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Design of a Long-Distance Martian Rover

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Abstract

Martian spacecraft have played a vital part in educating scientists about the Mars environment. Specifically, they have allowed us to believe that there are traces of water present on certain parts of the planet. One major scientific objective goal, based on this discovery, is to further explore these potential water sources. One way to achieve this goal is to send a long-distance Martian rover to Mars so that it can inspect these water sites. Although rovers have had successful missions on Mars, the idea of a long-distance rover involves re-designing many aspects of the past rovers. This paper explores the Martian environment and success of previous rovers to conclude that the Martian rover needs to be improved in the following areas: power source, landing technique, landing accuracy, dust accumulation defense, durability, communication system, and navigation system. In addition, different design solutions are proposed that will aid in the designing of the long-distance rover.

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1. Introduction

Mars, also known as the “red planet”, is fascinating to many people. Some people like Mars because if they look up into the sky on a clear night, they can always recognize it for its distinct red glow. Other people are curious about its chemical buildup and wonder if life did/could ever exist on Mars. NASA and other space-related organizations are constantly conducting scientific studies in hopes to satisfy the curiosity about our neighboring planet. The first step towards learning more about Mars came on July 14, 1965 when the Mariner 4 spacecraft flew by Mars collecting the first close-up photographs of another planet. Although NASA continued to send out spacecraft to collect Martian data, many believe that the first major breakthrough didn’t occur until 1997. In July 1997, NASA’s Sojourner rover became the first solar powered probe to operate on the surface of Mars. The Sojourner’s mission lasted a total of 82 Martian days, traversed approximately 100 meters, performed science and technology experiments, and transmitted images back to Earth. During its mission, the Sojourner relied on solar panels as its main power source. The main scientific instrumentation aboard the rover consists of an Alpha Proton X-ray Spectrometer and three Cameras. The Alpha Proton X-ray Spectrometer is used to study the soil of mars. Findings from the investigations carried out by scientific instruments suggest that Mars, at one time in its past, was warm and wet with water existing in its liquid state.

The belief that there was once water on Mars is consistent with the data from past Martian expeditions. This idea is attractive to many scientists because, in many senses, water means life. The question now becomes, where did this water go? Dr. Ken Edgett, a staff scientist at the Malin Space Science Systems (MSSS) claims that the water which once spanned the surface of Mars is still there but is buried underground. In addition, photographs of Mars predict the locations of these water sources. If only the rovers could explore these locations, then the rovers could potentially discover actual water sources on Mars. Furthermore, if it were proven that water does in fact exist on Mars, then humans could survive on Mars with greater ease and eventually rover expeditions could evolve into human expeditions.

The problem with this idea, however, is that the very flat spots of Mars (ideal landing spots) are not close to the water sources and therefore are presently out of reach of the rovers. If only we could get the rovers to either land closer to the water sources or traverse to these places, then we could take the next step of further exploring potential water sites.

This paper outlines some of the key factors involved in designing a long-distance Martian rover. Specifically, the following topics are covered:

Mars Environment:

- Martian temperature and their effect on the Rovers
- Solar Intensity and dust on Mars rover technology
- Martian rover landing techniques: how to get the rovers from space to the surface of Mars safely
- Martian rover power systems
- Martian rover instrumentation and guidance systems

2. Mars Environment

2.1 Temperature on Mars

The average temperature of Mars is around -63° C (-81° F). The maximum and minimum temperatures ever recorded are 20° C (68° F) and -140° C (-220° F) respectively. These temperatures are much more colder on Earth and therefore are hard to simulate when planning Martian rover missions. The seasons of Mars are much similar to that of Earth except with colder temperatures. The Martian year is approximately equal to 687 Earth days. Each Martian Sol consists of 24.62 Earth hours. Like Earth, the temperature on Mars is a function of the angular orientation of Mars with respect to the Sun (referred to as the solar longitude). The solar longitude can span 360 degrees, which makes up the four different seasons (spring, summer, autumn, and winter). Each season lasts a total of 90 solar longitude degrees. Spring lasts from 0 to 90 solar longitude degrees, summer lasts from 90 to 180, autumn lasts from 180 to 270 and winter lasts from 270 to 360. The length (in Earth days) of the seasons are as follows: spring lasts 196.13 days, summer lasts 182.39 days, autumn lasts 146.32 days, and winter lasts 158.06 days. The temperature ranges for the different seasons are summarized in table 1 [1].

