# Mars Exploration and Surveillance Assets

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**Mars is a planet with great latent potential, including many resources and evidence of water, which has great significance because it is closer and more hospitable than many others. The Mars Exploration and Surveillance Assets (M.E.S.A.) have been designed to build upon the understanding of the Martian surface and sub-surface through the deployment of the V.I.T.A.L. satellite and M.I.N.I. probes. The primary objective is to create a detailed geographic and resource profile of Mars with as much coverage as possible. The mission plan is to launch a satellite (V.I.T.A.L.) and the probes attached to it on a Falcon Heavy rocket. Upon reaching LEO, the satellite will separate from the rocket and begin its trajectory toward Mars. Once there, V.I.T.A.L. will orbit above the Martian surface until primary data collection is complete, including the terrain and elevation profile along with the first stage of resource identification. The probes launched from the satellite will be sent to areas of geographic notability and/or richness in resources. The data collected will be communicated to Earth using the Deep Space Network along with X-band and UHF communication systems.**

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**The mission's scale presents numerous challenges, including launch failure, hardware malfunctions, and the harsh Martian environment, which will be mitigated through pre-flight testing, redundancy in systems, and protective materials. The RFP requires that the mission deploy assets to Mars with the ability to cover at least 75% of the planet for data and be launched and collect the required data by at least December 31st, 2033. This mission aims to significantly improve the understanding of Mars with invaluable data for future exploration, including manned missions.**

# I. Introduction

## A. Background/Relevance

Mars is a planet with great latent potential, including many resources and evidence of water, which has great significance because it is closer and more hospitable than many others. The data indicating such potential has been growing steadily, which only encourages further surveying of what resources exist there. Despite numerous missions with similar purposes, it is imperative to the exploration of Mars that more missions are completed to broaden knowledge and uncover what could be available for future manned expeditions to the planet.

## B. Project and Team Objectives

The Request for Proposal (RFP) [1] given by the AIAA specifies that the mission designed will launch one or more assets within proximity to Mars to meet at least one of three objectives. These include: an atmospheric composition and density profile; geographic survey; and/or identification and quantification of potential surface and sub-surface resources. Team M.E.S.A. chose to create a terrain and elevation profile of the Martian surface from a satellite as the primary objective. A secondary objective chosen was identifying and quantifying resources on Mars from both the satellite and probes.

## C. Mission Scope

The Mars Exploration and Surveillance Assets (M.E.S.A.) have been designed to build upon the understanding of the Martian surface and sub-surface through deployment of the V.I.T.A.L. satellite and probes. The primary objective is to create a detailed geographic and resource profile of Mars with as much coverage as possible. This data will be critical in exploration missions in the future, whether unmanned or manned, for selecting landing sites and locating the resources needed.

This mission has five key phases: launching the assets aboard a Falcon Heavy Rocket from Florida's coast, rocket stage separation at LEO, the primary six-month period of interplanetary travel, inserting the satellite into a polar orbit, and finally, launching the probes and collecting data until the End-Of-Life protocol is enacted from total power failure or the mission is completed.

The satellite's overall goal is to map as much of Mars' surface as possible using high-resolution and thermal imaging as well as spectrometry. The probes, launched from the satellite, will land at specified coordinates to confirm the composition of the surface and additionally identify sub-surface resources. The resulting data from the mission will be communicated to Earth using the Deep Space Network along with X-band and UHF communication systems on the satellite and probes.

This mission's scale in terms of design presents numerous challenges. The risk of launch failure will be mitigated through pre-flight testing and launching before the launch window to allow for multiple attempts. The satellite and probes will have back-up barriers, computing units, and communication systems in case of hardware failure. For the harsh environment, including dust storms and radiation, will be managed through radiation hardened materials and protective layers.

Overall, M.E.S.A.'s mission aims to significantly improve upon the understanding of Mars with invaluable data for missions in the future. Not only could it contribute to the goal of manned missions to Mars but change how exploration spacecraft are designed.

# II. Mission Concept and Operations

## D. Overview

The mission plan is to launch a satellite (V.I.T.A.L.) and the probes attached to it on a Falcon Heavy rocket. V.I.T.A.L. will disconnect from the rocket in LEO and will continue toward Mars. Once there, V.I.T.A.L. will orbit above the Martian surface until primary data collection is complete. This will include the terrain and elevation profile along with the first stage of resource identification. The data will then be used to locate points of interest for the deployment of probes to collect further data on Mars' resources until their E.O.L. or the mission's end.

