GEM: Geological Exploration of Mars

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Scope Summary Page

Need: Determine the Geological History of Mars.

Goal: Extract heavy and precious metals, create an accurate, usable dataset of Mar's geological data and geological history

Objective: Create a permanent Mars Base, with an emphasis on Data Collection, Metal Extraction and Geological Sampling

Mission or Business Case: Test various fertilizers and treatments of Mars soil in comparison to Earthen soil, see which soil type works best for essential crops.

Operational Concepts: Prepare Transit Vehicle with Technology needed for base, and crew. Then Launch the crew, enter Mars, Land, build the base and begin research. After 5 years, return home with data, metal, and the crew, land on Earth, and share findings.

Assumptions: All technology is made available for this project, and can be refined to a mission critical level in 5 years.

Constraints: Phase III Base, must launch before 2040

Authority and Responsibility: NASA, Mission Manager, and US Government have shared responsibility and authority of the mission.

Mission Name/Significance

The mission is GEM. GEM stands for Geological Exploration of Mars. The missions main purpose is to investigate the geological composition of mars, and determine the geological history behind the planet, support the Mars exploration program goal #3 (Mars Exploration Program Goals, 2014).

Mission Statement

The GEM Mission is a revolutionary foray into Martian Geology, using industry techniques to extract crust data and samples. The GEM Mission also aims to extract heavy and precious metals from mars, and determine its viability as a precious metal source. The result/hypothesis would yield the geological history of Mars, and it would assess that Mars is in fact a hotbed for precious metals, and contains valuable data about the formation of the planet, the solar system, and our Earth.

Mission Requirements

The main purpose of the Mars Mission is to determine the geological composition of martian soil at various depth levels. The mission would also aim to extract heavy metals from the Martian Crust, and return by 2040 with heavy metals, geological data, and a healthy crew all while setting up a permanent mars base.

System Requirements

Base Design

The Base design must achieve the following goals:

1. Moduler, easy to build, robust design that can be quickly assembled with minimal human interaction in a 1 year timeframe.

2. Support Algae Pool growth in base structure to provide enough oxygen for 20 people for 3 years.
3. Must be airtight, and connected to a robust electricity grid to provide power for all life support systems.
4. Must provide space to store vertical farming racks to support enough food for 20 people in 5 years.

Transportation Rovers

The Transportation Rovers must achieve the following goals:

1. Support long distance travel (over 50 kilometers) on Martian Terrain.
2. Require minimal repair time, have modular subsystems that are easy to replace and recreate.
3. Support the weight of at least 2 humans (140 kg), and have the ability to store at least 100 kg of precious metal and rock samples.
4. Contain enough oxygen, first aid, and food to support life for about 1 day in case of isolation from the group, as well as serving as a radio signal amplifier/source to enable communication with the base.

Research Experiments

The Research Experiments must achieve the following goals:

1. Collect at least 40 samples of the Martian Soil at each depth level ranging from 0 - 5,000 meters from crater surface level, in intervals of about 25 meters.

2. Accurately determine the geological composition of the depth samples collected.
3. Determine the geological history of Mars through a rich, machine assisted, analysis of the depth samples.

Mining

The mining bases on mars must support the following goals:

1. Accurately, and efficiently sample geological data from various depth levels of the Martian Crust.
2. Determine heavy metal presence in the Martian Crust, and extract all sources of heavy and precious metals for further analysis.

Food

The Food Growth area is important as it is the only source of nutrition and energy for astronauts in the base. The Food component of the mission would consist fo two parts, one set of single use, non perishable packets for deep space travel, and a vertical farming set to accompany the food packets while on the Mars Base. The Food subsystem of the mission must satisfy the following goals:

1. Support the nutritional requirements of 20 astronauts for about 5 years during the deep space travel (account for both trips), the time during the base construction, and enough extra packets to accompany the vertical farming.

2. Use Vertical Farming to serve as a sustainable food and nutrition source for astronauts during the mission time on Mars, accompanying the non perishable food packets.

Fuel and Oxygen Support

The Base should provide enough oxygen for at most 5 years of research, and generate enough fuel for a return trip to Earth.

System Elements

Base Design

The Base design is the most crucial component of the mission. Without a robust, habitable base to live in on Mars, the mission would not be able to succeed. However, one major constraint of the base is that it has to be built on Mars. As a result, traditional construction practices would not work when designing and building the base. To combat this issue, 3D Printers would be implemented. These Printers would be relatively large, with a bed volume of about 49.04 cubic meters (3.66 meters on each edge), and they would utilize large, high temperature extruders and nozzles to achieve a high print speed. The printers would print insulated, airtight subdivisions or “blocks” that would be used to assemble the base. An autonomous fleet of manipulators and robots would also be at the base construction site to build the blocks produced by the printer. The print speed is extremely important, as it is the largest bottleneck to the base construction.

