to keep all electronic parts within their operational temperature range.

Due to its almost nonexistent atmosphere, the Martian surface is also exposed to high amounts of radiation in the form of galactic cosmic rays and Solar energy particles

[1]. This radiation also poses a hazard for the electronics aboard and is known to cause circuitry issues [8]. The lack of an atmosphere also leaves the Martian surface vulnerable to radiation from solar flares, which can be more concentrated.

The terrain of Mars itself is a hazard, with the majority of the planet covered in rough terrain with prominent amounts of mountainous material and hilly and cratered material [10]. All these rough terrains would provide significant navigational hazards for surface exploration, with rugged terrain and large slopes creating the possibility of the rover flipping or being otherwise rendered incapable. The Martian surface also presents smaller-scale navigational risks, such as sharp jagged rock formations, such as the one Curiosity encountered in 2014 [9]. These small razor-like formations tore at Curiosity's wheels, and many more unexpected formations could await on the unexplored surface [16]. Especially since a formation like that one would not be visible from satellite imagery. The unknown minutia of the rocky terrain is in and of itself a hazard.

The impact of the spacecraft's trajectory on Mars must also be considered. Due to the different atmospheric conditions on Mars [12], which necessitate precision calculations for a successful entry and landing.

When it comes to planetary protection, it is also important to keep in mind appropriate standards of sterilization to prevent any microbes or bacteria from Earth from reaching Mars [11]. This is important to prevent contamination to the ecosystem of study on Mars, and prevent foreign life from interacting with any possible life on Mars. The potential life on Mars must be kept isolated lest terrestrial forms of microbial life overrun it. In order to accomplish this, multiple sterilization tests must be performed, which can last weeks to months to ensure the accuracy of data testing on Mars and the reduction of biological hazards on any potential Mars life systems [18].

Achieving a successful mission to Mars demands unwavering precision at every stage, as risks and challenges exist at every turn. Such challenges when it comes to Mars include weather patterns, radiation, and the terrain on which the spacecraft will land. It is crucial for the team members working on this mission to understand and mitigate the multiple physical environmental hazards present to ensure a successful mission for P.H.O.E.N.I.X.

1.6 System Evaluation Criteria

The primary criteria team P.H.O.E.N.I.X will use in the evaluation of different options for each spacecraft subsystem shall be cost efficiency to satisfactory design constraint completion. While P.H.O.E.N.I.X will develop a state-of-the-art system, evaluations of successful heritage systems from other missions will determine necessary subsystem redesign and what systems may be implemented similarly from previous missions. In these evaluations, the Technology Readiness Level (TRL) of the system at this phase would be a 6, despite previous performance due to intended readiness testing and system redesign. Though the system is intended for use in the same environment, system modifications in conjunction with distinct mission-necessary instrumentation and mass allocation

Previous success was found by the Sojourner Rover, which was manufactured by NASA's Jet Propulsion Laboratory (JPL), where the rover spent 83 days on Mars exploring the Martian terrain, taking chemical and atmospheric measurements. This rover was powered by Ga-As solar cells and a silver-zinc battery. The primary source of the rover's power was the solar array during daylight operation [6].

Considering the customer constraints given by L'SPACE, the team's rover may not utilize a Radioisotope Thermoelectric Generator (RTG), which leads to the most feasible option of using solar arrays to power the rover. Although the team's rover will utilize solar arrays, several factors will still influence its Technology Readiness Level (TRL). These include the various stresses the rover will encounter, differences in volume and mass constraints compared to the Sojourner rover due to the team's specific payload, the increased number of scientific instruments onboard, and the rover's capability to collect samples from the Martian surface, a task that Sojourner was not designed to perform.

Each terrain will present unique challenges to the rover to achieve the science goal of locating ice glaciers for deposits of ice below the surface of Mars, whereas Sojourner's goal was to demonstrate a low-cost method for delivering scientific instrumentation to the red planet. Additionally, the team must ensure that all of the systems, including the payload, maintain operating temperatures to survive the harsh thermal environment on the Martian surface with temperatures as low as -153 degrees Celsius and as high as 21 degrees Celsius at daylight time [6].

