Proceedings of the 2023 International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/10/20230342

Research on the feasibility of Mars colonization

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Abstract. Nowadays, the planning on manned mission to Mars from NASA and other institutions have brought interest to Mars again. People wonder if Mars can be the first colony of humanity. To provide an insight to this question, this essay focus on various prospective to discuss whether it is possible for humans to colonize Mars now, or perhaps in the near future. The essay first identifies essential technology needed for a success Mars colonization. Then, examine the past researches to check whether current technology can meet the requirements for Mars colonization. The research finds that the transportation between Earth and Mars is not hard to do, but the efficiency is extremely low by now. Building space stations as intermediates and developing recyclable rocket may help on this problem. When building a settlement on Mars, the life support system will not be a big issue because there are already functional technologies to produce oxygen and plant food on Mars, while water can be extracted from ice sheets on Mars. Meanwhile, requirement for energy can be easily solved by relying on solar energy, wind energy, geothermal energy and nuclear energy. Reconstructing Martian environment is not hard when it comes to altering the atmosphere, but is constructing an artificial magnetosphere is currently unpractical. Mars colonization is still not feasible now, but might be possible within one or two decades.

Keywords. Mars colonization, astronomy, engineering, analysis.

1. Introduction

Ever since the first man was successfully sent into the space and the first man had landed on the moon, people always dream of colonizing the Mars. Mars is colder than Earth, and its atmosphere is mainly consisted of carbon dioxide, with only about 0.15% of oxygen. This environment is impossible for human to survive. However, it is still the most similar planet to Earth in the solar system, and such environment difference may still be able to be resolved by modern technology.

There are already many previous researches on Mars colonization, whether in the field of engineering, dynamics or biology. Scientists have made numerous technical breakthroughs to fulfil the purpose of sending people to Mars. Although many researches are made, none has focused on analyzing Mars colonization from a more general prospective. A conclusion of past researches is necessary for people to have a clearer view on the progress of this plan.

This essay will analyze whether human is capable of colonizing Mars by now. The essay will analyze from different prospectives, in order to provide a general overview of Mars colonization. The analysis begins from the value and potential of Mars Colonization, to finding an efficient way to send people and

DOI: 10.54254/2753-8818/10/20230342

equipment to Mars, to how to construct a habitable settlement. This essay will compare the technology needed for Mars colonization and current technology and discuss whether reality fit the needs.

This essay quoted information from many past research papers. There is various information about rocket dynamics and spacecrafts in [1-6], in order to address the problem of transportation between Earth and Mars. [7-10] provides information about building sustainable and life-supporting settlements on Mars. Information about the development of nuclear fusion reactor is included in [11]. In-depth research on reconstructing Martian environment is from [12].

2. Method

2.1. Subjects

The research will be based on several part of subjects. Chapter 3.1 is to discuss the value of colonizing Mars. Analyze what colonizing Mars can bring us. Chapter 3.2 will be about how to send people to Mars in an efficient way, focusing on past Mass missions and researches of personnel institutions. Chapter 3.3 is to discuss how human can build a sustainable settlement of Mars. Chapter 3.4 will be about the feasibility of reconstructing the environment of Mars to make it more similar to Earth.

2.2. Research methods

This research will be based on the sorting and analysis of previous researches on different technologies. A requirement of technology will be listed according to the need for the colonization of Mars. Then the current technologies will be examined if it fit the criteria of Mars colonization. The essay will analyze whether the technology is advanced enough from different prospectives, so that an overall view on the feasibility of Mars colonization can be reached. Readers can also gain a better understanding on what kind of technology human would need for the colonization to be successful and how far human are from a success in Mars colonization.

3. Result and discussion

This chapter is mainly about the research results on four different aspects. The value of Mars colonization, the efficient transportation between Mars and Earth, the construction of sustainable habitats on Mars and the reconstruction of Martian environment. The essay will than discuss the different results.

3.1. Value of Mars Colonization

3.1.1. The benefit of space colonization. There are many reasons why humanity should start space colonization. A main reason is the constantly growing population. In 2022, global population already exceeds 80 billion people, and it's still growing. Earth is already very crowded when considering the dense population concentration of modern cities. In the future, if the population continues to grow, Earth will eventually lose its ability to provide space and resources for people living on it. Therefore, it is a prominent task to find new places for people to live, so that the population stress on Earth can be relieved. Meanwhile, colonizing exoplanets can provide more resources. For example, exoplanets may contain ores that may be insufficient or hard to excavate on Earth.