To house about 20 astronauts, solar panels, fuel storage areas, mines, farming areas, and research labs, the base would have to be very large, with a floor area of roughly 20,234 m^2, or about 5 acres. The base would be structured in a step by step basis, with the first stage being the solar panel array and electricity grid. The next step would be to construct the living quarters and the farming areas, which would allow the crew to move in and inhabit the main base. While the crew would focus on rover deployment for transportation and surface and elevation data collection, the mines, and fuel storage areas would be built in order to process the waste generated from the base. After that, the research lab area would be built, allowing for proper experimentation to occur without risking astronaut lives.

The research areas, mines, and fuel storage areas would also be built with their own charging stations, and the research area would have its own life support system, with enough oxygen to support about 5 researchers, and 2 doctors for 2 years. The researchers would work about 8 hour days, 5 days a week, for 50 weeks in a year. This totals to about 10,000 hours of working at the center for 5 years. 10,000 hours is less than 2 years, so in order to save costs by not provisioning too many resources to the research center, it would only be equipped with enough food, water, and oxygen to support 5 people for 2 years. The mines would have about 2 years worth of oxygen, but it would be stored in compressed gas tanks, allowing astronauts to carry it further into the mine. The astronauts would spend their break eating in the mine “house”, a small base with a dedicated life support system, and enough oxygen to support about 5 miners, and 2 doctors for 1 year, considering they would spend considerably less time in the mine house than the researchers. All food would be packaged and brought from the vertical farms in the main base. The astronauts would eat 1 meal at their respective workplace. The technicians, and data scientists would work at the main base, working on repairing the transport vehicle, and preparing an automated launch system for the return trip. All astronauts would eat 2 meals at the main base, and 1 meal at their respective workplace.

Transportation and Data Collection Rovers

A crucial mission aspect is transportation. Long distance transportation is key to a successful base as it enables quick transport of goods, research data, and people from the living quarters to various mining and data collection areas set up across the planet. The rovers would be similar in size to a modern autonomous rover, but they would be modded so that only the base chassis, electric motor, and steering system would be included. The rover would be made of stamped steel, allowing it to withstand debris collisions at a high speed. The stamped steel would also increase the weight, making it easier to control in Mars, which has a lower gravitational force. In total the rover would not only have to support its own weight of about 2,500 kg, but it would also have to support two humans (combined 140 kg), and up to 100 kg of rock samples and precious metals. In order to maintain a high speed with extra weight, the rover would use a quad motor design, with a high torque, brushless motor powering each wheel. By using air shocks, and a hollow tire design, it could also be modded to withstand large shocks caused by rough martian terrain. The rover would also contain an extremely large graphene battery, and supercapacitor array, allowing it to quickly charge, and store a lot of power, enabling it to have a higher watt/hr usage, thus resulting in a faster speed. The rover's main power source would come from its charging station. A fully charged battery would enable the rover to travel about 400 km. The rover would also have solar panel arrays to recharge the battery. It would also have an open roof, and be controlled standing, to allow for quick mounting and dismounting.The rover would also have to support Human life in case of an emergency. It would contain about 600 liters of compressed oxygen tanks, a radio signal amplifier and source generator for communication with the base, first aid, and 4 meal packs. This would be able to support two people for at least 12 hours in case of a rover malfunction.

Fuel, Water, and Oxygen Generation

Oxygen generation is the key to human survival anywhere, but it also plays another very important role in space travel. Liquid Oxygen and Hydrogen are the key components of rocket fuel, which is important for the return trip(“NASA - Liquid Hydrogen-the Fuel of Choice for Space Exploration”, 2010). A possible method for oxygen generation is electrolysis. Human waste collected from the base contains large amounts of water and other chemicals. Some of the water would be recycled for human usage. The rest of the filtered water would be sent to the oxygen generation chamber. By filtering out the water, the electrolysis process can begin. All the water is stored in a large chamber, where extremely high voltages of electricity from platinum electrodes are passed through the liquid. This causes the water to split into O_2 and $2H_2$. The oxygen and hydrogen are then stored in separate tanks, and cooled to -440 ℉. This allows both elements to phase change into their highly volatile, liquid forms, where they are then used as fuel. The full reaction process is illustrated below:

$$2H_2O + \text{electricity} \Rightarrow 2H_2 + O_2$$

Another aspect of fuel generation would be to use catalytic convertors. Catalytic converters break down human waste and trash in order to create rocket fuel. All leftover waste from the filtration system would be fed into a large catalytic convertor to create rocket propellant, serving as emergency fuel.