Table 1: Temperature Distribution on Mars

Season	Temperature Range °C (°F)
Spring	-100 to -25 (-148 to -13)
Summer	-90 to –20 (-130 to –4)
Autumn	-100 to –20 (-148 to –4)
Winter	-120 to –150 (-184 to –238)

The lowest temperature ever recorded by the Pathfinder rover is –81.2° C. Although these temperatures are quite cold, the pathfinder isn't rated with a significant thermal lifetime.

There are two major consequences of these cold temperatures that must be considered when planning a long-term rover mission: solar intensity and heat. During the winter seasons, the solar intensity decreases drastically and therefore, if the rover is relying on solar panels as its main source of energy, the rover will not get as much energy as it does during the warmer seasons. In addition, much more energy will be needed to keep the rover warm during the colder seasons. If the rover isn't constantly heated during the winter, then the electronics will essentially freeze to death. One way that the Sojourner rover dealt with cold temperatures was that, in addition to the solar panels (which provided the rover with some heat), it also had a small plutonium heater pellet to help keep it warm.

Conclusion: If the long-distance Martian rover is relying on solar panels for its main source of power, then the tasks of the rover must be reduced during the winter season to compensate for the solar intensity reduction. Table 1 shows that the drastic winter months does not favor the use of solar panels as the primary source of power for the rover.

2.2 Solar Intensity and Dust on Mars

When considering solar-powered Martian rovers, it is necessary to research the amount of solar insolation on Mars. Solar insolation (INcoming SOLar RadiATION) is a measure of the amount of solar radiation that reaches a planet from the sun. The reason that solar insolation values are so important is that solar panels are dependent on this radiation for power. The varying amount of solar insolation that is provided from the sun can be used to determine the amount of power that can be produced from the different solar panels. Martian data shows that that the average solar insolation on the surface of Mars is less than that on Earth. For example, the average solar insolation at the orbit of Mars (at noon) is 590 W/m^2 (compared with the 1370 W/m^2 of Earth) [1]. Scientists Appelbaum and Landis organized the solar energy data from the surface of Mars and concluded that the solar insolation ranges for spring, summer, autumn, and winter are 2.5 to 3.8, 3.8 to 2.3, 2.5 to .8, and .6 to 2.5 respectively (see table 2) [2]. These results tabulate the range of insolation values found at noon on Mars. The units for these values are kW hr/m^2-day.

Table 2: Solar Intensity Distribution on Mars

Season	Solar Intensity Range ($kW\ hr/m^2$-day)
Spring	2.5 to 3.8
Summer	3.8 to 2.3
Autumn	2.5 to 0.8
Winter	0.6 to 2.5

The lower levels of solar intensity shown in table 2 is partly due Mars being farther away from the sun, partly due to the tilt of the planet, and partly due to the dust that is present in the Mars atmosphere.

Mars has always been well known for its high levels of suspended dust (hence the reason why Mars has a distinct red glow to it) but now scientists are able to make a correlation between the levels of dust and the resulting solar insolation values. Scientists have shown that the dust on Mars negatively affects the energy output of the solar panels in two ways. First, the dust acts as a mechanism that scatters the incoming radiation in varying angles before they reach the solar panels. Second, the Martian dust, over time, collects on the solar panels and blocks out the radiation

Since the dust particles of Mars are so small, any sunlight that hits them gets scattered in an array of angles. This means that the sunlight that finally reaches the surface of the planet doesn't reach the surface at a ninety-degree angle, but rather at a range of angles. This decreases the overall intensity of the radiation and hence decreases the power output of the solar panels.