3.1.2. The reason to choose Mars. Why do people choose Mars as humanity's primary destination? There are several advantages of Mars over other planets. First of all, the current technology of human is unable to send people to other solar systems. The closest solar system is 4.3 light years away from Earth, which will take nearly ten thousand years for human to reach there. Therefore, it is impossible for humanity to send people out of our solar system to build a space colony by now. This limits the possible destinations into the planets in our solar system. The gas giants such as Jupiter and Saturn can be ignored. Gas giants are mainly made of gases with extreme pressure and weather inside them. Therefore, it is impossible to colonize them. Mercury and Venus both have extreme environment such as significantly

DOI: 10.54254/2753-8818/10/20230342

high temperatures or enormous atmospheric pressure. Moon may seem to be a good choice as it's close to Earth, but its lack of any atmosphere makes human hard to produce oxygen or make any further reconstruction. After all, the best option is Mars.

Mars is still quite different from Earth. Martian atmosphere is very thin, and is primarily consist of carbon dioxide, while Earth's atmosphere is mainly made of nitrogen and oxygen. A year on Mars is approximately 687 days, about twice of Earth. 70% of Earth's surface is covered by liquid water, while no liquid water was yet found on Mars. The temperature of Mars is much lower than Earth, with an average temperature only about -65 Celsius. These conditions may make it hard for human to survive on Mars, but it is still the most similar planet to Earth in our solar system.

3.2. Efficient travel methods between Mars and Earth

3.2.1. Past space missions to Mars. Many countries had launched space mission to Mars before. The Soviet Union and USA had sent many probes to Mars in the middle of 20th century. Later, many countries such as UK, China, India had successfully sent probes into Martian orbit or onto the surface of Mars. Recently, personnel institutions like SpaceX are also working on Mars missions.

In the 20th century, USA and USSR had already succeeded in many space missions to Mars. The more famous Mars mission is in 2011, when NASA successfully sent the land rover Curiosity onto the Martian surface. The more recent Mars missions from USA and China, both in 2020, had both succeeded in landing a probe onto Martian surface.

The multiple success in missions to Mars seems to show that human is completely capable of transporting between Earth and Mars. However, sending probes to Mars is quite different from operating manned missions and massive colonization on Mars. Various problems still need to be solved.

3.2.2. Steps in a Mars mission. A manned mission to Mars in theory can be considered as 4 separate parts [1]. Part 1, sending people out of Earth to start journey to Mars. Part 2, travelling between from Earth's orbit to Martian orbit. Part 3, Landing on Mars and re-launch spacecraft into Martian orbit. Part 4, building a settlement on Mars. In chapter 3.2 the main focus will be on the first three part.

3.2.3. Launching out of Earth. To start a space mission, the first thing is to get out of the bound of Earth's gravity. The most efficient way for a space mission is to start from Earth's orbit directly. Starting a mission to Mars directly from Earth's orbit is easier than starting from Earth, as the spacecraft can carry more fuel if they don't need to get rid of Earth's gravity first. To achieve this, a space station acting as intermediate is necessary. Building a space station is not a difficult thing for human now, because there are many previous records such as the International Space Station and Tiangong Space Station. However, even if the space station is built, astronauts and supplies still need to be carried from Earth to the space station.

The most common way is to use rockets. For many years people have been using rockets to send spacecrafts into outer space. It is by far the most efficient method. A good choice is to use Hybrid rockets, which contain fuels of different states of matters. These hybrid rockets are proved to be more reliable and cheaper than traditional rockets [2].

A problem of rocket is its cost. In order to work against gravity and travel into space, rockets need enormous numbers of fuels and delicately designed body. The rocket must be both sturdy and firm to successfully enter Earth's orbit without exploding. Therefore, the manufacture of a rocket is extremely expensive. Currently, most rocket can only be used once, as they are thrown away in midair after the fuel is used up. Doing this constantly will make space travelling too costly to afford. Fortunately, people have been working on solving this issue. SpaceX, a famous company has been concentrating on designing rockets that can be recycled after launch in the past decade. The main idea is that to allow the rockets to use the rest of its fuel to decelerate itself after they are thrown off from the main body of spacecraft, so that they can land safely on platforms. After some maintenance, the rocket can then be used in different launching missions again. After a few failures, the SpaceX team succeeded on their

DOI: 10.54254/2753-8818/10/20230342

fifth trial in May 2021 [3]. Although this technology is not that stable now, it is not far from being operational.

Despite using rocket, there is also another way, that is to build a space elevator. A space elevator is a huge elevator that can directly send things into outer space. If such facility is built, its efficiency will be extremely high. The only consumption for people to send things up into space will only be some electricity. However, a space elevator requires a strong material that is still far beyond the ability of most materials now. A common believe is that carbon-nanotube can be used to manufacture space elevator, but current study still cannot fulfill such need.

