Designing a Portable Crop Growth Habitat on the Martian Surface

An Analysis of the Benefits of Terraforming Mars Compared to

Reversing the Damages of Climate Change

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Aerospace Engineering
By
Kerem Kutlug

November 8, 2024

Technical Team Members:

Callie Ellsworth & Yejun Kim

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR

Rider Foley, Department of Engineering and Society

Natasha Smith, Department of Mechanical and Aerospace Engineering

Introduction

NASA plans to send a crewed mission to Mars in the year 2040, as it will give ample time for necessary research and technologies to complete as well as the shortest path to the planet (Williams, 2017). The mission to Mars will build on many existing technologies used for lunar missions, however, some aspects are far more complex. One such problem will be the radiation exposure of a longer journey through space as well as Mars' thin, unprotected atmosphere that allows for radiation values up to 700 times the average found on Earth (European Space Agency, 2019). Another treacherous part of the Martian environment is its thin atmosphere that allows for very fine dust particles to be spread around constantly, blocking the astronauts' views and getting caught in their suits (Hille, 2015). There are global phenomena on Mars where the dust picks up speed to over 60 mph and covers the entire planet. Thus it is important to create habitats that can withstand these storms should they be an issue at the time of the mission.

In order to verify that Mars as a planet is fit for human life and research, the presence of water is essential. Although it has been found that Mars used to have much more similar characteristics to Earth such as oceans covering large portions of the now desolate cratered lands, that is no longer the case (Sanders, 2024). Liquid water once existed on Mars 3 billions years ago, but since then it has all frozen into ice, mostly found on the poles. Depending on the season, the ice caps shrink and evaporate into the air. The abundance of clean, usable water should not be of concern for these missions, but the techniques can vary. There are 4 main ways to get water: melting the ice, collecting the water vapor, combining carbon dioxide with hydrogen, or heating the water out of the soil (Davis, 2022). Along with water being available, carbon dioxide is plentiful making up 95% of the atmosphere. However, oxygen makes up much less than 1%, meaning it must be found through other methods such as extracting it from water or carbon dioxide (NASA, 2023).

Some research regarding Mars that still needs to be investigated is a feasible plan to allow crop growth in Mars' harsh environment (NASA's Space Technology Mission Directorate, 2024). The geological makeup of Mars is the closest to that of Earth in the solar system. There are many resources on Mars that will have to be manipulated in order to recreate essential survival sources for living organisms. The crops are an important topic of research in the exploration of Mars, as it will reveal the extent to which Mars can nurture life. The crops that are grown can also serve as a fresh source of food and vitamins for the crew that will be surviving off dried food packages. Due to the many Earth-like qualities of Mars, a portable crop growing habitat will be designed and implemented for future Mars missions.

Technical Topic

The overall design of a crop growing habitat on Mars has been researched prior to this study. All of the designs considered have been for long term habitation solutions, however, and the unique quality of the proposed design will allow for an easier temporary setup. One factor that increases the complexity of a lightweight design is the need for radiation protection. There are simply 2 methods for decreasing the impact of radiation, which is through passive and active shielding. Passive shielding, as shown in Fig. 1, is the very basic idea of putting materials between the radiation waves and the protected section. It follows the principle that denser materials and increased thickness of a material decreases the total radiation that makes it through (Slaba et al, 2013). For permanent habitats on Mars, Martian regolith (the soil made up of numerous different materials) can be used as a construction material (Kim et al, 1998). The more useful but less explored active shielding for radiation protection is the use of magnetic fields to slow down the radiation waves to safer levels (Frazier & Hatfield, 2015). This significantly decreases weight concerns but leads to an increase in power usage for the mission. A successful example of this phenomenon can be found naturally created by the Earth, Fig. 2.