With regards to the dust accumulating on the solar panels, NASA scientists implemented a Materials Adherence Experiment (MAE) into the Sojourner's mission. Scientist developed the MAE in order to gain more insight about how dust accumulation on solar panels affects the power output of the panels. MAE showed that the rate of dust accumulation during the first 20 sols of operation was about 0.33% power output reduction per day [3]. After these first 20 sols, the accumulation decreased to 0.28% per day. In fact, the time scale for this settling has been measured to be on the order of 100 days [4]. Studies show that this factor is a major lifetime limiting factor for a solar power system on any Mars 100+ day mission [6].

Table 3 lists the effects of dust accumulation for a variety of missions.[1]

Table 3: Dust Accumulation Effects for Short and Long Term Missions [5]

Martian Sol	Martian Year	% Obscuration
90	0.13	4.84
270	0.40	14.51
330	0.49	17.73
510	0.76	27.41
570	0.85	30.63
690	1.03	37.08
990	1.48	53.20
1050	1.57	56.43
1110	1.66	59.65
1470	2.20	79.00

Table 3 shows that, for long-term missions, some sort of dust removal technique is pertinent. Different dust removal techniques have been researched and documented [6] [7] [8]. Some different dust removal techniques that are presented include utilizing an articulated array that is periodically rotated into a vertical orientation, physically clearing the array surface using mechanical wiping, blowing a stream of air onto the array surface, periodically shaking the array, shocking the array, or using some type of electrostatic dust removal technique. Typically, the Martian environment tends to favor the electrostatic dust removal technique. The reason for this is that it is highly possible that the dust

[1] Note: This data was interpolated from the data found in reference [7].

might be binding to the solar array via electrostatic adhesion. Most of these references show that dust removal techniques are still under experimentation and we can expect to see some of these ideas tested on the upcoming Mars missions.

So far, we have only considered the harms of dust on the solar array of the rovers. There has been little research conducted on how the dust affects the mechanics of the rover. The past missions have been short enough so that no considerable damage was reported, but it is more than likely that the dust is going to have a greater impact on a long-distance mission and therefore it is necessary to explore how the dust is going to affect other aspects of the rover during a long-term mission.

Conclusion: If solar panels are to be a source of power input on any long-duration Martian rover, then a dust removal technique is necessary. In addition, more experimentation needs to be done with respect to how the dust affects the mechanical aspects of the rover.

3.0 Rover Technology

The goal of a long-term Mars rover is to explore potential water sources and report findings to scientists on Earth. When designing the rover and conducting mission planning, it is important to consider all factors that impact the rover being able to achieve its mission goals. The individual rover systems that encompass these factors are: landing system, power system, and instrumentation system. These factors are examined individually below.

3.1 Landing System

Landing a rover on Mars is much different than landing anything on Earth. The biggest problem that engineers face when designing the landing system, is the Martian atmosphere. The atmosphere of Mars is much thinner than that on Earth (the Martian atmosphere is about 1% of that on Earth) and therefore traditional landing techniques (such as parachutes) are not successful at low altitude because there simply isn't enough atmosphere to slow down the load. A variety of landing techniques have been attempted on the various spacecraft that has been sent to Mars. Table 4 summarizes these different techniques.

Although most of the landing techniques have been successful in the sense that they safely brought the spacecraft onto Mars, they also have the disadvantage of not being very accurate. It is hard to determine exactly where the spacecraft is going to land and therefore it is necessary to choose a landing spot that is very flat with very flat surroundings. It has already been mentioned that potential water sources on Mars are near very rocky terrain and not near "ideal" landing sites. If these spacecraft could land with more accuracy, then it would be easier for the rovers to utilize their long-distance endurance to explore the more interesting spots of Mars.