Not all of the oxygen gas would be cooled however, some of it would be compressed into tanks, and serve as breathing air. The main supply of breathing air would come pools of algae. By injecting CO_2 and Nitrogen Phosphate into the algae pools, the algae experiences rapid growth, expanding to huge sizes, and producing large amounts of oxygen. The reason algae pools would be used instead of traditional trees of plants is because algae pools are much more efficient. The average person requires about 740kg of oxygen every year, and a fully mature sycamore tree would only provide about 100 kg of oxygen each year (Villazon, 2019). This would require about 7-8 trees per person, in ideal conditions, with a healthy amount of light and resources. 7-8 trees per person, with an 18 inch diameter, and ample root space (6 feet) would take up a lot of space (“Trees for tight spaces”, 2014). The most space optimal solution would be to stagger the trees in a hexagonal figure, with each tree about 6 feet from the center tree. Not including the root area of the outer tree, or the tree diameter, the area of the hexagon would be roughly 8.69 meters squared. Including the outer root area, it would be roughly 34.76 meters squared, as each tree requires another 6 feet of distance for ample soil room. Mature, sycamore trees would require about 3-4 feet (1-1.3 meters) of soil depth, putting the total soil volume at about 46.34 meters cubed. This means that each person would require 46.34 meters cubed of soil, and about 34.76

meters squared of space for their oxygen supply. The total soil amount required would be roughly 926.7 meters cubed, and the total space requirement would be roughly 695.2 meters squared. Using traditional trees and plants would not only take up an exorbitant amount of space and volume, but they would also require a lot of maintenance, soil terraforming, and a lot of UV light centralized in one space.

Algae pools on the other hand, utilize very little space in comparison. Under optimal conditions, Green Algae can grow up to .47 to 1.22 divisions a day under optimal conditions, and can grow in an area as small as a petri dish("Doubling Time under optimal conditions - Green algae Dunaliella sp. - BNID 106132"). Algae pools are very versatile, and allow for horizontal as opposed to vertical scaling. Vertical scaling is keeping a small number of objects, but having those objects be very large. Horizontal scaling is having a large amount of small objects. Horizontal scaling is a lot more versatile, and is also more space efficient as it can be integrated into building structures. This means that instead of having one or two large pools, you could have multiple small pools, and integrate them in the base structure, like a wall. Vertical Farms that would provide food would also produce a non substantial amount of oxygen, but nearly enough to support 20 people.

Mining

One of the main goals of the Mars Exploration Program is to explore the geological contents of Mars. This could be achieved by sending semi-automated mining crews to extract soil, rock, and metal samples. The mining would be one of the key research aspects as well, as the entire mission is centered around geological composition and precious metal mining. Traditional mining equipment would not be effective as it is very bulky, large, and not properly equipped to handle rough martian terrain. A team of small drones or rovers would be much more cost effective, and fuel efficient. By equipping the drones and rovers with explosives, drills, and composition testing kits, the number of humans needed at the mining site would be a lot lower, saving costs, and reducing risks. Fleet robotics is a principle that is based on hive thinking, in which the ideology is that several low cost devices who specialize in one small thing can do a larger task quicker, and better than one large device designed to do the entire task. The mining group would also play a key role in the research phase as they would be the ones to extract the crust and soil samples that the research team would analyze.

Food

One of the major mission aspects is food. The majority of the food in the mission would be stored in single use packages for the space transit vehicle, and emergency food supplies. These packets would meet all nutritional requirements, enabling the astronauts to thrive. On Mars, vertical farming labs would be set up in order to create a sustainable, renewable food source.

