Proceedings of the 3rd International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/13/20240854

Review of the technologies and preparations required for Mars colonization

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Abstract. Based on the recent increase in information gained from the growing number of space research missions, many researchers and scholars have begun to reconsider the interplanetary expansion program and have chosen Mars, a resource-rich planet, as a prime research target. The recommendation and implementation of this program need to take into account the needs for long-term space missions, including transportation, equipment, energy, carrying capacity, technology, and life-sustaining carbon, hydrogen, and oxygen. Through the research methods of literature review and theoretical analysis, this paper organizes and analyzes the factors and technological requirements that need to be considered for a long-term space mission, the Transplanetary Colonization Program project, as well as presenting the prerequisites for the colonization of Mars, using the current widely accepted program as a case study. As Mars possesses richer natural resources, the principles needed for transportation survival can be obtained through the exploitation of the resources of Mars itself. Therefore, as a transportation rocket, it can have the greatest flexibility in the design of carrying capacity. In addition, artificial intelligence, 3D printing technology, and nanotechnology are the main priority areas that need to be overcome, which can help in the construction part of the subsequent mission execution.

Keywords: Mars, Aerospace, Spacecraft, Space Colonization.

1. Introduction

The climate crisis, the exploitation of natural resources, and concerns about the growing world population are leading more and more people to think about new solutions. Based on recent advances in spaceflight and commercial space programs, plans for interplanetary expansion have been revived and are becoming a topic of increasing discussion in science today. Of all the known planets in the solar system, Mars is rich in resources, including large amounts of water and carbon dioxide, minerals, and life-sustaining carbon, hydrogen, and oxygen. Some space programs are therefore looking to Mars as the next stage of human development. Although the environmental and ecological conditions on the surface of Mars are not considered friendly for human survival, the energy and resources it possesses support all the natural resources needed to establish a self-sufficient base. Therefore, based on the currently available data and information about Mars and related issues, some researchers have proposed plans for interplanetary colonization and long-term space missions (e.g., JEANNE Habitat, In-Situ Resource Utilization (ISRU), etc.), including safe and affordable manned rocket spacecraft technology, Mars energy resource development and utilization, base construction, personnel safety and security, etc [1-3]. This paper summarizes and analyzes the research on Mars colonization projects based on a literature review, aiming at exploring the possibilities of interplanetary migration as a space and aviation enterprise, the technical support needed, and the ways to achieve it.

By analyzing and summarizing the current research and content, it is hoped that it can provide space research enthusiasts with relevant information and increase their attention to the relevant project technologies. At the same time, as society's interest in space and aviation increases, the impact of the aerospace program can be increased.

2. Preparations

2.1. Transportation

The arrangement and selection of transportation carriers were important factors throughout the overall colonization plan and plans for future development. For the early pioneers of the colonization program, the need for transportation was to be able to carry the necessary items to the destination safely.

Considering the distances traveled and the fuel and energy required for the rockets, it was recommended that the materials to be transported to Mars for infrastructure purposes be minimized since more massive rockets are required to transport more mass, which requires more fuel and energy to propel the rockets [4]. Additionally, NASA has stated that increasing the capacity of rockets is extremely expensive to manufacture and transport, and therefore recommends reducing the capacity of individual rockets to carry only the relevant necessities, and switching to the ISRU (In-Situ Resource Utilization) method, which reduces the amount of energy required for individual rockets to travel to Mars, thus further optimizing the utilization rate [2-3].

McHenry et al. propose to construct the base through 3D printing techniques and the use of pre-coded programs, such as the CORELAP system (Computerized Relational Layout Planning), which is commonly used for planning facility layouts [1]. Simultaneously, some basic equipment and machinery would be sent to Mars to support the pre-build infrastructure. Raw materials for 3D printing can be obtained from the ISRU robotic mission, while the dome and pill-shaped structures are coated around inflatable structures shipped from Earth. Based on the proposed construction of the JEANNE Habitat in 2031, McHenry et al. speculate that the technology in place at the start of the Mars colonization program will be able to complete the program [1].

Hajduk proposed a new scenario for transportation in the early stages of colonization, which could start by arranging for an unmanned emergency return vehicle to arrive at the destination 2 years before the first batch of colonists (about 10 people) to provide information support for subsequent arrivals. The task of the first batch would be to provide the second batch (about 100 people) with farms, water supplies, and shelter. The rockets used for the first crew were very small, so the resources needed for the construction of the buildings, including "polyethylene, polybutadiene, steel, aluminum, and cement", arrived with the second crew [2].