3.2.4. Between Earth and Mars. As previously mentioned in 3.2.1, human have already sent probes to Mars for many times. Therefore, there's no need to discuss human's ability to send objects to Mars, but more on the efficiency of transportation.

The first thing to consider is time. When considering the most recent two space mission, they both launch at July 2020 and reach Mars on February 2021. It is clear that the time taken for spacecrafts to travel between Earth and Mars now is approximately 6 months. The time to travel is unlikely to be shorter as spacecrafts in Mars missions mainly rely on the gravity of planets instead of their engines. This long period time of travel brings two issues. One is that astronauts need to have enough oxygen and food for more than 6 months. If astronauts reach Mars before a settlement is set up, they will need even more.

When analyzing the data from NASA, equations relating the mass (in kg) and days taken (d) are :3 astronauts: mass = 16.585 d + 13,545; 4 astronauts: mass = 20.178 d + 15,015; 6 astronauts: mass6 = 28.255 d + 17,101 [4]. Considering the case for 6 astronauts, the mass will be approximately 22 ton. Since most of the power relies of planets' gravity as spacecrafts travel between Earth and Mars, fuel won't be a big worry. However, there still needs to be enough fuels reserved for emergency situation and final landing. Those will take about 18 ton [4]. Therefore, the overall mass of the spacecraft leaving from Earth's orbit will be about 40 tones. 40 ton not a very unacceptable weight for a spacecraft. In fact, many man-carrying spacecrafts itself weighs more than 100 ton. However, building a colony on Mars means that much more passengers needs to be carried than a few astronauts. The weight needed for life support will be significantly bigger if, for example, 20 to 30 people is travelling to Mars. To carry so much passengers, the size of spacecraft also has to be increased. Building such a spacecraft with such a payload will be out of human's ability now. If human can develop a new type of engine that are both fast and long-cruising, the problem may be solved. However, for now, the writer would conclude that human is still unable to efficiently send large amount of people to Mars.

The other one issue is the lack of fast response to unexpected situations on Mars. For example, if the colony of Mars encounters an unexpected lack of food, the supplies can only arrive more than 6 months later. This can be disastrous to the colony. That's why a self-sustained settlement is needed, which will be discussed in chapter 3.3.

3.2.5. In and Out of Mars. Landing on Mars is not a new thing to human. Many probes such as the curiosity land rover has landed on Mars, some even succeeded in returning to Earth. These past missions usually make use of parachutes and air bags to land safely on Mars. However, transporting people onto Mars is another case. To carry enough passengers and their life support system, the lander will be much heavier. This makes it impossible to simply use parachutes [4]. The current best solution is to use a huge heat shield to decelerate the lander, while also solving the problem of heat produced by friction with atmosphere [4,5].

Launching a rocket from Mars is relatively easier than from Earth, because Mars has a mass that is much less than Earth. This results in a lower gravity, so it will take less fuel and power to escape from the Martian gravity. Most of the current missions reuse the lander to launch back into space. This method contain potential danger as the lander may be damaged during landing and launching it may cause explosion [4]. The best way is to build up a launch site on Mar's surface, so that both landing the

DOI: 10.54254/2753-8818/10/20230342

launching will be easier and safer. If SpaceX's recyclable rocket is successfully developed and can be applied on Mars, the transportation in and out of Mars will be easier.

It is also important to build up a space station as intermediate in Mar's orbit, because of similar reasons to building an intermediate in Earth's orbit. This can be done by sending parts of space stations to Mar's orbit separately and assemble them in space. There were already detailed researches on using the Mar's orbit, separating it into orbits for normal satellites and orbits for space wastes [6].

3.3. Building a sustainable settlement

3.3.1. Importance of building a settlement. Building a self-sustained settlement is the key part to Mars colonization. If the colony on Mars requires constant supply from Earth, it will be too vulnerable, because the long distance between Earth and Mars make any fast response to problems impossible. However, it won't be that easy to build a sustainable settlement on a planet with a completely different climate than Earth.

3.3.2. Structure and materials. The gravity on Mars and atmospheric pressure are all lower than Earth. This means that the habitats needed won't have to be as strong as the buildings on Earth. However, there are other factors to consider. To ensure habitants to perform regular activities, the pressure inside the habitat need to be pressurized to about 55.06kPa, which is much bigger than outside the habitat [7]. Moreover, Mars has a surface temperature of approximately -63 Celsius, while temperature inside the habitat needs to be about 25 Celsius for human survival [7]. The habitats need to be able to endure the high difference in pressure across its walls and prevent heats from flowing out of itself.