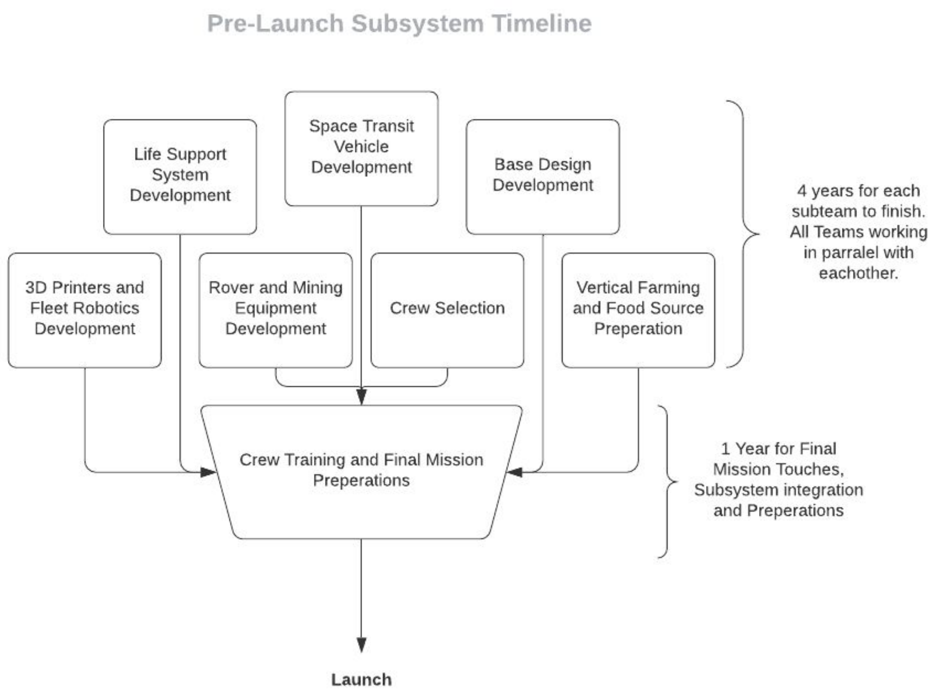
Mission Timeline

The overall timeframe of the mission would take roughly 20 years, with the entire crew returning back to Earth by 2035.

Pre-Launch - 5 Years

The Pre-Launch stages of the mission are some of the most important. All major subsystems need to be completed, including the transit vehicle development, life support systems, and base design. So, in order to achieve this, the Pre-Launch stage would consist of multiple research and development teams working on subsystems simultaneously in a 5 year timeframe. This is shown in the figure below:

Figure 1: A diagram visualizing the 7 pre-launch subteams and their respective



goals. The diagram also shows the timeline that the pre-launch stage will follow.

Launch Stages - 1 Year

The Launch stage would take roughly 6-8 months, to prepare the launching site, and about 2 months for final preparations. The launch team would be budgeted two extra months, if needed, to make sure the space transportation vehicle is completely safe before launching. The overall time frame of the Launch Stage is roughly 1 year.

Deep Space Travel - .75 Years

The Deep Space Travel period would take about 9 months to reach Mars orbit. In this time, astronauts would prepare for orbit entry, and run final system checks on the 3D Printers and the robots used for mining and building the base.

Orbit Entry and Landing - 1 hour

The Orbit Entry and Landing Period would only take a few hours. Upon entering orbit, the space transit vehicle would enter a fully autonomous phase, and land in the center of the boseman crater. It would then release the 3D Printers, Filament Spools, and Robots to begin building the base.

Base Deployment - 1.5 years

Infrastructure Setup

The first step in the infrastructure Setup would be to build the electricity rails. The robots would first unload solar panels and generators from the space transit vehicles cargo bay. While some robots are setting them up, the human astronauts would assist the other robots in 3D Printing the base. Every block would have a cutout to store a small algae pool, which is imperative for oxygen generation. The entire process of setting up the infrastructure and printing the blocks would take about 6 months.

Base Construction

After all the critical infrastructure pieces are set up, the base construction period would begin. The robots would build the base and handle the heavy lifting, while the astronauts would work on the airlock and vacuum seal around the base. After building the exterior of the main base, the astronauts and robots would move algae pools, computers, and vertical farms inside, as well as other furnishings like beds. The entire base construction process would take about 6 months. After the base is completed, the astronauts would move in, and start growing crops with vertical farming to create a sustainable, renewable food source.

Mine and Research Construction

After the construction of the main base, all the astronauts would move into the base from the space ship. They would then work with the robots to build the mining house, and the research center area. As these bases are smaller, and use a similar construction strategy to the original main base, the construction time for both work centers would be 6 months combined. In this period, charging stations for rovers would be set up for all 3 centers - the main base, the research center, and the mines. Radio Stations, and communication pathways would also be set up during this time.

Research, Mining, and Launching Preparation - 5 years

This is the main focus of the mission. During this 5 year timeframe the mission crew would work on 3 tasks simultaneously. The technicians and robots would work on fuel generation chambers, and prepare the space transit vehicle for the return mission. The mining crew would work on geological data sampling, and heavy metal extraction, while the research crew would collect data and run analysis tests. In the final year of the 5 year timeframe, all crews would prepare for the return mission, by loading the vessel, preparing food and water supply, and running final checks on all systems.

