MOTIVATION, FEASIBILITY, AND ETHICS OF COLONIZING MARS

Presented by Divya Kolli

in partial fulfillment of the requirements for completion of the
Evidence and Inquiry certificate and the
Polymathic Scholars honors program in the College of Natural Sciences at
The University of Texas at Austin

Spring 2021

Supervised by:

David W. Hoffman, Ph.D.
Department of Molecular Biosciences
The University of Texas at Austin

Second Reader:

John W. Traphagan, Ph.D.
Department of Religious Studies
The University of Texas at Austin

I intend to submit a copy of my Polymathic Scholars thesis to the Texas ScholarWorks (TSW) Repository. For more information on the TSW, please visit https://repositories.lib.utexas.edu/.

MOTIVATION, FEASIBILITY, AND ETHICS OF COLONIZING MARS

Divya Kolli | 05/11/2021

[Your Name] | Date

Table of Contents

ACKNOWLEDGEMENTS

I would like to thank my thesis supervisor, Dr. David W. Hoffman, for his help and guidance throughout the thesis writing process, as well as my second reader, Dr. John W. Traphagan, for providing helpful feedback and revisions to the thesis. I would also like to thank the Polymathic Scholars Program for providing me with the opportunity to write this thesis, as well as Dr. Rebecca Wilcox and Joseph Denny for being instrumental in the thesis development and writing processes. Lastly, I would like to thank Dr. Brian Shirey of the Planetary Protection Engineering team at the Jet Propulsion Laboratory for mentoring me when I first became interested in the field of astrobiology.

ABSTRACT

Space exploration has excited Americans since the Space Race in the 1950s, which led to humans first stepping foot on the Moon in 1969. The next goal in space exploration is to send humans to Mars, which is driven by scientific interest and the current advancing climate change, overpopulation, and resource depletion of Earth. The potential habitability of Mars makes the planet more amenable than other planets in our solar system for supporting human life, which private companies claim will allow humans to successfully colonize the planet. However, many scientists and ethicists have stated that a pioneering population will face new obstacles in the journey and life on Mars. These hurdles are examined through a literature review focused on the feasibility of a successful colonization, human health in space, and the ethics of space colonization. Space sciences are highly affected by political tensions between technologically developed countries which will likely impact the sociopolitical structure and success of a long-term Martian colony. The pioneering population will also face dangers to their health from the isolation, microgravity, and radiation of space. Lastly, colonization of Mars will lead to the eventual environmental damage of the planet, which is both a scientific and ethical dilemma. The political, scientific, and ethical concerns that are currently unanswered outweigh arguments in support of Martian colonization. To protect the future pioneering population and the environmental health of Mars, these concerns must be mitigated by space agencies before developing the technology needed to send humans to colonize Mars.

Key terms: Mars, colonization, ethics, terraforming, health

INTRODUCTION

Human expansion and exploration have been prevalent throughout the history of the human race. Expansion has been imperative for the survival of humans across our planet and has, historically, been pushed by resource depletion and curiosity about what opportunities a new land can offer. Advances in science and technology have allowed humans to explore further than ever before, to the Moon and to the International Space Station in lower Earth orbit. Scientists continue to develop rovers and orbiters that travel further than ever before, which raises questions regarding the limitations of human expansion and what the future of the human race holds.

The Space Race and the establishment of the National Aeronautics and Space Administration (NASA) in the 1950s to 1960s led to increasing American and world-wide interest in space. Human expansion and exploration have had deep roots in American history since the colonization of the country and subsequent western expansion. The growing political tensions between the U.S. and the Soviet Union (USSR) that arose from the Space Race further tied American nationalism to the concepts of space exploration and humans in space (Paikowsky et al., 2015).

The USSR sent the first human to space in 1961 and the United States sent the first two humans to the Moon in 1969, which proved to the world that human expansion is not bound to Earth. Since the Space Race, the United States has been a major contributor to the global advancement of space science and space exploration. In the 1990s, the International Space Station (ISS) was built and launched as a collaborative effort between the American, Japanese, Russian, European, and Canadian space agencies and has since proven that humans can survive for prolonged periods of time in lower Earth orbit. The ISS is now a site for many scientific experiments that help the world better understand how to support human life in space and displays the collaborative efforts between countries in the space sciences. Space exploration continues to serve as a sign of a country's status in both technological and scientific advancement, which maintains the tie between this field of science and a sense of national pride.