This will lead to making use of Multi Layered Insulation (MLI) as well as multiple heaters to balance the temperature fluctuations and ensure a high thermal inertia as the rover travels to various research points. The team would also want to ensure an accurate state estimate of the rover and pathfinding, for which there are various options to be considered, such as an Inertial Measurement Unit (IMU) or Global Navigation Satellite System (GNSS) using the Mars Reconnaissance Orbiter, which is currently orbiting Mars. Many operating constraints affect how much power can be generated by the solar arrays and whether it can be enough to power the scientific instrumentation, rover propulsion, and the Command and Data Handling system (CDH).

1.7 Concept of Operations

P.H.O.E.N.I.X shall be a semi-autonomous exploration rover, designed to contribute to the goals of the NASA Science Mission Directorate (SMD) and Exploration Systems Development Mission Directorate (ESDMD). The Concept of Operations (ConOps) encompasses the operational steps across landing, all activities on the Martian surface, and decommission.

P.H.O.E.N.I.X shall begin surface deployment procedure upon T-1 sol, Martian day, of landing at the designated chosen landing site. The rover shall begin activation of the system operational instruments. The power systems shall first be stabilized. Upon power stabilization, the scientific instruments shall be deployed and brought online, and initial communication and telemetry tests shall be conducted. Thermal control systems shall be activated for the appropriate daylight temperature, which would include heaters, ensuring the electronics are within the operating temperature range. The rover shall then calibrate the scientific instruments and await initial command from ground operations located at Kennedy Space Center.

After verification of all systems, P.H.O.E.N.I.X shall begin autonomous travel to the designated science site at TBD rate of travel by the design of the rover and the environment, which shall occur at TBD sol after surface deployment procedure and instrumental calibration.

Traversing to the science site will take time; hence, P.H.O.E.N.I.X shall consist of a day mode and night mode to better allocate available power during the autonomous travel period. Night mode significantly reduces the travel rate and instrumental operation to aid with power conservation. In all modes, power will be focused on thermal control systems and maintaining appropriate temperatures throughout the system. The transition from day mode to night mode shall repeat throughout the Martian sol cycle during the autonomous travel period to the designated science site.

Upon arrival at the science site, P.H.O.E.N.I.X shall switch from either day or night mode to science mode. Once switched to science mode, P.H.O.E.N.I.X. will deploy its science instrumentation for use similarly to that of Mars 2020 Perseverance [28]. Once science instrumentation is deployed, P.H.O.E.N.I.X shall begin calibration of science instruments and ready systems for data collection.

Once science instruments have been successfully deployed and calibrated, P.H.O.E.N.I.X shall begin data and sample collection of ice on the Martian surface. P.H.O.E.N.I.X shall relay all collected data during its time in science mode to the Mars Reconnaissance Orbiter, which shall relay stored data to Earth for scientific research on the future of sustainability on Mars.

Upon completion of the data collection objectives at the designated travel site, P.H.O.E.N.I.X shall travel to the next site and repeat travel mode and science mode procedures until completion of the mission objective.

1.8 Alternative Mission Concepts

Before the finalization of the mission concept for PHOENIX, the team explored a range of alternative options. The team discussed various ideas for alternative mission designs. These alternatives addressed mission architecture, location, focusing on astronaut risk, and scientific objectives. The decisions were made collectively to ensure that the final mission met all assigned criteria, both scientific and practical. The proposed mission is aligned with NASA's strategic goals and reflects team consensus.

1.8.1 Objectives

The team evaluated several different possible science goals before selecting the final primary objective: Glacier depth tracking, seasonal glacial trends, geographic indicators of water artifacts, and geological water and ice indicators. Two that were ultimately not chosen due to mission constraints could be valuable on future missions.

Water chemicals: Will require detoxification technology or synthetic biological implementation, such as the use of a microbial bacterium called Bacillus subtilis strain 168, to remove the toxic perchlorate that is present within the Martian water. This will provide the increased logistical risk, plus the risk of the microbe not surviving deep space travel [20].

Ice depth: Human habitats will require large water supplies, and ice provides hope for water extraction for human consumption and potential propellant fuel via electrolysis to produce liquid oxygen (LOX) and methalox that can be utilized for interplanetary travel. By identifying the depth of ice and geographic features that indicate deeper ice formations, future habitation sites can be more effectively identified and selected. This is the objective that will be carried out for the mission.

1.8.2 Location

Two main geographical options were presented for landing and exploration: The mid-latitudes and the polar regions.