In terms of transportation, SpaceX has developed the Starship with a payload of 100 metric tons and a payload volume of 1,100 cubic meters. The Starship can also refuel itself after returning to orbit using methane produced on the surface of Mars [1]. In addition, Musk proposes another vehicle option, the Mars Vehicle and the Interplanetary Spaceship, with a payload of up to 550 metric tons, and the Interplanetary Spaceship using liquid oxygen as an oxidizer and a near-freezing propellant [5]. Carbon fiber is the raw material of choice for rocket construction, but problems with carbon fiber production that need to be circumvented include striving to achieve impermeability to liquids and gases and not having gaps occur due to cracking or pressurization that would make the carbon fiber leaky [5].

2.2. Base Construction

In terms of colony design and the construction process, Hajduk proposed building "underground housing units" for up to 50 people. Due to the hazardous nature of Martian radiation, connections between housing units could utilize underground tunnel networks, and the exposed housing domes would need to be designed with radiation-resistant glass that would also maintain internal pressure [2]. McHenry et al. suggested water and hydrogen-rich plastics for neutron shielding and concrete and lead for gamma ray shielding, based on the underground base concept. In terms of wall construction, 3D-printed Martian basalt walls with a layer of water or ice sandwiched in between are suggested to shield against radiation [1]. Considering the cost and energy consumption of transporting materials, it is recommended to use a ratio of Martian soil and molten sulfur to make concrete for base construction, or to bake crumbly rock into bricks to break down the deadly perchlorates and release the oxygen in them [2,6].

2.3. Energy Harvestation & Usage

Considering the optimal carrying capacity of rockets and spacecraft, every kilogram of fuel carried by a transport vehicle is important, and therefore a high power-to-mass ratio is required as the initial fuel for transportation to Mars. Upon arrival at Mars, there is a need to ensure energy utilization for a survival base, so methods of obtaining power and energy on Mars are critical.

McHenry et al. state that power will be distributed through electronic equipment, thermal control, in-situ resource utilization, and greenhouses, and that the primary energy source will be solar radiation and energy released from the fission of uranium atoms [1]. It is estimated that 100 kilowatts of power will be required for normal operation of the Habitat, and that the solar panels required to harvest enough energy to cover an area of approximately 10,000 square feet in the absence of dust storms and maximum solar energy intake would weigh approximately 33,465.7 kilograms.

Nuclear power is proposed by the use of the Kilowatt Reactor, developed by NASA, which uses uranium-235 isotopes with the fact that it exhibits radioactivity levels between 1000 and 10000 times lower than current radioisotope systems. [1] Based on the energy requirements of the habitat, it is anticipated that ten 10 kW reactors would be placed on the habitat, with their total weight being 18308 kg.

In addition, Hajuk pointed out that a base that could accommodate 1,000 people would have huge energy requirements, with the two most energy-intensive aspects being the growth of food and transportation fuel. Preference therefore needs to be given to nuclear energy that is more compact to carry in order to save on rocket capacity [2].

The majority of the energy required for farming comes from the heat produced by the nuclear reactor, which produces excess heat compared to electricity, and the electricity generated will be used to synthesize methane and oxygen for rocket fuel and vehicle transportation [2]. The amount of power needed to survive colonization by a team of a thousand people is about 3.6 MW, which equals approximately 360 times the power of NASA's KiloPower project, and the fissile mass required would be 15.7 tons of Uranium-235. In addition, if the base's personnel mastered precise silicon production and doping techniques, solar panels could be produced independently at the base, thus providing the base with more energy and power supplies. However, this may be beyond the capabilities of the 1,000-person team and the range of resources available for its development [2]. Similar to McHenry et al. and Hajduk's suggestions, the majority of the research regarding this topic propose the use of solar radiation or nuclear fission as the energy source [1-2]. Alamoudi et al. noted that energy saving is a key requirement to support the concept of sustainable development, so electricity can be collected through solar panels [7]. However, it is necessary to consider that solar energy may not be accessible due to dust storms on certain days. Alamoudi et al. also mention the KiloPower project as a system that uses reasonable fission of nuclear energy to support extended stays on planetary surfaces, which could be one of the suggested sources of nuclear energy to consider [7].