The cancelled 2001 Lander was supposed to test a guidance system that would actively control its entry path into the Martian atmosphere to ensure that it could come down within 10 km of its target point (the present day spacecraft are typically rated to land within 30 km of their target point). It seems as if a lot of progress has been made in terms of landing techniques over the past decade. The two priorities in the designing of a long-term mission rover are safety and accuracy. Eventually, it would be great if spacecraft could land within a 100-meter accuracy but technology hasn't brought us to that point quite yet. One can probably expect the design of rover landing techniques to continue to evolve as more spacecraft utilize different tactics.

Conclusion: The landing techniques of Martian spacecraft are still under experimentation. Most likely, the next step on landing techniques will involve rockets on the bottom of the lander that will both slow down the speed and direct the lander with more accuracy. For long-distance rovers, it isn't necessary to increase the landing accuracy of the rover but it is definitely favorable.

Table 4: Summary of Martian Spacecraft Landing Techniques

Landing Date	Mission	Landing Technique	Landing Accuracy (km)	Failure/ Success
July 20, 1976	Viking I	Three monopropellant hydrazine engines were used during terminal descent and landing. Control was achieved through the use of an inertial reference unit, four gyros, an aerodecelerator, a radar altimeter, a terminal descent and landing radar, and the control thrusters.	30	Success
September 3, 1976	Viking II	Same as above	30	Success
July 4, 1997	Mars Pathfinder	Mars Pathfinder utilized a parachute to initially slow it down and then a giant system of airbags was deployed to cushion the impact of landing.	30	Success
December 3, 1999	Mars Polar Lander	Utilizes roll thrusters to continually adjust lift profile as it descends. The landing phase will include a 20-meter parachute. Then terminal descent thrusters will fire to slow the lander to a touchdown velocity of 2.5 m/s. In addition, the legs of the lander are designed to crush upon impact.	10	Failure. The lander was lost upon arrival

3.2 Power System

The power system is also an important aspect of spacecraft design. Traditionally, solar panels have been used as the primary source of energy. However, given the environmental conditions on Mars, a nuclear power source may be more effective than the solar panels.

Previous discussion on the environmental conditions of Mars showed that there are two primary factors that negatively affect the use of solar panels on long-term Martian rovers: solar intensity and dust accumulation. Not only does Mars have lower solar intensity values than Earth, but it also has an extremely low intensity value during the winter months. In the past, this has not been an issue since the missions have taken place during the summer, but in the case of long-term missions, it is impossible to avoid that fact that the rover will be getting very little power in the winter season. This is also the season that the rover needs the most warmth since it is so cold. In addition, Table 1 shows that (for long term missions utilizing solar panels) a dust removal technique is necessary for any long-duration Mars mission.

For years, scientists have been studying the use of solar panels in spacecraft in order to design highly efficient panels suitable for low-insolation areas and many different papers have been written that compare/contrast the different solar cells. Of these results, two of the most efficient cells are the GaInP/GaAs photovoltaic cells (which have been shown to produce efficiencies between 25.7 and 30.2% [9]), and concentrator arrays. The concentrator arrays are a unique type of array that relies on minimizing cell area and replacing it with high-efficiency, light-concentrating optics. The disadvantage of concentrator arrays, however, is that a tracking solar panel array (accurate to a few degrees) is necessary to yield optimal performance. [10] Although tracking arrays are advantageous for certain spacecraft applications, a NASA study showed otherwise for Martian rovers. In 1989, B. D. Hibbs published a report that fixed array solar panels are advantageous for Martian Rovers because the added robustness of the fixed arrays makes up for the energy loss associated with the tracking solar arrays. [11]

When selecting the optimal cell arrays for the Martian rovers, it is important to consider the environmental conditions for which the cells were designed. A good portion of the photovoltaic cells is rated for orbital spacecraft use. The Martian environment, however, is not like the orbital environment and therefore special considerations must be made when choosing the ideal solar panels for the Mars rovers.