### E. Goals

The goals for the mission are to collect data that furthers the understanding of Mars and innovate better designs, which will both be needed for exploration of the planet in the future. These goals are split mainly into two categories: a scientific category centered collecting and analyzing data, and another category focused more on engineering and sustainability.

#### *1. Scientific*

The scientific area here aims to collect data that will be of great value to future exploration, such as ideal locations for landing and resources. The satellite will record the geography of Mars, including the terrain and elevation, and the composition of the surface. To accomplish this, Mars will be mapped using high-resolution cameras along with thermal imaging and spectrometry. The probes will be used in further analysis of the surface resources as well as identifying sub-surface resources below the surface.

#### *2. Engineering*

To achieve this mission and improve upon previous ones, the team designed a satellite able to launch probes to the specified points on Mars based on data collected in the mission. The satellite will be focused on communicating to both Earth and the probes, while maintaining orbit, avoiding any collisions, and withstanding the harsh environment. The probes will be capable of surviving the dust storms and climate as well as maintaining operations for as long as possible, much like the satellite.

### F. Target

The V.I.T.A.L. satellite aims to insert itself into a low polar orbit around Mars, around 300 km above the surface, to collect its data. The probes launched from the satellite will be sent to areas of geographic notability and/or richness in resources.

### G. Constraints and Assumptions

The RFP requires that the mission designed will deploy assets to Mars with the ability to cover at least 75% of the planet for data. These assets used must be launched and collect the required data by at least December 31st, 2033, and not exceed a budget of $1 billion USD before the required data is collected. Moreover, the design is intended to remain operational and continue its data collection until the late 2030s.

To complete the data collection before 2033, the plan is to have the assets in Mars' orbit by June 2033 to allow for at least six months of data collection. For the best energy efficiency, Mars and Earth need to be properly aligned, which only occurs every twenty-six months [2]. This leads to a smaller launch window, assuming the spacecraft is prepared by 2030, but a duration of four to five months is achievable if launched in March 2031 [3].

## III. Mission Architecture

### H. Spacecraft Systems and Subsystems

#### *3. Propulsion*

The propulsions system options for each craft were limited due to their complex designs and maneuvers. Below is a description of how each system works to fulfill the thrust requirements and why it was chosen.

**Satellite**

The propulsion system on the team's VITAL satellite utilizes solar electric thrusters for maneuvers and thrust. Solar electric thruster is an advanced propulsion system that uses electricity from solar panels to ionize and accelerate a propellant. Unlike chemical propulsion, which relies on combustion for high thrust over short periods, solar electric propulsion (SEP) is highly efficient due to its ability to operate low-thrust acceleration over long durations. This allows the spacecraft to carry less propellant, which reduces overall mass and extends mission capabilities.

The system works by using solar energy to power an ion engine, where electric fields accelerate charged particles (ions) to produce thrust [4]. The steady acceleration builds up over time, making SEP ideal for deep-space missions. Key advantages of solar electric thrusters include fuel efficiency, extended operational lifetime, and precise maneuvering capabilities.

**Probe**

A chemical thruster was chosen for the Mars probes because of its high thrust and ability to perform rapid orbital maneuvers [5]. Chemical thrusters generate instantaneous and powerful acceleration, and their proven record in deep-space missions minimizes technological risks, offering a dependable and time-tested solution for reaching and operating around Mars.

While chemical thrusters consume more fuel than electric alternatives, their ability to execute fast and decisive burns makes them the optimal choice for our mission's needs.

*4. Power Production*

Power production was arguably the most important requirement in all spacecraft involved, as, without enough continuous power, many systems would fail, shortening the intended timeline of the mission.

**Satellite**

To ensure one of the most vital parts of the system is reliable and predictable, traditional folding solar panels were attached to the sides of the satellite capable of generating plenty of power for all the required instruments and computing systems. This power production is supplemented with batteries for when power generation is not possible and in case of a power failure from a solar panel or the primary batteries.

**Probe**

For the probes, power production was a more complex topic, as size was a major limiting factor in their design. In this case, the team chose a more experimental but also more efficient power source in terms of cost and size to ensure the probes survived the harsh conditions with enough power. Using a lower TRL perovskite based solar cell system, the tops of the probes were used as solar panels to generate and transfer just enough power for each probe's operations on the planet.