2.4. Material Gathering

The Martian surface contains many minerals and metals available for use, such as polyethylene, gold, palladium, platinum, rhodium, rubidium, silver, thulium, iridium, and germanium, etc., as well as metal oxides that exist on Martian surfaces that could be combined with carbon monoxide to reduce the metal into a usable form [3]. Polyethylene, a versatile plastic, can be formed into polyethylene and water by combining carbon monoxide and hydrogen, and this is the primary way polyethylene is produced on Maxs [2]. Glass could be extracted from the Martian regolith after the iron oxides have been magnetically extracted to make steel, leaving the silicon dioxide leftover to make glass. Since available metals could be mined more easily on Mars, which has a lower gravity than Earth and a low geothermal output, this allows for easier mining operations [3].

In order to minimize the amount of energy used to transport materials from Earth to Mars, many have turned to ISRU (In-Situ Resource Utilization) projects. According to the JEANNE Habitat plan [1], many ideas have been proposed due to the need to collect materials essential for survival, such as building fabrication, water, and oxygen, as well as the abundance of minerals in the Martian crust. Alamoudi et al. proposed the ETFE (Ethylene tetra fluoroethylene) and concrete made on Mars could be used as the main building materials with the aim of controlling the energy consumption of buildings [7]. Martian soil contained minuscule iron oxide compounds that could bind the soil together when put under pressure to form a strong yet simple brick, which is stronger than steel-reinforced concrete. Alamoudi et al. also noted one material in development with NASA called Hydrogenated boron nitride nanotubes that may be useful in the future [7]. On the other hand, McHenry et al. focused more on the concept of radiation shielding outside of the constructed base. They suggested using the most abundant igneous rock on Mars as radioactive shielding material, since thermal and mechanical properties are suitable to build a structure, and its radiation shielding properties are comparable to those of concrete (Figure 1) [1].

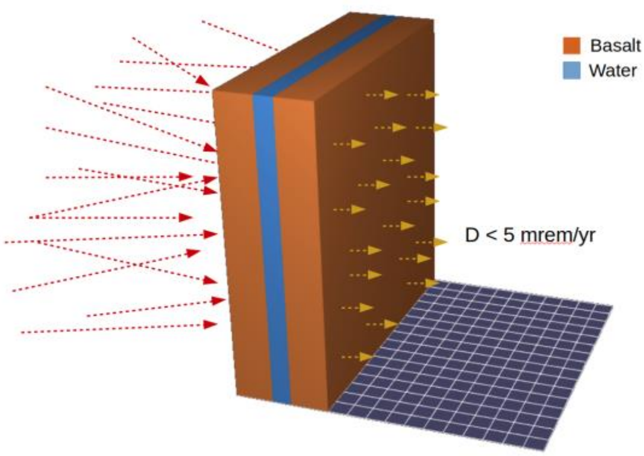

Figure 1. Multi-Layer Radiation Shielding Design [1].

Water and Oxygen are both extremely essential requirements to human survival, and obtaining them on Mars via ISRU seems more feasible as it lowers energy requirements, as mentioned before [8]. Arias proposes that the most effective way of extracting water is to first sublimate the water inside Martian regolith, which could be done through heating [8]. For regolith with relatively lower water content, a heating & depressurization process is suggested to be more efficient (Figure 2) [6]. Alamoudi et al. states that according to NASA, hydrogen could be combined with the excess carbon dioxide in the air to form water and methane, where the methane would be reused in thrusts or vented out [7]. Oxygen can then be obtained from hydrolysis of water, where the excess hydrogen from the reaction could then continue the process [4]. On the other hand, Hajduk cites Zubrin that baking Martian regolith at 500 °C for the trapped water inside would be a viable option, as they release oxygen into the atmosphere and decompose the deadly perchlorates that the regolith contains [2]. Excavating 5.019 tons of Martian regolith would be nearly enough space to build a housing unit and farm, to which Zubrin states that 3 kWh/kg energy consumption for 4% soil. And as for using 8% soil, 1.62 kWh/kg of water is could be excavated from the regolith excavated [2].