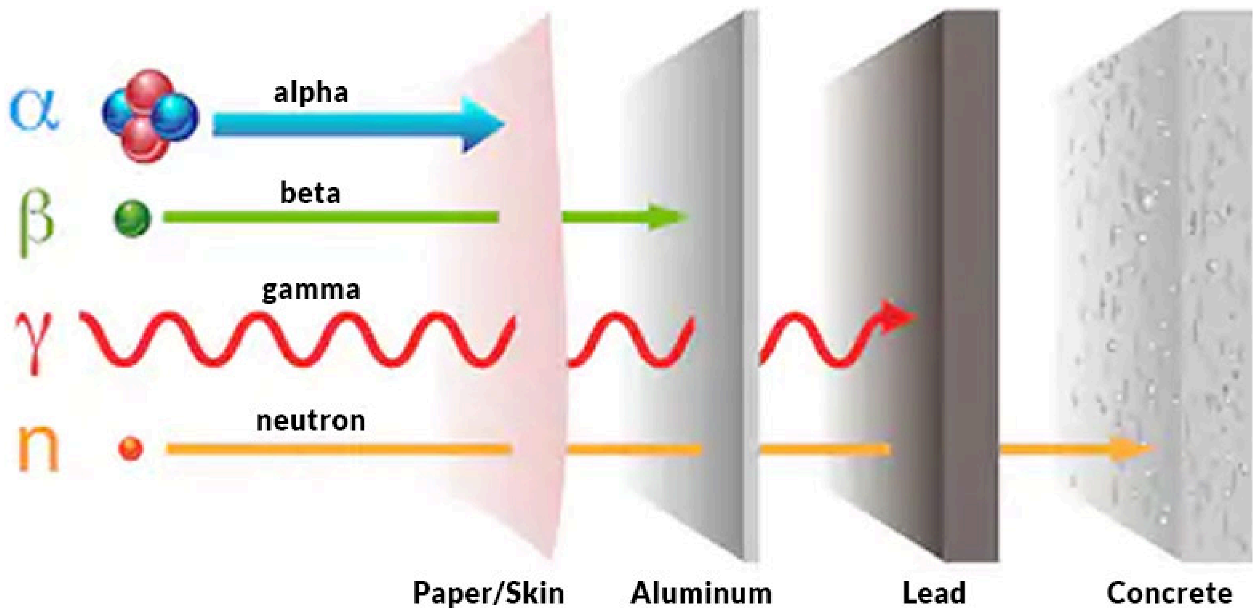

Figure 1: Passive Shielding through Different Materials and Thicknesses

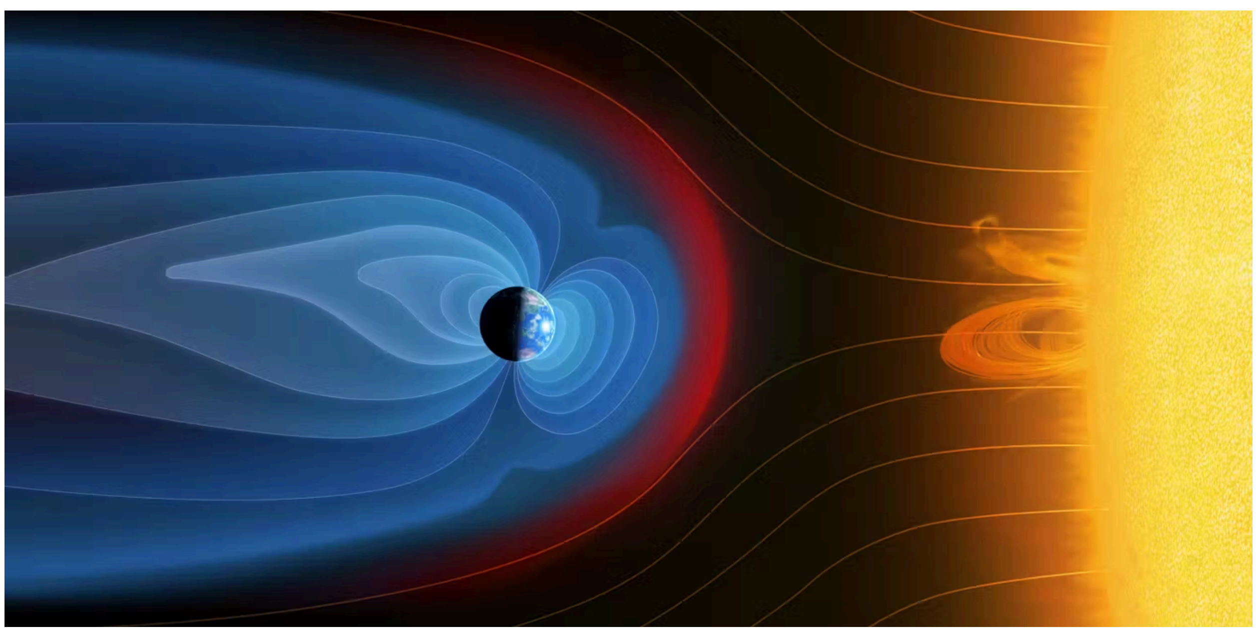

Figure 2: Magnetic Field of Earth Protecting from Radiation Waves

The construction of the habitat can be assumed to be made on the planet rather than be sent as payload on a rocket. Recent developments in large-scale 3D printing devices have allowed for a realistic path for constructing outside of Earth (Pender, 2019). A creative aspect of the design will be to utilize the abundant source of craters on the Martian surface to simply add a roof to one of them and create a pressurized environment with minimal structure. This will create an easy to print design as well as eliminate the effect of the high winds from potentially damaging the structure as it is now parallel to the ground. Within the thick roof will be a pressurized environment contained by an innovative lightweight fabric technology (Brown et al, 2003). Although there is a high proportion of carbon dioxide in the air, it is so thin that it is not enough to support plant life. Thus the pressurized environment will need to simulate increased carbon dioxide levels.