Mid-latitudes: The equatorial region of Mars provides more solar power, as well as more moderate temperatures than the polar regions, and it also offers fewer environmental risks for colonies. Another thing to consider when choosing the mid-latitude location is its geological value, as this specific zone contains many of the answers when it comes to investigating the Martian past.

Polar regions: Polar regions provide the highest chance of finding large volumes of ice. This ice will likely be very deep and difficult to analyze as a liquid, and melting samples would require energy. The far polar regions also pose a risk of seasonal darkness as the poles point away from the sun. These annual dark periods also create seasonal water movements that can be only partially studied by satellite, requiring surface instrumentation.

1.8.3 Spacecraft Type

Telescope: The primary limitations of telescopes to observe terrestrial features are finite capabilities regarding chemical composition identification and observation during dust storms that are very frequent on Mars. There would be strong limitations by orbital paths creating short perception windows, and Martian weather formations, such as dust storms, limiting visibility. A telescope would drastically decrease mission costs, risks, and implementation timeline. Despite the decrease in costs and risks, telescoping technology wouldn't be ideal to study the Martian surface, as the orbital velocity of the telescope is extremely fast, up to thousands of meters a second, which is not ideal and leaves large gaps in transmission windows. Furthermore, it is not possible to identify ice using a telescope as it is buried beneath the Martian surface and would require further inspection using scientific instrumentation such as a spectrophotometer for accurate measurements and data.

Satellite: A satellite would provide a wide scanning area and long operational lifetime, but would have limited resolution, and would not be capable of collecting samples of physical quantities necessary to determine water depth or the chemical composition of a particular area. Measurements relating to water-created geographic formations would be entirely limited by the resolution on board; thus, a satellite is not ideal. Prior research done by the Mars Reconnaissance Orbiter is valuable. It brought back high-resolution imagery and subsurface data maps that could be studied on Earth. That information laid the groundwork for current missions being done by surface rovers and by rovers in the past decade. Currently, NASA's Perseverance [12] is collecting samples of Martian cores to return to Earth, which has never been done. Satellites and landers complement the science being done on Earth, while rovers bring new data and collect samples for study. These samples would provide invaluable new information and crucial analysis for further crewed missions.

Lander: A lander would allow for on-surface exploration and testing. A lander would introduce risks related to atmospheric entry, requiring additional subsystems, and therefore increase development and operational costs. A lander would not be able to travel from its initial landing location and would therefore be highly susceptible to any flight path deviations. A lander would also be limited to a single location for samples to be collected, as it is a stationary vehicle and lacks the mobility instruments that a rover consists of.

1.8.4 Crewed Status

Manned: A manned mission would allow for practical experiments on human life on another planet, long-term effects of partial gravity; however would serve as a full system test for habitation modules, water sanitation systems, sustainable food sourcing, and air recycling systems. Many of these modules are not near enough to the application and would not be attainable with the mission budget. Furthermore, proposing a crewed mission would be unprecedented. The duration of a crewed mission poses imminent health risks for the crew. Current propulsion systems would be unable to land crews on Mars in fewer than nine months [19]. Long-term exposure to solar radiation both during the journey and during surface operations could be detrimental to the crewmembers. Producing a safe, long-term environment is an additional risk. Astronauts are unable to grow enough crops for sustenance while on the surface, and would face difficulties in producing the necessary amount of oxygen to sustain crop life.

Unmanned: An unmanned mission exploratory would be feasible within the allocated budget due to the lack of life support systems, and with reasonable hybrid remote control and autonomy, scientific experimentation is feasible for future habitation without uncertainty risk to human life. All of NASA’s missions to Mars have been unmanned, which include the Phoenix lander [22], Curiosity rover [14], Sojourner rover [8], and Perseverance [16]. With temperatures going way below freezing point at night and much more than the boiling point at daytime [6]. Furthermore, the radiation levels are dramatically greater than what astronauts in the International Space Station (ISS) have experienced [12]. This makes a manned mission extremely dangerous and not cost-effective, as each seat on SpaceX’s Dragon capsule or Starship will cost approximately 55 million USD [31]. As a discovery mission, a crew is not necessary to conduct the relevant science. It would also be very efficient to utilize hybrid autonomous mission control systems that have been the norm in most of NASA’s missions.