The world's most developed countries continue to fund scientific and technological advancements in the field of space science, both collaboratively and competitively with other countries (Paikowsky et al., 2015). The next big milestone in this field is to send humans to Mars. In the United States, NASA has launched multiple landers and orbiters to Mars to study the planet, its deep interior, signs of past life, and the history of water on the planet. Currently, NASA's Artemis Program is focused on sending more humans to the Moon to better understand human space exploration and to develop a sustainable plan for future human space exploration to Mars. This goal serves as a first step in learning and preparing for the ultimate mission of successfully sending astronauts to Mars.

Sending humans to Mars is both a scientifically and ethically challenging feat. Many researchers around the world are working to develop the science and technology needed to send humans to Mars, which opens up a possibility for future long-term colonization of the planet. While eventually, technology and medicine may advance enough to send humans to Mars, we should question whether humans should colonize Mars. This thesis is a literature review that seeks to answer the question of whether humans should colonize Mars. First, the thesis will highlight the current political and scientific challenges of human colonization of Mars which will determine if the journey to Mars is feasible. Assuming these challenges are met and that human colonization of Mars is possible, the thesis will then discuss some of the current ethical challenges revolving around colonization of other planets and the contamination or destruction of the planet's environment.

A SUCCESSFUL MARTIAN LIFE

Movies and television have portrayed Mars in a multitude of ways, ranging from dangerous to docile, habitable to inhabitable, and similar to Earth to alien. The general public receives mixed signals in regards to what a Martian life would be like due to the sensationalism of space in the media and the extremely limited knowledge that we have about life in space. Scientists around the world continue to study how space effects the human body and other living organisms. Science and technology are likely to develop to a point where humans can travel to Mars safely, however, the success of a Martian colony is dependent on both the sustainability of the colony as well as the political framework that regulate it. Exploring the current state of research in this field is important to determining whether or not a human colony will be successful, which ultimately informs the decision about whether humans should colonize Mars.

Sustainability of Life in Space

The human mission to and from Mars is currently estimated to take approximately 3 years, which is 2.5 times longer than the longest consecutive time a human has spent in space (Skelly, 2021). A long-term mission and potential establishment of a colony on Mars will require more sustainability efforts for supporting life in space than is currently implemented for astronauts on short-term missions to the ISS. A major concern regarding sustainability of a human mission to Mars is that supply replenishments will be more difficult due to both the longer duration of the mission and the increased distance between the Earth and Mars in comparison to the distance between the Earth and the Moon or ISS. According to NASA (2020b), sustainability efforts to provide more long-term food supplies are currently a focus for the Mars mission. The currently focus revolves around replacing perishable packaged diets with more sustainable food crops. “During a two- or three-year mission to Mars, the vitamins and quality of packaged food would degrade over time” and crops would provide a more consistent and varied nutritional supplement (NASA 2020b).

To meet this goal, the European Space Agency (ESA) and NASA have collaborated to study plant behavior in space and how changes in gravity effect plant development. The European Modular Cultivation System is currently being used to control and sustain life for biological studies by implementing rotors that can create gravitational forces between 0g and 2g (NASA, 2013). It can also control for light, humidity, temperature, and gas composition to mimic various atmospheres. These studies currently focus on plant biology, but will be expanded to include cell and tissue biology. One particular goal for these studies is to better understand how plant development is affected by changing gravitational fields and light, and how the changes to both parameters may interact and impact plants. NASA has stated that a particular advantage to these studies is that it may lead to the employment of plants and other biological material “in bio-regenerative life support systems aboard spacecraft during long duration space missions” (NASA, 2013). This means that plants grown in space may be harvested for long-term use in sustaining a population in space. The Advanced Plant Habitat (APH) is another major project from NASA that focuses on optimizing growth conditions of plants in space. It is currently the largest growth chamber aboard the ISS and will be used in the future to grow a wider array of crops. This autonomous system only requires addition of water and exchange of gas filters and serves as proof that larger quantities of plants can grow aboard the ISS without much maintenance (NASA, 2020b). The APH works alongside the Vegetable Production System (Veggie) which is a smaller and lower power system to grow crops. Veggie is currently being used to implement a new and promising system using seed film. This experiment, VEG-03J, has shown that red romaine lettuce can. Be grown and harvested using a new system called seed film, which utilizes water-soluble polymer film and seeds to create small square films of evenly spaced seeds. Water solubilizes the film and allows the seeds to germinate (Lockhart, 2021). The success of these initial experiments have shown that red romaine lettuce grows faster using this method in comparison to the previous method, which had to be pre-assembled on Earth (NASA, 2020b). This new method provides a low-cost, low-waste, space saving, and successful alternative to the old method and will allow for easier harvesting of crops on space missions (Lockhart, 2021).