Studies show that the "redder spectrum of Mars and the low operating temperature tend to favor solar cell technologies, such as GaAs and dual-junction GaInP/GaAs cells." [12] In addition, a lightweight flexible array is favored due to the strong winds that occur on the surface of Mars. Unfortunately, there still is much more research that needs to be done with regards to how the different cell arrays respond to variables such as temperature, sun angle, and atmospheric dust.. However, current studies favor the GaInP/GaAs array. Further explorations into the solar cell selection and Mars are to be integrated into future Mars missions. [13]

The other type of feasible power source under discussion is nuclear power. There are two different types of nuclear power sources that have been evaluated for spacecraft performance: radioisotope and reactor. Radioisotope power sources are used to provide Radioisotope Thermoelectric Generators (RTGs). These are optimal for rover missions since they provide the electrical power to the rover. Reactor power sources, on the other hand, are useful to power electric propulsion systems. Typical applications of the reactor power source are long-range missions such as spacecraft designed to explore outer planets. Since the scope of this paper is in rover missions, it was decided to focus on the radioisotope nuclear power sources.

The design of radioisotope nuclear power source is a multistage operation. First the nuclear heat source (either a radioisotope heat source or a nuclear reactor heat source) generates the energy. Then a converter is needed to convert the thermal power to electric power. Typical converters are thermoelectric, thermionic, thermophotovoltaic, Brayton, Rankine, Stirling, or magnetohydrodynamic. Finally, a thermal management system is needed to remove the unused heat. The advantages of the nuclear power source are its long lifetime, ability to withstand external radiation, independence, and reliability. Since the nuclear power source doesn't rely on the sun for its energy, it is able to provide a constant source of energy under any environmental conditions. The nuclear power source is also more independent since it doesn't rely on any sun-tracking systems that some solar arrays need.

Nuclear power sources have played an important role in past spacecraft missions. From 1961 to 1996, the US has flown 41 RTGs and one reactor to power 25 space systems. Of these 25 missions, 22 of them are either still in space or on the surface of other planets. [14] With any nuclear power source, there is always a safety concern. Safety has always been a priority in designing spacecraft and so far there have not been any tragedies associated with the nuclear power source. The US space industry has also designed a smaller form of RTGs referred to as radioisotope heater units (RHUs). The RHUs are used primarily to keep the sensitive scientific instrumentation at the desired temperature. These RHUs utilize plutonium-238. The lifetime of the RHUs is 87.8 years.

The Mars Pathfinder mission utilizes three small RHUs and there were four 42.7-We (Watts) RTGs on the two Viking Landers. Although the mission length of the landers was 90 days, the RTGs continued to power the Landers 6 years into the mission. [15] Other spacecraft that utilized RTGs are Apollo 10, 12, 14, 15, 16, Voyager I and II, Galileo (Jupiter Orbiter), Cassini (Saturn orbiter), and Ulysses (solar orbiter).

If RTGs are going to be used aboard spacecraft, a converter is also needed. Past technological advances led to the development of two different types of conversions systems: static and dynamic. The main difference is that static conversion systems do not contain any moving parts. These systems generally range from 15-29% efficient. [16] Conversely, the dynamic isotope power conversion system utilizes a rotating turbine (Brayton, Rankine, or Sterling Cycle). It is proven that the performance of the dynamic isotope power conversion system far exceeds that of the solar-array/battery system in the context of spacecraft design. [17] In addition, studies have shown that a rotating turbine utilizing the Sterling Cycle is more efficient than either the Rankine or Brayton cycles. [18] Furthermore, the dynamic isotope power conversion system is qualified to meet a range of applications on the Martian surface. [19]

Radioisotope Thermoelectric Generators (RTGs) is one option to providing the Mars rovers with energy. The RTGs are used to produce both heat and electrical power (via a generator) to a system. They are attractive to the space science industry because they are small, they operate with or without solar radiation present, and they have a long lifetime. The Galileo, Ulysses, and Cassini missions utilized RTGs as its primary heat source. The Cassini mission, which was a mission to explore Saturn, depended on the RTGs since Saturn is so far away from the sun. The RTG for these missions generate about 285 watts, have a mass of 55 kilograms, and use radiatively coupled unicouple thermoelectric elements. [20] A more detailed report of the in-flight performance of this generator can be found at [21].