1.9 Programmatics

1.9.1 Team Organization

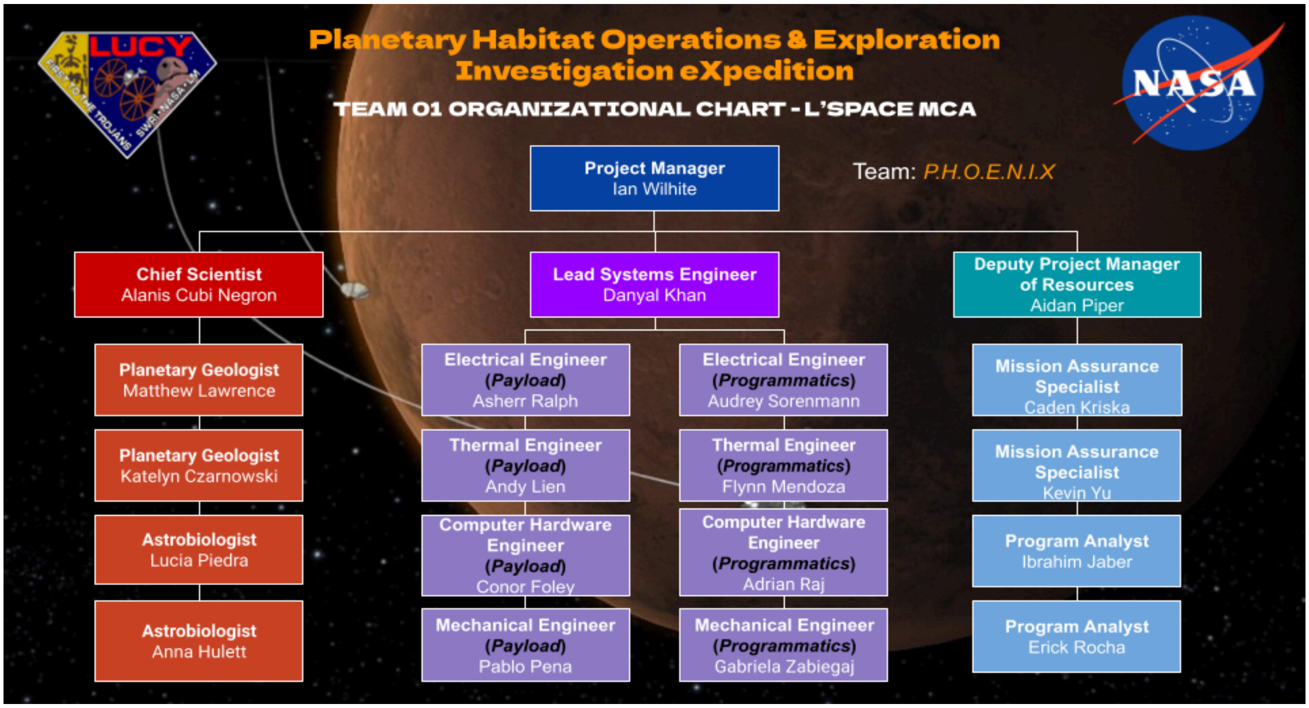

Figure 1.3: Team 01 Organizational Chart

Workloads for major deliverables will be analyzed by the team to determine relevant tasks to be assigned to each subteam as dictated by the project manager and/or team leads. To ensure consistent progress, team leads will further delegate tasks to specific individuals as it relates to their role within the sub-team (i.e., bases of estimate will be given to both a program analyst and a mission assurance specialist).

Team organization will follow the structure outlined by the organizational chart, shown in Figure 1.1. All subteam roles have two team members assigned to them, with engineering roles having the distinction of being either focused on payload integration or programmatics. Roles across the team were selected through a democratic voting process to select the best individuals for the role based on their prior roles and experience.

The decision-making process will consist of input from all team members regarding the particular problem, but will ultimately be up to the discretion of the project manager and team leads on a broader scale. In instances where a decision is time sensitive, relevant subteam members will be contacted for input if the team leads and project manager deem it necessary before making a final judgment. Additionally, differences in team opinions will be handled through trade studies and analysis if time persists to fully comprehend the benefits and shortcomings of each approach. This approach allows for the input and analysis of all members to be considered, covering any potential biases that may be present. Considering this information, the team leads and the project manager will deliver a final decision regarding the issue. Should a scenario arise where there is not time for a fully-fledged trade study, the team will make a decision following the aforementioned protocol for time-sensitive decisions. Lastly, conflict resolution within the team will be addressed by the leadership team working with those involved to comprehend and resolve the scenario. LSPACE mentors and staff will be involved should the conflict either prove too challenging to de-escalate or the conflict involves the team leadership.