A recent solution is to directly use soil on Mars as building materials, because sending materials from Earth will consume a lot of time and resources. Back in 2016, Martian concrete is developed by scientists. Martian concrete is mainly composed of Martian soil and molten sulfur, which are all very common on Mars.

Previous research articles propose a shell-like structure to optimize the utilization of materials and resistance to pressures [7]. The walls have to be between 91cm and 182cm to ensure enough structural rigidity against pressure differences. Such design of habitat is perfectly stable under computer simulation [7]. This implies that this design of habitat is most likely to be operational.

3.3.3. Life support system. Life support system can be generally separated into two parts, nutrition and oxygen. The discussion will be focusing on how to grow food on Mars and how to produce oxygen from Martian surface.

Growing foods outside of Earth has been practiced for many times since human started space exploration. Scientists already grew food successfully on space stations using hydroponics. However, because the choices of hydroponic plants are limited, growing plants from Martian soil will be a better solution. There are recent researches on growing food using soils from Mars. Scientists use a mixture called Martian Medium, which is a mixture of Mars regolith and astronauts' urine simulants, to grow plants [8]. The experiment result is very successful. The mixture even shows a higher biomass productivity than soil on Earth [8]. The result reveals that it is perfectly possible to use soils on Mars for food growing. Using similar technology to greenhouses on Earth, food production will be easy to conduct. For nutrition like protein and fat, astronauts may have to use synthetic meat at the beginning. After the settlement is completely built, people can then consider to farming animals on the Martian habitat.

Oxygen is essential for humans' survival on Mars. Generating oxygen is a rather complete technology now after decades of development. In 2021, the equipment MOXIE has already succeeded in producing oxygen from carbon dioxide on Martian surface. The equipment can generate about 10g of oxygen every hour, while the byproducts, carbon monoxide, is released out into the atmosphere [9]. Researchers claims that if a bigger equipment is built, it can produce tones of oxygen for the use of astronauts.

DOI: 10.54254/2753-8818/10/20230342

Water is another crucial factor for human survival. Human had not discovered any liquid water on Mars yet, not even under the surface of Mars [10]. Fortunately, Mars is not that dehydrated as it seems to be. There are huge ice sheets on the poles of Mars. These ices can be extracted and then made into liquid water for drinking or irrigation. Water can also be recycled by reusing the urine of habitants and water moisture in the air.

Overall, nutrition, oxygen and water are not limiting factors of Mars colonization, as there are perfectly feasible solutions to their deficiency on Mars.

3.3.4. Energy. Energy is important for the construction of Mars colony and the survival of people living in. It's not possible to rely on traditional fuel cells on Mars, because there are no crude oils on Mars. Crude oils are formed by organic compounds of dead organism, which is probably not present on Mars according to current researches. Meanwhile, transporting them from Earth to Mars will be very expensive and inefficient. Therefore, the energy on Mars will have to be from new energy resources

Solar energy is a popular choice. Mars have a thinner atmosphere than Earth, which means that solar panels can be more efficient on Mars. Panels can be set on the top of buildings to reduce waste of land. However, constant sand storms on Mars can be damaging to solar panels, which means that some protection have to be developed to ensure the operation of solar panels. Wind energy is very suitable for Mars, because its huge temperature differences across its surface can produce strong wind. The constant wind and storms can provide large amount of energy to turbines. Geothermal is another possible source, because Mars have the same crustal movement as Earth.

A potential choice of an energy source is a nuclear reactor. A nuclear fission reactor on Mars won't be much different than on Earth. It is still perfectly functional but facing the same problem of producing nuclear wastes and possible nuclear leak. The more promising technology is a nuclear fusion reactor. Theoretically, a nuclear fusion reactor can produce infinite energy without of producing any harmful wastes. However, nuclear fusion reactors are still under development and optimization of scientists. It is only recently is the reactor able to produce more energy than input energy, but its efficiency is now quickly growing. It is believed that nuclear fusion reactor will soon be commercially feasible and functional in the middle of 21th century [11]. If an efficient nuclear fusion reactor is developed, it will be extremely beneficial for the colonization of Mars and further space colonization, since it can be used as energy source of space stations, exoplanet colonies and spacecrafts.

Overall, there are various feasible ways to generate energy on Mars. Therefore, energy is not a problem to the colonization of Mars.