Launch Stages and Deep Space Travel - .75 years

Since the launch preparatory time was incorporated with the main research time, only 1 month at the most would be required to launch the vessel. The vessel would then spend about 9 months in transit on the return trip to earth. Astronauts would go over final system checks, and review data collected on the ship.

Return to Earth - 1 hour

At this point, the landing stages would initialize, and the space transit vehicle would engage in an automated landing, similar to what it achieved on Mars, but on a dedicated NASA Landing Pad. The landing process would only take a few hours at most. The entire mission timeline would end before 2035, which budgets enough time to account for delays in the pre-launch and launch periods, and for the mission to still return to earth before 2040.

Outpost Location

The mission would be located at the Hellas Planitia on Mars, which has a latitude and longitude of 42.4°S 70.5°E (“Hellas Planitia”). The Hellas Planitia crater is a circular depression with a diameter of about 2300 km, which is large enough to hold the base, mines, transit vehicle, and research center (Administrator, 2015). The crater is a planar depression, which makes it easier for humans and rovers to travel at faster speeds. In addition, the depression surrounding the base makes mining easier, and allows the research crew to analyze crust samples from a greater depth.

Mission Constraints

The mission has several constraints. The most important constraint is that the mission return by 2040, and that all astronauts return home safe, and in good health. Another constraint is the requirement of a permanent base. Permanent bases require a lot of extra life support systems, and require extensive consideration into food, water, and air supply.

Risk/Dangers

Regardless of how much time is spent behind research and development, any mission will have risks. The main danger in this mission is to human life in space. While backup life support systems exist in the space transit vehicle, and the Mars mission has a decoupled architecture with 3 seperate life support systems, anything could go wrong with a multitude of systems, ranging from the oxygen compressors, to the recycling and waste management systems. Another risk to astronauts is physical damage on Mars. The martian environment is rough, and desert dust storms plague the planet. While the risk of dust storm damage is minimized due to the base being in a planar depression, it is not completely gone. Dust storm damage could affect virtually all parts of the base, ranging from minor exterior damage to the rovers, to life support system failure, a breach in the base, and a leak in the fuel storage chamber. Another issue is possible data corruption on computers. While magnetic storage drives might be affected on Mars, solid state drives would all but minimize the risk. While the risk of Human Injury (both mental and physical) remains high, it would be reduced by having trained doctors, and therapists on board.

Crew Responsibilities

The Crew would consist of 20 people. The crew responsibilities would be divided into 4 main groups. The crew would consist of 5 miners, 5 researchers, 2 technicians, 3 doctors, 1 therapist, 3 subteam leaders (and trained pilots), and the mission manager (also a trained pilot). The 5 miners would work with the robot fleet to collect soil samples. They would be accompanied by a doctor, and their subteam leader who would manage the group. The 5 researchers would also be accompanied by a doctor and a subteam leader who would manage the data collection and scientific experiments. The mission manager, subteam leader, therapist, doctor, and technicians would work near the fuel storage area and also assist with general repairs throughout the base. The fuel storage crew would also work on preparing the automated launch sequence for the return trip. All astronauts would live at the main base, and give reports to their subteam leaders, who would report to the mission manager. All astronauts would pitch in to help with the vertical farming, and they would take shifts to check on life support systems, and on the rovers. In transit, the 3 subteam leaders and mission manager would control the space transit vehicle. All crew members would be trained in first aid, and they would be given extensive technical training to work with the robots and 3D Printers as they would all work with the robots to construct the base elements.

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Outreach Page

GEM is the United State's first foray into a permanent Mars base. The mission aims to obtain an accurate geological history of Mars, and provide the public with an accurate geological dataset of Mars. The mission would also provide permanent infrastructure on Mars for a future settlement, and is crucial to diversifying the precious metal supply chain.

The mission would have a crew of 20 people, with roles varying from pilots to miners. The crew would consist of 5 researchers, 5 miners, 3 subteam leaders (and pilots), 1 mission leader, 3 doctors, 1 therapist, and 2 technicians. The crew would be the first people to set foot, and settle on Mars. They would set up critical electric, and communications infrastructure, and would create oxygen and fuel generation plants in addition to their research goals.

The mission would serve as an innovation stimulus in fleet robotics, AI, and software task orchestration. It would also change how humans collaborate and work with robots to accomplish tasks. Rather than control the robot, the crew would work WITH a fleet of low cost, specialized devices to accomplish tasks quickly, saving costs, and increasing efficiency.