When planning to power a mission with RTGs, is necessary to decide what types of energy are needed. For example, the Mars rover mission needs heat to keep itself warm and it needs electricity to power the rover and to operate the equipment aboard the rover (and therefore RHUs were used). However, if RTGs were used to provide the rover with electrical power, then a generator would be necessary.

The Department of Energy, curious about the possibility of using RTGs for multiple uses, funded a program to develop a multicouple thermoelectric converter for RTG applications. The advantages of the multicouple thermoelectric converter are that there is a 20 percent mass reduction plus the ability to choose the power output. [22] The NASA Lewis Research Center took this research a step further and examined small Stirling dynamic isotope power systems that can be used power units in the multi-hundred watts to several kilowatts range. Given this information, it seems like the nuclear power source is the favorable power source in the Martian rover.

The advantages of using nuclear power for the Martian rovers are efficiency, durability, and accessibility. If the rover is completely run off nuclear power then you don't have to worry about the rover running out of power during the winter months (of low sunlight), or freezing to death during the cold days. You don't have to worry about tilting solar panels towards the sun or dust removal techniques. The rovers could operate the same mechanically whether it was night or day, summer or winter. The disadvantages of using nuclear power are human safety and cost. Nuclear power is very dangerous to handle and special precautions must be made when using designing anything that has to do with nuclear power. In addition, nuclear power is much more expensive than solar panels.

Conclusion: Nuclear power seems to be more efficient, longer lasting, and durable than solar panels. The disadvantage of nuclear power, however, is that it is very expensive.

3.3 Instrumentation System:

The instrumentation system of the Martian rovers includes the communication and navigation subsystems. These are discussed individually below.

3.3.1 Rover Communications:

One of the biggest lessons learned from the Pathfinder mission is the necessity of good communications links for long-term missions. After the Pathfinder landed on Mars, the Sojourner was deployed and went out to explore Mars. Before the Sojourner could move, however, it needed a command from Earth. The operators on Earth would send a command to the Pathfinder lander and the Pathfinder lander would then, in turn, relay the command to the Sojourner. When Earth finally lost touch with the Sojourner, scientists believe that there was a disconnect in the link between the Pathfinder and the Sojourner. In fact, many people have visions of the Sojourner, long after the communication between the Pathfinder and Earth was gone, still alive on Mars patiently awaiting its next commands. For any long-term mission, it is almost necessary that the rover be able to communicate directly with Earth.

3.3.2 Rover Navigations:

There are basically two different approaches to rover navigations: autonomous (having a guidance system build into the rover) and controlled (where operators from Earth direct the rover's every move). Most rovers utilize a combination of the techniques. With regards to the Sojourner rover, the autonomy consisted of monochrome stereo forward cameras that were designed to detect hazard terrain. Although the Sojourner was capable of some obstacle avoidance, it couldn't do much else on its own.

In a long-term mission, rover navigation becomes increasingly important with regards to mission planning. If rovers are being controlled from Earth, then this puts a lot of stress on the operators that are controlling the rovers. They have to spend most of their time in the lab monitoring the progress of the rovers and transmitting new commands to the rover. For short-term missions, this isn't too big of a problem but for long-term missions it is important to keep in mind the health and sanity of the scientists navigating the rover.

There are different approaches to making a rover more autonomous. For example, a Mars Equivalent of the Global Positioning System (GPS) could be implemented into the mission planning so that target positions could be uploaded to the rover and the rover could utilize the GPS and obstacle avoidance to navigate itself to its destination. Presently, a Mars GPS system sounds like a good idea but realistically, it couldn't happen any day soon.