3.4. Reconstructing Mars environment

3.4.1. Reason of reconstruction. Although having a self-sustained settlement can allow human to survive on Mars, it is not efficient enough. Most part on Mars will remain uninhabited, and colonizing these new areas require humans to build new self-sustainable habitats again and again. This can be costly and very inconvenient for colonization, especially when considering the land utilization rate.

Reconstructing Martian environment will not be an easy task, but it's far from being impossible. The main cause of difference between Earth and Mars is its climate. Mars is much farther from Sun than Earth, and its thin layer of atmosphere makes it hard to hold heats from Sun. This results in significant difference in temperature, which frozen all the liquid water, causing Mars to be lifeless. If this temperature problem can be solved, Martian environment can be similar to Earth's.

To reduce the heat lost on Mars, there are mainly two project that can be introduced. Altering the Martian atmosphere and creating a magnetosphere.

3.4.2. Atmosphere. There are two problems regarding the Martian atmosphere. One is that it's lack of oxygen, which only take up 1% of the Martian atmosphere. The second is that the atmosphere of Mars is too thin, making it unable to hold heat.

DOI: 10.54254/2753-8818/10/20230342

Simply adding oxygen to Martian atmosphere will not be feasible. Oxygen can be lethal to human at high concentration in air. The ideal percentage of oxygen should be around 21%. Meanwhile, high concentration of carbon dioxide is also lethal. Its concentration should be controlled to less than 1% in air. This means that human would need something else to fill up the rest 78% of atmosphere. The best choice is to use nitrogen, as it is the same gas that take up 78% of air on Earth and is harmless to human.

As previously mentioned in 3.3.3, it is feasible to convert carbon dioxide to oxygen. This technology can help reducing carbon dioxide concentration and increase oxygen concentration. However, because it is also necessary to make Martian atmosphere thicker, there is need to produce more oxygen and carbon dioxide instead of simply converting. Oxygen might be generated by electrolyzing water while carbon dioxide can be produced by decomposing carbonates. At the same time, nitrogen can be generated by electrolyzing nitrates and decomposing nitrogen-containing compounds, supplied from Earth or Mars itself.

3.4.3. Magnetosphere. Mars itself does not have a magnetosphere. The lack of magnetosphere leave Mars unprotected from cosmic rays, especially those from a solar wind. These rays can harm the health of human, damage equipment and blow away the atmosphere of Mars. Therefore, producing an artificial magnetosphere is a beneficial thing to do to completely reconstruct Mars.

Producing such a huge magnetic field requires a lot of energy, the plan may not be feasible until the development of efficient nuclear fusion reactor. However, it is still possible to look into some of the possibilities. The current solution is to use a huge solenoid that orbit Mars [12]. The solenoid may take a geostationary orbit, but to make the magnetic field stronger, it is better to take a lower orbit. In this case the spacecraft carrying solenoid would need constant propelling power to keep it in orbit. It may be better to use a super conductor as well, which is not a reliable technology by now.

Generally, the plan to produce a magnetosphere is still unpractical for human. The plan may only be operational after an efficient nuclear fusion reactor and a reliable super conductor technology are developed.

4. Conclusion

The essay has already discussed the feasibility of Mars colonization from several aspects. Now a conclusion can be made.

The transportation between Earth and Mars is perfectly functional, but is far from required efficiency. Mass colonization of Mars could only be possible after the technology of reusable rocket is developed and a massive intermediary space station is built in Earth's and Mars' orbit. It is also important to design a bigger rocket that could carry more people and resources to increase efficiency. The reusable rocket technology may be developed by SpaceX in a few years, while building space stations will take more time.

Building a sustainable habitat on Mars is feasible at now. The problem of materials, life-support system and energy can all be solved by current technologies. Meanwhile, the operation of the habitat will be much easier if an efficient nuclear fusion reactor can be developed. According to recent research, it won't take long for an economic nuclear fusion reactor to be made.

Reconstructing the Martian environment is a rather difficult task. The renovation of Martian atmosphere is theoretically possible, but requires a large-scale utilization of present technologies. Meanwhile, producing an artificial magnetosphere may need more energy than human can generated using current technologies. The plan might again require a nuclear fusion reactor and well-developed super conductor technology to function well, which will still take many years a accomplish after colonization started.

Overall, it is clear that although many current technologies are enough for human to colonize Mars, some essential parts are missing. Fortunately, most technologies that human still need are about to be developed successfully within one to two decades. Therefore, this research concluded that, Mars colonization is still not feasible for human now. However, it may soon be possible in the next decade or two decades. In 20 to 40 years, it may be possible for people to see a fully operational colony on Mars.

DOI: 10.54254/2753-8818/10/20230342

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