*5. Communication*

To retrieve the data from the satellite and probes without a return mission, a network of communication with short- and long-range capabilities will be needed. The method of communication we chose was X-band and UHF because of their reliability. The mission we have developed will utilize the satellite as the main center for communication between Mars and Earth. It will communicate with X-band radio frequency to Earth's Deep Space Network (DSN) to ensure effective and efficient data transmission. This will utilize a high-gain antenna (HGA) primarily with low-gain antennas (LGAs) as a back-up system [6].

To retrieve the secondary data from the probes, the satellite and probes will both be equipped with UHF transceivers for simpler yet effective communication. The satellite will then transmit this data back to Earth as previously mentioned.

*6. Scientific Instruments and Payload*

Each system was provided with unique instruments to obtain as many types of data as possible with high redundancy. This data is only recorded and sent back to Earth to be interpreted; more detailed information about the satellite and probes is described below.

**Satellite**

The VITAL Mars satellite is equipped with various advanced scientific instruments designed to gather critical data about the planet's surface, atmosphere, and magnetic field. The High-Resolution Imaging Camera captures detailed images of Mars' surface, identifying geological features, mapping terrain, and monitoring changes over time. The Thermal Imaging Camera measures infrared radiation to detect temperature variations across the Martian surface. This helps identify volcanic activity, subsurface heat sources, and thermal properties of rocks and soil. It is also useful for detecting ice deposits and studying how Mars retains and loses heat. The spectrometer analyzes light reflected or emitted from Mars' surface and atmosphere to determine chemical and mineral composition. This is critical for detecting elements such as water-bearing minerals, salts, and potential organic compounds. The Magnetometer measures variations in Mars' magnetic field, providing insights into the planet's core structure and how it lost its global magnetic field over time. Understanding these magnetic properties help scientists study past atmospheric loss and how solar wind affects Mars today. The Atmospheric Sensor monitors temperature, pressure, wind speeds, and gas composition in Mars' atmosphere. It helps study weather patterns, dust storms, and seasonal changes, which are vital for understanding climate dynamics and preparing for human exploration.

**Probe**

The team's Mars probes are equipped with a diverse set of scientific instruments to study the planet's environment, surface, subsurface, and resource potential. The "Weather Station" part of the probe will track temperature, atmospheric pressure, wind speed and patterns, humidity, and dust levels, providing insights into daily and seasonal weather changes on the surface of the planet. A radiation detector will measure cosmic and solar radiation, crucial for assessing risks to future astronauts and equipment for missions in the future. To analyze Mars' surface and subsurface composition, the probe carries a core sampling system, which is a drive tube that will collect accurate representations of the soil layers beneath the surface [7]. The probes also include a spectrometer (x-ray, infrared, or laser-induced), small imaging camera/microscope, and ground-penetrating radar. These instruments will study rock and soil chemistry, detect signs of past water activity, and map underground structures such as ice deposits. The STRATA system will analyze how Martian dust and regolith behave, while a seismometer and teleseismometer will detect mars-quakes, revealing details about the planet's internal structure and tectonic activity. A thermal imaging camera or heat flow sensor will measure surface and subsurface temperatures, allowing the identification of potential volcanic or geothermal activity [8]. For resource detection, a neutron spectrometer and soil moisture sensor will search for hydrogen and water content beneath the surface, identifying potential water ice deposits that could support future missions [9].

*7. Thermal Protection*

For the satellite, thermal protection is light, as any heat from the system is used for efficiency or vented into space easily. However, there are still several outer layers designed to keep all components functional throughout the entire mission that help with thermal protection among various other dangers. On each of the probes, aside from the propulsion system mitigating the reentry speed and heat buildup, a heat shield and several protective outer coatings were integrated into each probe to prolong the expected lifespan from launch. Heat from the instruments is distributed across the system to maintain operating temperatures and ventilation is included for emergency exhaust.

## I. Launch Vehicle

Falcon Heavy was selected as the launch vehicle for the team's mission to Mars due to its high payload capacity, proven reliability, and cost-effectiveness [10]. It has a lift capacity of up to 63,800 kg to low-Earth orbit (LEO) and approximately 16,800 kg to Mars. Its reusability significantly reduces launch costs, making it a more economical choice compared to other heavy-lift rockets. Additionally, Falcon Heavy has a successful flight record, demonstrating its ability to handle complex missions, including interplanetary launches (Europa Clipper).