A more plausible approach to making the rovers more autonomous is to periodically upload maps to the rover form the controllers via a communication link. Each week, for instance, the rover could get information that outlines its weekly goals. This package would include a map of the weekly area to be traversed and a set of commands for obtaining/transmitting data back to the scientists on Earth. At the beginning of the week, the scientists on Earth can determine the exact location of the rover and then decide how much terrain should be traversed during that particular week (if the rover happens to be in a very rocky part of Mars, then this distance might not be as far as when the rover is in a smooth part of Mars). The rover could then determine the most direct route to the target destination and set off towards that direction. If the rover were to hit an obstacle then its intended trajectory would shut off and the obstacle avoidance system would kick in. While the rover was avoiding obstacles, it would determine the direction change and distance traveled in that direction. When the rover has successfully avoided the obstacle, the rover would do a position update. It would take the position that it was before it got sidetracked, determine its new position by adding in the distance it moved during obstacle avoidance and then recalculate the most direct route to the target and head off in that direction. Once the rover reached its target position, it would cease movement, report back to Earth that it has reached its target and wait further commands. In addition, if the rover happened to go off the map while doing an obstacle avoidance maneuver, it could cease movement and send a message to Earth saying that it want out of the bounds and then it will await further commands. The advantages to this approach are that the scientists only have to work hard during one day of the week (assuming that the rover doesn't go out of bounds). The disadvantages of this would be that the rover might not take the most direct route to its target. A long-term mission, however, isn't very plausible without this added autonomy and therefore it seems as if the advantages of the added autonomy outweigh the losses.

Conclusion: The design of a long-distance Martian rover must include an improved self-guidance system and better communications with the operators on Earth.

4.0 Future Mars Exploration

Mars exploration has only just begun. The recent success of the Sojourner rover has only paved a path for the future of Mars exploration. There are still many unanswered questions about Mars and scientists are eager to continue dedicating time and money to learn more about our neighboring planet. Table 5 summarizes the next steps in Mars exploration.

In addition to the missions outlined in table 5, the space industry has already outlined some major goals for future Mars missions. These goals include:

- **Improved Mars Orbiter**: The purpose of such orbiter, already termed the Reconnaissance Orbiter, is to analyze the surface of Mars at new scales in an effort to follow tantalizing hints of water detected in images from the Mars Global Surveyor spacecraft, and to bridge the gap between surface observations and measurements from orbit. The goal of the orbiter is to measure thousands of Martian landscapes at 20- to 30-centimeter (8- to 12-inch) resolution.

- **Scout Missions:** NASA has recently proposed to create a new line of small "Scout" missions. These missions involve sending a new type of spacecraft to Mars. Some proposed scout missions include designing airplanes or hot air balloons that can aid in Mars exploration.

- **Sample Return Mission**: Scientists are eager to launch a sample return mission to Mars. Such mission would be a huge breakthrough in Mars exploration since it would be the first time a scientist could sit in a lab and examine actual pieces of Mars.

5.0 Discussion:

Table 6 summarizes the successful missions that consisted of placing a spacecraft onto the surface of Mars. One thing that is similar to all three of the missions outlined in Table 6 is that they all outlived their original mission lifetime. For example, the Viking mission was planned to continue for 90 days after landing. However, the Viking 2 lander functioned for a 4-year span. In addition, the Pathfinder outlived its rated 30 day mission and some scientists believe that the Sojourner might still be alive on Mars awaiting its next set of orders from the Pathfinder.

One obvious next step in the Mars rover timeline is a long-endurance long-traverse rover. A rover that will be able to cover a much larger portion of Mars which would aid scientists in their search for water on Mars. The past rover/landers have shown us that the potential is there. We simply need to harness it and design a rover that will fit a long-distance mission plan. The key factors involved in designing a long-distance Martian rover are power, durability, and navigation.

For any long-term autonomous mission, power is clearly a top concern. Although solar panels have been proven effective in past missions, nuclear power is the most efficient power source for long-term missions. If solar panels were used then the rover would also need a dust-removal mechanism to clean the solar panels. There is also additional concern about whether or not the rover would survive the cold winter months of Mars on minimum solar intensity values (such as those present on Mars during the winter).