As a team, the members bring a range of prior skills and experience, ranging from aerospace industry internships, leadership, and hands-on experience in student organizations, to prior experience and completion of a LSPACE program, equipping the team with strong baseline capabilities, which will develop the mission concept. If there are any gaps in technical knowledge or confusion, the team will consult LSPACE resources such as skill modules or relevant role mentors. The following tables show a breakdown of the weekly time commitment of each team member as well as their role, with *Figure 1.1* being the team leads, *Figure 1.3* representing the science subteam, *Figure 1.4* for engineering, and *Figure 1.5* for programmatics:

TEAM LEADERSHIP		
Name	**Role**	**Hrs/Week**
Ian Wilhite	PM	10
Alanis Cubi Negron	CS	10
Danyal Khan	LSE	10
Aidan Piper	DPMR	10

Figure 1.4: Team Leadership

SCIENCE SUBTEAM		
Name	**Role**	**Hrs/Week**
Matthew Lawrence	Planetary Geologist	10-15
Katelyn Czarnowski	Planetary Geologist	8-10
Lucia Piedra	Astrobiologist	10
Anna Hulett	Astrobiologist	3-4

Figure 1.5: Science Subteam

ENGINEERING SUBTEAM		
Name	**Role**	**Hrs/Week**
Asherr Ralph	EE Payload	6-8
Audrey Sorenmann	EE Programmatics	8-15
Andy Lien	TE Payload	10
Flynn Mendoza	TE Programmatics	6-7
Conor Foley	CDH Payload	3-10
Adrian Raj	CDH Programmatics	10-15
Pablo Pena	ME Payload	3-4
Gabriela Zabiegaj	ME Programmatics	5

Figure 1.6: Engineering Subteam

PROGRAMMATICS SUBTEAM		
Name	**Role**	**Hrs/Week**
Caden Kriska	Mission Assurance Specialist	2-3
Kevin Yu	Mission Assurance Specialist	4
Ibrahim Jaber	Program Analyst	10
Erick Rocha	Program Analyst	4

Figure 1.7: Programmatics Subteam

1.9.2 Schedule Basis of Estimate

The Schedule Basis of Estimate spans phases C to F, beginning with the completion of the Preliminary Design Review (PDR) and ending with the completion of the mission lifecycle. Scheduling will be based on the assumption that all planning is centered around fiscal years instead of calendar years. This assumption allows for simplification as the integration date of October 1, 2029, aligns with the end of the federal fiscal year. P.H.O.E.N.I.X must be fully tested, integrated, and ready to launch to leverage the launch window to Mars on December 1st.

Ground Rules

The scope of analysis features phases C-F only, beginning at the submission of the Preliminary Design Review (August 18, 2025), and ending with the System Integration Date (October 1, 2029), followed by the Launch Readiness Date (December 1, 2029). These constraints reflect the narrow launch window to Mars and the necessary integration period before launch. A 15% time contingency is therefore imposed on the critical task path to mitigate risks from unexpected delays.

Assumptions

Fiscal Year (Oct 1–Sept 30) is used instead of calendar year to align with NASA and federal budget cycles. Phase C begins in FY26. Any acquisitions are slated to begin at the beginning of the next fiscal year after the completion of the CDR, projected to be Q3 of 2026. Personnel are expected to work at least the number of hours as stated in Tables 1-4 (Section 1.9.1) each week for approximately 44 to 48 weeks each fiscal year, considering federal holidays, vacations, and illness. The interest rate given by the financing agency is 2.6% APR. The launch, Entry Descent Landing system (EDL), and transit will be handled by contractors.

Drivers

Stakeholders for this mission shall determine its scope, and each stakeholder has mission expectations that must be accounted for in mission planning and execution.

The NASA Science Mission Directorate (SMD) serves as the mission sponsor and funding agency. The NASA Exploration Systems Development Mission Directorate (ESDMD) acts as a subsidiary of the NASA SMD, focusing on human exploration needs for interplanetary travel and habitation. The NASA SMD and ESDMD have interests relating to the feasibility of human habitation, and therefore, all scientific objectives must relate directly to the key directorates of the funding agencies, and propose feasible budgets and timelines to contribute meaningfully to their respective causes.