*8. Justification*

Falcon Heavy provides the thrust and payload capacity necessary to carry the VITAL satellite and propulsion system efficiently to Mars. Its three-core booster design ensures a high level of redundancy and mission success, while its ability to reuse boosters helps keep mission costs down. Falcon Heavy offers an optimal balance of power, cost, and availability, ensuring our mission stays within budget without compromising reliability.

## J. Mission Phasing

As the mission architecture of M.E.S.A. is quite extensive, the activities and procedures must be broken down to be better understood. These processes are set up in five key phases that make the mission a success. The shortest but also most important operation is launching the satellite and following its main delta v is considered the first of the main phases that will be completed if the mission is to go forward. Phase two begins after reaching a relatively fixed speed and travelling on a flight path located in the gravity-free, near-vacuum environment between Earth and Mars. After arriving and beginning an orbit around Mars, the data gathering activities of phase three begins and ends within a few solar weeks to maximize the time and accuracy needed for the next stage. Finally, in the second-to-last phase of the mission, the probes will launch from satellite to gather more information.

If all goes well, the final stage of the mission will be the data gathered, recorded, and sent back to Earth for analysis from both the probes and the satellite itself until the end of the planned mission by the end of the year. These phases are detailed more in the subsections below.

*9. Launch*

M.E.S.A.'s mission will begin aboard one Falcon Heavy rocket holding the V.I.T.A.L. Satellite aboard. Lifting off from Launch Complex 39A at Kennedy Space Center, the rocket will deliver the satellite to its flight path outside Earth's gravity well. From this point on, the satellite will reach a cruising velocity, only moving via onboard thrusters for the purpose of collision avoidance in emergencies.

*10. Cruise*

For the next six months, the V.I.T.A.L. satellite will travel on the long journey from Earth to Mars in a mostly dormant state to minimize power usage. The only systems used will be that of collision avoidance and communications back to Earth to ensure the satellite stays on the flight course.

*11. Arrival*

Finally, after many months of travel, the satellite will put itself into a low polar orbit around Mars and will start its data gathering activities. Using its imaging system, V.I.T.A.L. will map out Mars' surface in high detail and send the images back to Earth to construct a complete or mostly complete map of Mars' surface. After completing several full rotations of Mars' surface, the probes attached to the satellite will be launched off to begin their descent towards Mars' surface.

*12. Probe Launch*

Once detached from the main satellite, each probe will be sent out to their specified coordinates via a custom flight plan executed by controlled ejection from the satellite and a controlled landing from an onboard thruster. While dropping through each layer of Mars' atmosphere, the probes will additionally gather more detailed data on the weather conditions of Mars. Once this operation is complete, each probe will land on the surface of Mars to initiate ground procedures and data gathering. From this point on, both the satellite and the probes will stream data from Mars until their E.O.L. or until mission completion in about six months.

*13. Data Collection and E.O.L.*

In the final six months of the mission, data collection from each of the active probes and the V.I.T.A.L. satellite will be recorded and organized to be sent back to Earth in the priorities they are ranked in to maximize efficiency. Each of these data sources will continue to stream data back to Earth until either all instruments cease functionality, or the mission timeline ends in which the following procedures are beyond the scope of this mission (e.g. continuing data collection or proceeding with a planned deorbiting protocol).