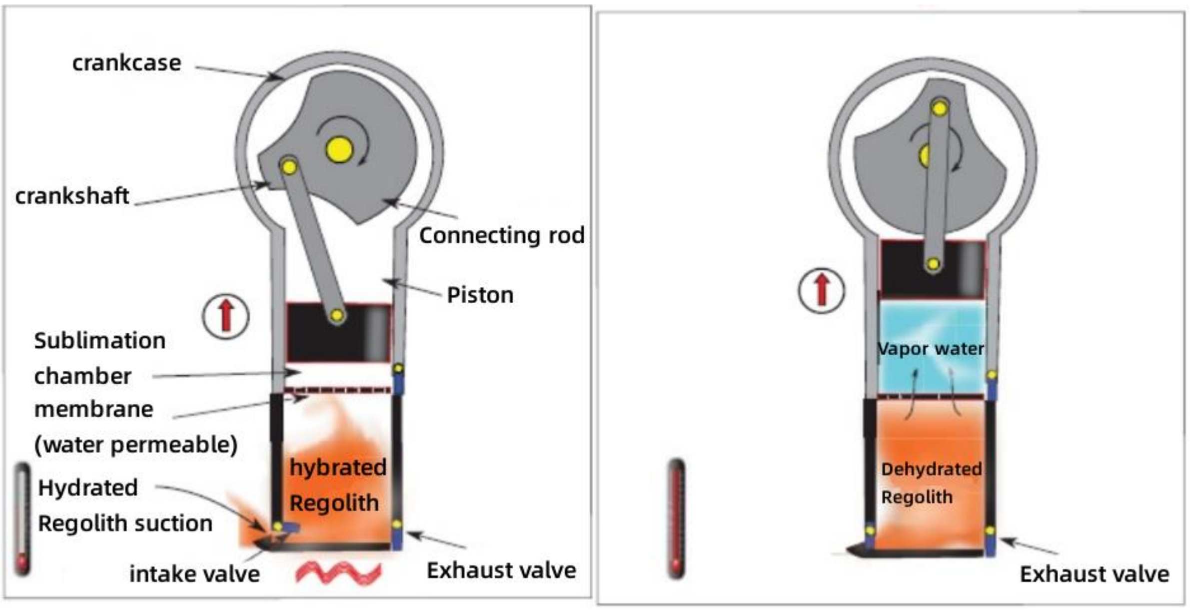

Figure 2. Combined depressurization/pre-heating process for regolith dehydration: Left: intake and pre-heating; Right: Depressurization and sublimation of water [6].

2.5. Nutrition

Of all elements, the nutrition and food aspects of the crew is essential to the mission. All crew members need to receive a well-balanced meal although food options will be limited. According to JEANNE Habitat, water fountains and heaters need to be provided for the further processing and handling of food when providing for immigration program personnel [1].

Based on the macronutrient and micronutrient requirements of the human body, it is recommended that foods such as rice, soybeans, romaine lettuce (red lettuce and romaine lettuce), potatoes, sweet potatoes, cassava, cabbage, kale, watercress, tomatoes, blueberries, strawberries, and edible flowers (pansies, lilacs, lavender, and hibiscus) be prepared at the same time [9]. Further screening was conducted based on nutritional value and potential yield per kilogram of plant alignment. To avoid radiation damage to the food, the plants were grown in pill-shaped glass enclosures so that the plants could successfully receive sunlight. However, the above recommendations are primarily for grains and fruits and vegetables, which is consistent with the current inability to produce meat products in space. Shaw and Soma point out that lab-grown meats have a long way to go to replicate the diversity of micronutrient compositions, varieties, and cuts, and that more research is needed on the effects of production on the system [9].

3. Conclusion

This paper analyzes and summarizes the exoplanet migration program based on the fundamental problems that need to be solved in Mars migration, such as transportation, base construction, energy, and materials. The development of necessary technologies such as artificial intelligence, nanotechnology, and 3D printing increases the possibility of interplanetary migration and can solve the problems of rocket capacity, energy storage, and spacecraft carrying capacity at the initial stage of the program. The proven abundance of resources on Mars provides a good solution for the construction of base infrastructure and the use of base energy. However, regarding the nutritional problems needed for the survival of the personnel, it is necessary to follow up the optimization of technology to provide better solutions.

However, this paper is only based on a summary of the literature to explore the possibility of long-term space exploration missions, and the literature involved is relatively small in terms of variety and quantity. In addition, the possibility of implementing some of the solutions needs to be further verified

DOI: 10.54254/2753-8818/13/20240854

empirically. In the future, the author's own theoretical knowledge and experimental experience in aeronautics will be enriched to improve the shortcomings of this paper.

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