The team serves to plan the P.H.O.E.N.I.X mission from Phases C–F. The team is interested in high-level system objectives and ensuring that all subsystems are designed, integrated, and tested to meet mission requirements for science return, reliability, and launch readiness.

The mission will outsource many subsystems to contractors. Contracted subsystems and processes include Entry Descent and Landing (EDL), Guidance, Navigation and Control (GNC), transit, and launch. These contractors will have an interest in clearly outlined documentation, timely expectations, open communication, budget allocations, and minimal redesign. The contractors are interested in understanding the scope of work for the system and what can be done to accomplish the given scope as efficiently as possible.

NASA Headquarters (HQ) will serve as a reviewing agency for all Key Decision Points (KDPs) before the beginning of each phase. HQ is interested in maintaining the established budget and timeline as initially proposed, and reviewing deliverable extensions and budget overages to determine continued mission feasibility. HQ is therefore interested in receiving comprehensive documentation for the entirety of the mission.

Kennedy Space Center (KSC) will serve as the largest contracting agency and will be ultimately responsible for launching the final design. The KSC is therefore interested in maintaining all timelines for integration tests and ensuring the on-site system integration date is upheld.

System Timeline

Phase C: Final Design (Q3 2025 – Q3 2026)

Phase C is primarily focused on finalizing the system design, followed by generating documentation as it pertains to the system, subsystem, and component, and the fabrication of the aforementioned elements. Additionally, all prior phase documentation is updated as trade studies are continued to provide a means of verification for later stages. Key requirements as set out in NPR(s) 7120.5 and 7123.1, where applicable. Phase C encompasses a CDR and PRR (project readiness review) before concluding with a SIR (system integration review) as major deliverables [29] [30].

Phase D: Assembly, Integration, & Test (Q4 2026 – Q3 2029)

Phase D consists of the full system integration and the development to attain a favorable assessment. Individual software and hardware components are evaluated and integrated before being assembled to validate and verify through testing conditions. Conditions are determined by previous trade studies and research meant to simulate mission environments. Any issues that arise either during testing or in ensuring the system meets client expectations need to be addressed as well. All issues impeding system function must be resolved before the completion of the full system integration. Assuming a successful review at KDP 5, the system is then cleared to launch from the Kennedy Space Center in Cape Canaveral. Phase D closes out with a Post Launch Assessment Review (PLAR) as the vehicle is in transit to Mars [29] [30].

Phase E: Operations (Q4 2029 – TBD)

Phase E consists of early operations propelling towards Mars, cruise, Martian atmospheric Entry Descent and Landing (EDL), science conduction, and data return. This phase is where the main science needs that drive the mission are addressed through the onboard science payload. Engineering and science data obtained from the mission are transmitted back and analyzed, and final reports and post-flight evaluations are written. Plans regarding the decommissioning and deactivation of the system are finalized as the vehicle completes its flight. [29]

Phase F: Closeout (TBD)

After the functional life of the rover, mission staff will begin post-mission data analysis, then final reporting and decommissioning. The functional life of the rover is TBD, and dependent on system performance, environmental factors including dust storms, and instrumentation accuracy. Post-mission data analysis will include developing data-driven conclusions of science objectives as described in the Science Traceability Matrix (STM). Final reporting will include analysis of engineering system performance, failure analysis on any system degradation, and a consolidated evaluation of system operational performance.

1.9.3 Budget Basis of Estimate

The Budget Basis of Estimate for P.H.O.E.N.I.X is developed for phases C through F of the mission's life cycle. To determine a Budget Basis of Estimate, a few key rules, drivers, and assumptions will be made: Firstly, a $450M cost cap is established specifically for the Rover System as given by the Mission Task Document. All other components of the mission will have independent budgets that are managed separately. Secondly, a fixed rate inflation of 2.6% annually will be assumed following the practice of NASA. Third, the team will use the following Salary Estimation Table (Table 1.4) for estimating the personnel budget, derived from the mission task document and adjusted for the 28% benefits rate. The table assumes a minimal team of all current members without any additional support staff to provide a cost floor and will be further refined. In addition, funding should be allocated for 30 additional support staff, assumed to be split ⅔ technicians and the remainder engineers or scientists, depending on mission phase. A breakdown of the roles can be found in Table 1.3.