## IV. Main Operations

### K. Mission Timeline/Concept of Operations

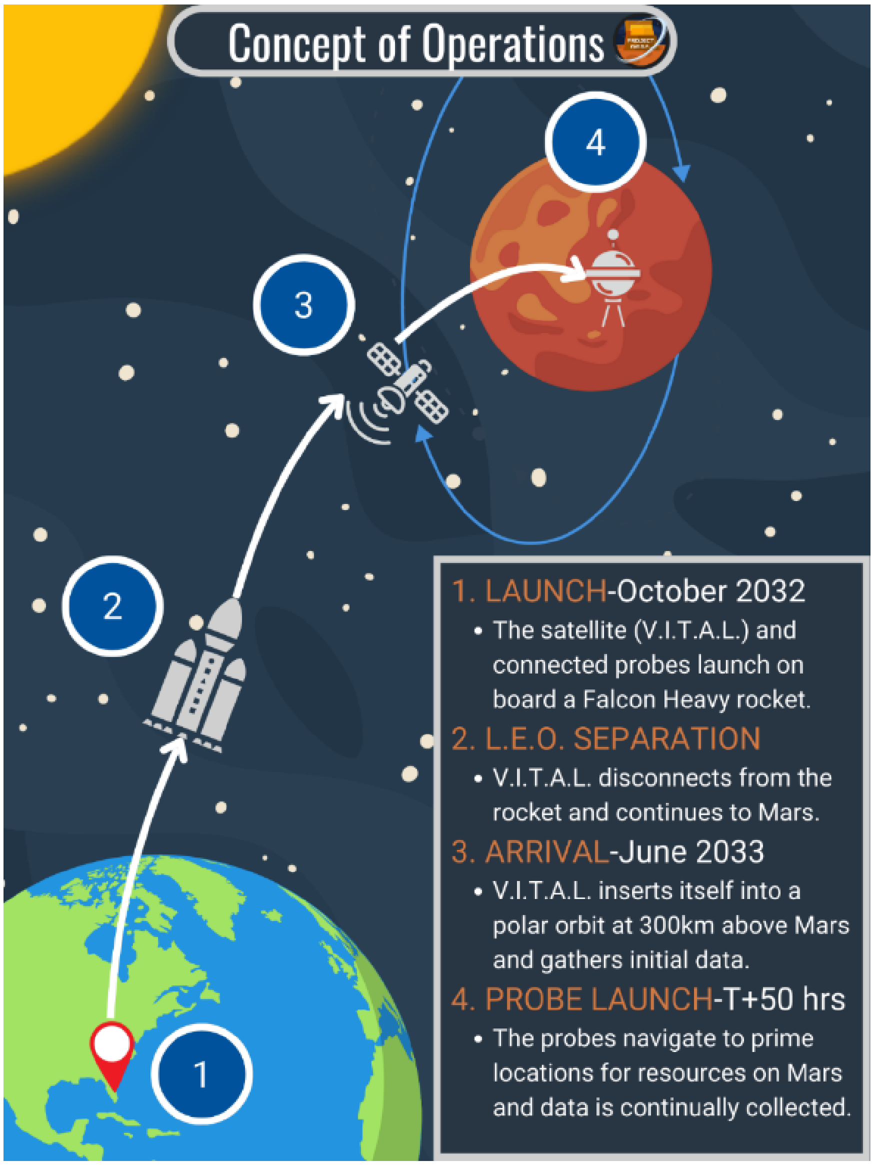


**Fig 1. The team's "Concept of Operations" Infographic, displaying the four general phases of the mission: Launch, L.E.O. Separation (Now L.E.O. Maneuver), Arrival, and Probe Launch.**

### L. Trajectory

The main trajectory of this mission is mostly explained previously by the phased planning system and the Falcon Heavy rocket itself, as the trajectory formation relies on these factors to be put together. This is because data points like the altitude reached, and delta v created relies principally on the launch vehicle itself. However, the trajectory in this mission also has unique planning by being split into three main parts.

From the launch site on the east coast of the United States up until about 200 kilometers up to L.E.O. is considered stage one of the trajectory. This is where the first delta v is calculated and where the "transfer" from Earth orbit to the main flight course to Mars is completed. From this point, the main maneuver is started, that is the process from LEO to arriving at Mars in about four to five months. After finally reaching Mars, the next stage and delta-v maneuver is completed, and the satellite reaches a semi-stable polar orbit around Mars. This is the final stage of the main trajectory, referred to as the Mars Operations Stage, and any additional trajectories from the probes from the satellite to the surface are considered a part of this final section. These additional maneuvers and related delta v's depend on the location of interest for each probe.

### M. Key Risks and Mitigation Strategies

As space missions are a massive endeavor to take on, there are a lot of inherent risks and strategies to resolve or at least mitigate these risks with every step of the way. With MESA's mission timeline and trajectory in mind along with the various constraints initially listed, there were a lot of relatively large risks that came up just in designing a mission like this. Some key risks and their related mitigation strategies are listed in the paragraphs below.

The first and most obvious danger is that of the launch vehicle failing to take off due to some problem with the various systems within a rocket or even because of the payload itself. This has been a problem for missions since their beginning, which has led to common mitigation strategies in the form of procedures and checks always being done up to the very last moments of a launch, with M.E.S.A.'s mitigation tactics not differing and setting an early launch.

Malfunctions or total failures in systems on the satellite itself are a possibility regardless of how well engineered the craft may be. For this situation, the common solution (and choice the team went with) was to have some form of redundancy for all or most systems onboard the satellite and each probe. This was implemented mainly by including backup data transmission, computing, and storage systems as well as secondary batteries to prevent a critical failure resulting in a premature end to the mission. With data transmission systems specifically, there are several backup systems onboard or in proximity to the satellite that allow for communication to continue in the case of a primary broadcast failure.