The current successes in growing and harvesting crops aboard the ISS as well as the improving agricultural methods employed for germination provide confidence that a pioneering population aboard a long-term mission to Mars will have a well-established and sustainable system for food and nutrition. Food sustainability methods greatly reduce the need for frequent resupply missions and effectively mitigates one of the great challenges of human deep space travel.

The Politics of Inhabiting Mars

To ensure the safety and sustainability of a human colony on Mars, there must be laws that regulate the population to prevent overuse or exploitation of resources and to maintain the technology that supports life. Many critics of Martian colonization question whether there is a substantial political framework that will maintain the balance of the colony. I argue that the framework already exists, however, it needs to be expanded to meet the values of the Martian colony and the governments that run it.

The ISS provides the closest example of how a pioneering population on Mars may be governed because it is the only continuously inhabited region outside of Earth. The International Space Station was built from the collaboration of five different space agencies in Canada, Europe, Japan, Russia, and the United States. The ISS is regulated by a legal framework which controls what is allowed and what each country must contribute to the ISS to ensure that there is fair use and upkeep of the space station (ESA, 2020). Understanding the political control of the ISS provides an example for how a Martian colony will be regulated, which is an important part of maintaining a balanced colony.

The International Space Station Intergovernmental Agreement (IGA) is a treaty signed by 15 participating governments, 10 of which are members of the ESA (ESA, 2020). NASA and each of the participating space agencies have a Memoranda of Understanding, which regulates "the roles and responsibilities of the agencies in the design, development operation and utilization of the Station" as well as the current management structure of the ISS (ESA, 2020). This ensures that the upkeep and management of the ISS is distributed amongst the space agencies, which is imperative to the success of the space station and the science aboard it.

The IGA also implemented an extension of each partnering government's territory into space. Each partnering government retains jurisdiction over any personnel who are on the ISS and are a national of that government as well as any laboratories and equipment registered back to them (ESA, 2020). Each government is legally responsible for their own extended territory aboard and around the ISS, and astronauts and equipment must follow the laws and regulations of their specific partner. Issues between members of different partnering governments are handled through international laws that are already in place on Earth (ESA, 2020). There is no ability to file a claim or sue between governments for equipment damage, however, the rights of personnel aboard the ISS as well as conflicts that arise within one government's jurisdiction are not subject to this rule (ESA, 2020). Lastly, intellectual property is shared at the discretion of the subject or subjects that first developed the data. These laws provide a precedent for the political infrastructure that will regulate the territory boundaries and determine which countries' laws will be in effect in a Martian colony and where. This conclusion, however, is only valid for a single generation in a Martian colony, because it does not account for individuals born on Mars, and assumes that there will be clear divides between people and equipment from different countries while on Mars.

In addition to the IGA, the United Nations Office of Outer Space Affairs has five space law treaties and five space law principles currently in effect. The five space law treaties include the Outer Space Treaty, the Rescue Agreement, the Liability Convention, the Registration Convention, and the Moon Agreement (United Nations Office for Outer Space Affairs, 2015e). These treaties protect space by enforcing the following regulations:

- space is free for exploration by any State
- the use of outer space is for all mankind and may not be used for national sovereignty or national occupation**
- space may not be used for weapons of mass destruction
- celestial bodies must be used for peaceful pursuits
- States are responsible for their own space activity, regardless of if the activity came from a governmental organization or private entity*
- States must prevent harmful contamination of space and damage of space objects*