On the inside of the habitat will be a pressurized, Earth-like environment where the crops will grow in the Martian regolith. The soil itself is highly nutritious apart from containing many toxins that can simply be washed off with water. More information can be gathered about the makeup of Martian regolith as it is made of many different elements (Shi et al, 2024). The proposed solution to the issue of creating an environment for crop growth on Mars is essentially combining the technologies discussed prior. The unique grouping of radiation protection, pressure vessel, flat roof, water extraction, and crop growth lead to a good solution to this problem. Once humans begin terraforming Mars in the foreseeable future, the research and development of this technology will become of increasing importance.

STS Topic

In order to understand how such a solution has come about, one must look further beyond the immediate problem. Why do humans want to test the ability for crops to grow on Mars?

There is a belief that it is not the technologies that dictate social changes, but rather social issues that mold the development of technologies (Hughes, 1987). The problem starts on Earth from problems being faced by the average person. For decades the high rate of emissions has led to increasing temperatures, natural disasters, and unpredictable climates. The effects of this are being seen by many concerned people who have lost shelter, food supplies, and/or lives. They are looking for solutions to the problem, one being to enact regulations to reverse the effects and sustain the health of the planet. The other more extravagant idea is to terraform another planet to sustain the lives of future generations.

Space exploration has reached the point of technological momentum for decades now. In the 60’s there was the space race where the US bolstered its knowledge, interest, and infrastructure in space technologies. A crewed mission to the moon has not occurred since 1972, over 50 years, as there was not much left to benefit from extensive research on the desolate rock. The agenda for Mars exploration has become inflated due to the need to reach a new milestone with the technology that is prevalent. On one hand Mars does in fact have the best liveable conditions outside Earth, and it is reasonably close. However, colonization as it has been advertised will be incredibly hard and Martian exploration may meet the same fate as the moon. This mission was bound to happen purely for the minimum outlook on conducting experiments to understand the Martian environment better.

There are many stakeholders involved in the colonization of Mars including citizens and businessmen trying to inhabit the planet. The third group would be the aerospace industry that is always striving to reach new heights in research and development. They do work in the interest of the people, however, without their influence they would’ve surely tested the Martian environment for scientific studies. Inadvertently these two incentives lead to the same goal of confirming whether Mars can be colonized or not. Hughes' also suggests that technologies go through various stages of development: invention, development, innovation, transfer, growth, competition, and consolidation. One clear example of the stage that this problem has cleared is the consolidation of power, as there are many organizations and groups that are backing NASA's program to colonize Mars by 2040. They are still in competition with opposing countries to conduct research before them, helping push such an optimistic timeline.

To bring validity into the desires of the common person, many scientists have been optimistic about their feelings towards Martian colonization. The Martian environment has been described as harsh, but the truth is that it evidently has many similarities to Earth (Plant-Weir, 2021). When one looks at the other options within the solar system, there are none better than Mars to transform into a habitable environment (Smith, 1989). Especially when compared to the moon's environment, Mars is exponentially better having an atmosphere, water, and nutritious soil as a few examples (Zubrin, 1996). On the other end of the spectrum, however, one can predict that without solving the climate problems that Earth faces, humans won't survive long enough to inhabit Mars long term (Risen, 2017). This culminates in the essential question that must be answered before the technology can be designed: Should humanity put emphasis on colonizing Mars or focus attention on saving the Earth's environment?

Research and Methods

Are long term habitats for crop growth on Mars a useful solution to sustain human life? That is a question the stakeholders must ask themselves before jumping to such a complex and expensive solution. It would be irrational if the agenda of terraforming Mars was pushed heavily while not being an effective solution. To research this topic on an STS level, the timeline and economic cost of such an infrastructure to be created on the planet will be looked into through prior literature. The beginning of Mars colonization is set to be the year 2040, however, it will take years after that to instill more and more permanent infrastructure. The technical design for this solution is a temporary crop growing habitat, which would look very different from permanent large-scale farms. The ideal design and implementation of permanent farms will be further in the future, and a date can be estimated. From this, the necessary production of crops on Mars can be calculated based on the scenario that carbon emissions regulations stay the same.

The other area of research to collect data and sources for is the economic factors that play into both solutions (Black, 2022). A deeper look into the pros and cons of solving climate change and terraforming Mars will be pragmatically compiled. Terraforming Mars will be no easy feat financially; creating these farms would require more resources than manipulating the Earth for similar crop output. However, trying to naturally reverse the root of the problem for climate change and food shortages would implement constraints on most of the existing infrastructures seen around the world. Thus it is not simply a comparison of the cost of creating new farms on either planet, but rather the losses in profits of all industries from stricter carbon emissions policies compared to the cost of Martian colonization.