Some other risks that were considered include instruments affected by space and Mars' conditions, such as the thin atmosphere, dust buildup, and solar radiation. All these risks are mitigated as much as possible mainly through the design and materials of each craft, with each being radiation hardened and having protective coatings for these exact issues.

### N. Sustainability

On the sustainability side of things in terms of the team's mission, all spacecraft were designed to be safely deorbited destructively into Mars' orbit once data collection is no longer feasible, also known as the End-of-Life protocol for this mission. Following this same process, the propulsion system for each probe was designed to impact Mars as little as possible and the structures on the satellite are entirely electric.

## V. Financial and Cost Projections

### O. Cost Estimate Strategy

The budget was calculated using NASA's proprietary Project Cost Estimating Capability (PCEC) software [13]. Individual subsystems, functional properties, development, and overarching global characteristics of the mission such as orbit type and learning curve, was used to generate a realistic model of the costs associated with executing the given mission. These costs were divided amongst ten primary components: Project Management, System Engineering, Safety and Mission Assurance, Science/Technology, Payload, Flight System/Spacecraft, Mission Operations System, Launch Services, Ground Data System, System Integration and Assembly. Although Education and Public Outreach is considered in the PCEC as a major component, it was deemed negligible due to the given scope of the project.

### P. Schedule and Planning

All costs will be recorded in FY2024, $M. Production of components will be beginning the start of the calendar year of 2025, with projection of launch in 2032, concluding the mission the end of 2035. Of the $1 billion total budget, 3.66% of that shall be allocated to reserves mission wide. This value is expected to be adjusted to better reflect the real-life cost as new projections are made. With a remaining budget of $963.4 million after initial reserves, an estimated $36.6 million is required level of burden. This accounts for any developmental uncertainties and unavoidable delays that may occur. This figure was drawn by both triangular distribution and examining previous projects of similar nature. This number is also likely to change as more accurate projections are made closer to submission date.

## VI. Technical Challenges and Conclusion

### Q. Major Technical Challenges

With an analysis of the risk factors associated with the mission to Mars, there are some technical challenges that could occur during the duration of the mission. With the situation of the mission being interplanetary and long-term, there could potentially be communication delays which could lead to trajectory changes. Precise orbital insertion calculations are required [11] and potential failed orbital burns could cause navigation errors upon the arrival of Mars's orbit. Therefore, there are risk factors involved with the orbital mechanics of the mission as it requires a strategic timeline.

For the probe system of our mission, the thin Martian atmosphere makes controlled descent difficult. Entry, descent, and landing (EDL) require precise timing and a large drop in velocity due to reduced drag and minimal aerodynamics that are part of the atmosphere present on Mars [12]. Additionally, the harsh environmental conditions of Mars, including extreme temperatures, dust storms and radiation exposure, can degrade the electronic and mechanical components of our probes. Dust accumulation on the probes can reduce power generation efficiency the longer they stay on the surface. All the data on the probes must be sent back to Earth which includes high-resolution images, sensor data, and telemetry. But limited bandwidth, interference and/or hardware failures could restrict data return.

### R. Unique Features

The unique features of this mission include the copious data collection to thoroughly analyze the surface and subsurface of Mars. The orbit of our satellite will calculate the best landing areas for our probes that will optimize surface analysis. With our mission, including multiple probes that work together, it covers a larger area of the surface where the probes will complete their own data collection that reduces mission time and reduces risk of losing the mission if one of the probes has an autonomous error.

The probes are a rounded hexagonal design that allows multiple to connect to the satellite in an efficient manner. These probes carry both instruments common on all designs and unique parts on each type depending on where each probe is set to land. This is done to collect additional types of data while keeping the designs cost-effective for their limited operational period.

### S. Potential Impact

The impact this mission could have is further data from Mars for scientific analysis which would be useful in fitting together a timeline of the past, present and future of the planet. By mapping out Mars and collecting more detailed data than ever before, a more thorough understanding of Mars and the events related to its past can be obtained. A mission type created in this way, if successful, could obtain more detailed data from entire planets with one launch, further establishing a process of exploring new worlds. Human exploration is extending further into space, and therefore there is a need for intricate knowledge of a potential habitable planet. Mars may very well be the gateway to this information.

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