One of the main mission objectives for a long distance Mars mission is exploring potential water sources. Unfortunately these key sites are surrounded by very rough terrain. When designing a rover for such missions, it is important to keep in mind the environmental conditions. If the rover is going to run into large rocks and such, it is important that the rover is designed to deal with these situations. For example, if the rover had larger tires, then it would be able to go over larger rocks. The previous rover, Sojourner, was designed to go around all obstacles and therefore it is not capable to go over anything. This aspect of the rover needs to be re-analyzed. If the rover is going into rocky terrain, maybe it should be equipped with the ability to go over rocks in addition to having obstacle avoidance technology. Essentially, the rover needs to be durable enough so that it doesn't get stuck during its mission.

One of the biggest lessons learned from the Sojourner operations is the need for real-time observation, rapidly produced maps, and flexible

Table 5: Future of Mars Exploration

Mission	Date	Comments
2001 Mars Odyssey	*Launch:* April 7, 2001 *Arrival:* October 24, 2001	2001 Mars Odyssey is an orbiting spacecraft designed to determine the composition of the planet's surface, to detect water and shallow buried ice, and to study the radiation environment.
Mars Express	*Launch:* June 2003 *Arrival:* December 2003	As a joint program with the European Space Agency, the Mars Express which will explore the atmosphere and surface of Mars from polar orbit.
2003 Mars Exploration Rovers	*Launch:* May-July 2003 *Arrival:* January-February 2004	For this mission, two powerful new Mars rovers will be sent to Mars. These rovers are a huge step up from the previous Sojourner rover in terms of mobility. The rovers are designed to trek up to 100 meters (about 110 yards) across the surface each Martian day. The purpose of the mission is to search for evidence of liquid water that may have been present in the planet's past.

Table 6: Summary of Successful Martian Spacecraft

Mission	Date	Comments
Viking 1 & 2	September 3, 1976 Viking 2 landed	Besides taking photographs and collecting other science data on the Martian surface, the Viking lander conducted three biology experiments designed to look for possible signs of life. These experiments discovered unexpected and enigmatic chemical activity in the Martian soil, but provided no clear evidence for the presence of living microorganisms in soil near the landing sites.
Pathfinder	December 4, 1996. Pathfinder was launched	Mars Pathfinder was originally designed to test the rover delivery system. The Pathfinder successfully landed on Mars and deployed the Sojourner Rover onto the surface of Mars.

navigation tools. By increasing the mission length, one must consequently increase the autonomy of the rover. The rover will no longer be able to continuously rely on the operators for updated navigation commands. Although this technology is still experimental, it will need to be integrated into future mission if any increased autonomy is desired.

Relatively speaking, the design of long-distance rovers is still in the beginning stages. As more rovers are launched onto Mars, scientists will be able to gain more experience about rover design and mission planning. Scientists have already talked about deploying a MIP (Mars In-situ Propellant Production) onto Mars, which will test the technology of making rocket fuel on Mars. If this works, the idea of rover design will take on a whole new meaning. In fact, all of these missions are precursors to bringing people to Mars. Personally, I am excited to watch how Mars exploration evolved over the next few decades.

6.0 Conclusion:

The future improvements that could be made when designing a long-distance rover are as follows:

- The integration of nuclear power into more aspects of the rovers every day power supply.
- The ability for a lander to perform obstacle avoidance (to steer away from rough terrain) during its descent onto Mars.
- An improved safe and accurate landing.
- More experiments into the effects that the dust has on the mechanics of the rover.
- Improved self-navigation and obstacle avoidance techniques
- More durable rover that is rated to operate on rough terrain.
- Implementation of a dust removal technique on all rovers that contain solar arrays
- Implementation of a direct communication link between the rover and the operators (as will be seen on the Mars 2003 Fido rover).

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