Role	Description
Scientists	Responsible for mission experiment design and data analysis.
Engineers	Responsible for engineering decision making for P.H.O.E.N.I.X assembly, design, and testing.
Technicians	Responsible for assisting and providing technical support to engineers and scientists with manufacturing, testing, and assembling P.H.O.E.N.I.X.
Administration	Responsible for handling human resources, scheduling, and mission cost tracking.
Managers	Responsible for organizing mission budgets, scheduling, personnel, and key teams for mission success

Table 1.3: Mission Role Descriptions

PERSONNEL SALARY COST ESTIMATIONS		
Role	**Salary ($/yr)**	**Count**
Scientists	102,400	4
Engineers	102,400	8
Technicians	76,800	0
Administration	76,800	4
Management	153,600	4

Figure 1.8: Personnel Salary Cost Estimates

Personnel travel costs will be estimated through the City Pair Program for airfare in addition to lodging through Fedrooms and per diem reimbursement for meals and rentals. Tests are conducted at relevant NASA centers across the country, and launch takes place at Cape Canaveral, Florida. Key personnel will be flown in to oversee and conduct in-person testing of relevant components and subsystems with rental cars, lodging, and meals priced out using the aforementioned resources [19] [21].

Outreach costs are costs that relate to the team's effort in increasing public awareness of P.H.O.E.N.I.X and the impact that it will have on the scientific community and the end science goals.

A detailed budget for P.H.O.E.N.I.X will be developed as it advances towards the PDR (Preliminary Design Review). The budget will include breakdowns of costs for each Phase of the mission as well as a per-item cost breakdown. Following the totals of each component budget, a safety factor of 1.3 will be applied for any delays, hiccups, and potential issues that may arise during the mission's lifetime. Also referred to as the Total Cost Margin at the PDR stage.

1.10 Conclusion

The P.H.O.E.N.I.X mission concept successfully addresses key scientific objectives related to the assessment of Martian water accessibility, dust risks, regolith properties, and environmental hazards, with a clear focus on enabling safe and sustainable future human exploration. By targeting the northern polar region of Mars and building on prior missions such as the 2008 Phoenix lander [22], the team has established a coherent science traceability matrix that aligns with NASA's strategic goals for human spaceflight, ISRU development, and environmental safety [23]. This MCR demonstrates the mission's feasibility, with well-defined objectives, a compelling scientific rationale, and a forward-looking vision for data-driven site selection and astronaut health protection.

Looking ahead, the team will transition toward the System Requirements Review (SRR) by refining instrument specifications, defining mission requirements, and addressing current TBDs in performance metrics and hardware integration. Furthermore, the team would expand on its instrument calibration plans, simulate data return paths, and further evaluate terrain navigation strategies for enhanced landing and sampling precision. These developments will ensure the mission's continued maturity into the Preliminary Design Review (PDR) phase and position P.H.O.E.N.I.X as a foundational effort in supporting the long-term goal of Mars habitation.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this document, the team used OpenAI's ChatGPT to assist with re-phrasing and content refinement. The tool was used to rephrase content for conciseness and completeness. After using this tool, the team reviewed and edited all content to ensure accuracy, original contribution, and technical fidelity. Team 01 takes full responsibility for the content of this deliverable.

Appendix

TBD / TBR #	Plans and Timeline for Resolution
1	STM will be complete when instrumentation is selected
2	Requirements will be solidified after the instrumentation is selected.
3	Rover performance metrics will be decided after system integration
4	Rover landing time will be decided after testing and demonstration.
5	Rover travel rate will be decided after testing of the whole system
6	Scientific Instrumentation Calibration time after testing scientific instrumentation.

Table A.1

Discussion:

Currently in the STM, there are some TBD sections that will mainly be decided after the science team selects the instrumentation needed for the mission and together with the engineering team finalize on the number and type of scientific instruments to use. Requirements will be more specific after the rover has been designed and analyzed with different modeling simulations and tested in an artificial environment to give a rough idea of how long the systems will last on Martian soil. Rover landing time will be decided on the launch date, when the launch window is open and the scientific instrumentation calibration will also be decided after rigorous testing of each instrument before the rover is set to land on Mars.