Conclusion

Will terraforming Mars be the solution for future humans to survive? The proposed solution to this problem is to create an Earth-like habitat on the Martian surface to grow edible crops on. This solution could help yield additional crops in a future where the Earth loses ideal habitable characteristics. Prior literature reviews would yield the result that Mars colonization will occur far in the future after the effects of climate change will be disastrous for humans. It would also reveal that it is not an economically viable solution; if the main drive was wide-scale crop production, then solutions on Earth would reap better results. This should take away the

STS question as the driving problem for the solution and pivot it towards a fail-safe solution alongside reversing climate change.

References

Black, R. (2022, January 17). *Climate economics - costs and benefits*. Energy & Climate Intelligence Unit. https://eciu.net/analysis/briefings/climate-impacts/climate-economics-costs-and-benefits

Brown, G., Haggard, R., & Harris, P. A. (2003, June 1). *Flexible Composite-Material Pressure Vessel*. https://www.techbriefs.com/component/content/article/1193-msc-23020

Davis, J. (2022, October 25). *Your guide to water on Mars*. The Planetary Society. https://www.planetary.org/articles/your-guide-to-water-on-mars

European Space Agency. (2019, May 31). *The Radiation Showstopper for Mars Exploration*. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/The_radiation_showstopper_for_Mars_exploration

Frazier, S., & Hatfield, M. (2015, September 30). *Real Martians: How to Protect Astronauts from Space Radiation on Mars - NASA*. NASA. https://www.nasa.gov/science-research/heliophysics/real-martians-how-to-protect-astronauts-from-space-radiation-on-mars/

Hayes, A. (2023, December 17). *Simple Random Sampling: 6 Basic Steps With Examples*. Investopedia. https://www.investopedia.com/terms/s/simple-random-sample.asp

Hille, K. (2015, September 18). *The Fact and Fiction of Martian Dust Storms*. NASA. https://www.nasa.gov/solar-system/the-fact-and-fiction-of-martian-dust-storms/

Hughes, T. P. (1987). The Evolution of Large Technological Systems. In W. E. Bijker, T. P. Hughes, & T. Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (pp. 51-82). Cambridge MA: MIT Press.

Kim, M., Thibeault S., Simonsen, L., & Wilson J. (1998). *Comparison of Martian meteorites and Martian regolith as shield materials for galactic cosmic rays*. NASA. https://ntrs.nasa.gov/api/citations/19980237030/downloads/19980237030.pdf

NASA. (2023, September 6). *NASA's Oxygen-Generating Experiment MOXIE Completes Mars Mission - NASA*. NASA. https://www.nasa.gov/missions/mars-2020-perseverance/perseverance-rover/nasas-oxygen-generating-experiment-moxie-completes-mars-mission/

NASA's Space Technology Mission Directorate. (2024, July). *Stakeholder Webinar: Civil Space Shortfall Ranking* [Webinar]. NASA. https://www.nasa.gov/wp-content/uploads/2024/07/shortfall-ranking-results-july-2024-508-tagged.pdf?emrc=fd191e

Pender, S. (2019). MARSHA, MARSHA, MARSHA: How We Helped AI SpaceFactory Win NASA's 3D-Printed Habitat Challenge. Autodesk News. https://adsknews.autodesk.com/en/stories/how-we-helped-ai-spacefactory-win-nasas-3d-printed-habitat-challenge/

Plant-Weir, E. (2021). The Habitability of Mars. Mars Society. https://www.marssociety.ca/the-habitability-of-mars/

Risen, T. (2017). Selling Mars as Planet B. AIAA. https://aerospaceamerica.aiaa.org/features/selling-mars-as-planet-b/

Sanders, R. (2024, August 12). *Scientists find oceans of water on Mars. It's just too deep to tap. - Berkeley News*. Berkeley News. https://news.berkeley.edu/2024/08/12/scientists-find-oceans-of-water-on-mars-its-just-too-deep-to-tap/

Shi, E., Zhang, R., Zeng, X., Xin, Y., Ju, E., & Ling, Z. (2024). Spectroscopy of magnesium sulfate double salts and their implications for Mars exploration. Remote Sensing 16(9), 1592. https://doi.org/10.3390/rs16091592

Slaba, T., Mertens, C., & Blattnig, S. (2013). Radiation shielding optimization on Mars. NASA. https://spaceradiation.larc.nasa.gov/nasapapers/NASA-TP-2013-217983.pdf

Smith, A. (1989). Mars The Next Step (1st ed.). CRC Press. https://doi-org.proxy1.library.virginia.edu/10.1201/9780429332432

Williams, M. (2017, April 10). *When will Mars be close to Earth?* https://phys.org/news/2017-04-mars-earth.html

Zubrin, R. (1996). The Case for Colonizing Mars. National Space Society. https://nss.org/the-case-for-colonizing-mars-by-robert-zubrin/