- all states must work to protect the safety of humans in space and return any rescued astronauts to their respective State
- all States must assist if asked to do so to return any space objects launched from another State that have landed in their jurisdiction
- all States are liable to pay for damages to Earth or to objects in space
- States may add to the register of space objects in an effort to identify objects in space
- The United Nations must be informed of the location and purpose of any station established on a celestial body*
- The environments of celestial bodies must not be disrupted**
- The moon (and potentially extended to other celestial bodies) and its natural resources are heritage for all humans**
- When resource exploitation of a celestial body is possible, an international regime must be put in place for protection**

*Regulations that will be of special importance if a Martian colony is attempted or established

**Regulations that may be a source of conflict if a Martian colony is attempted or established

These treaties and principles are either in effect for all celestial bodies or are easily extendable to all celestial bodies which establishes a foundation for a legal framework to protect a Martian colony, the environment of Mars, as well as its inhabitants. These laws cover a wide range of environmental, political, and collaborative regulations that ensure the safety and fair use of space and increase confidence in the political regulation and control over a Martian colony which will increase its chances of success and sustainability.

I argue that the current politics that dictates the ISS as well as current laws and treaties in place to protect space are easily extendable to Mars and provide a strong foundation for a potential future political framework that regulates a Martian colony. The current system in place, however, was not built under the assumption that humans may inhabit another planet long-term. Regulations on childbirth, country boundaries, environmental and resource usage, and contamination control must be further specified to ensure that the political framework is built for both short-term and long-term durations in space. These weaknesses in the current political framework will be discussed later in the thesis because they are highly dependent how humans view Mars and their environment.

HEALTH OF A PIONEERING POPULATION

The political foundation to protect space and humans in space along with the successful results of plant growth and implementation of sustainability efforts aboard the International Space Station are promising factors that support the success of a future Martian colony. Despite these successes, there is no precedent for human survival on another planet or for long-term human survival in space. When technology advances to a point where human space travel to Mars is possible, we must also determine if the human body can sustain the journey and stay on Mars. While there are current discussions in the field of space ethics and bioethics regarding potential human enhancement and genetic editing to survive longer-durations in space, this thesis will only consider un-altered human biology.

Dr. Valeri Polyakov is a former Russian cosmonaut who spent 438 consecutive days in space and currently holds the world record for the longest consecutive time in space by a human

(Manzey et al., 2010). Scott Kelly, a former NASA astronaut, holds the current American record for the longest consecutive period in space at 340 days (NASA, 2020a). Both Scott Kelly and Valeri Polyakov were part of extensive research projects which studied the effects of space on human health and have given researchers a better understanding of the risks of space travel. Although these studies have provided information on human health in space, the duration of travel, 438 days and 340 days, is not comparable to the current estimated three-year duration of a roundtrip human mission to Mars or a longer-term colony on Mars (Skelly, 2021). Advancing technology may allow humans to travel to and from Mars faster than three years, however, the duration of any long-term mission to Mars will require humans to be exposed to space for longer consecutive durations than ever before. Better understanding of the physical and mental health implications that a pioneering population on Mars may face is imperative to answering the question of whether or not Martian colonization is possible or ethical for the humans involved. The current research on human physical and mental health in space will be discussed in this section of the thesis.

Life has been optimized to survive and thrive on Earth's levels of light, radiation, gravity, and chemical makeup. Human physiology is impacted by the drastic changes in environment when traveling to space which have led to deleterious and dangerous physical health effects. The NASA Human Adaptation and Countermeasures office researches the physiological responses of astronauts in space and develops countermeasures to mitigate the effects and to further inform scientists of the effects of space on the human body (NASA Johnson Space Center, 2006).

Two of the most drastic differences between the Earth and space is the changes in gravity and the increased radiation. The International Space Station continues to be the best example for studying the health effects of humans in space due to it being the only long-term human establishment outside of Earth. Earth experiences a surface gravity of 9.8 m/s^2, the ISS experiences 90% of Earth's surface gravity, Mars experiences 37.5% of Earth's surface gravity, and the Moon experiences 16.5% of the Earth's surface gravity. While many people believe that the astronauts aboard the ISS do not experience gravity or experience very little gravity, they are actually in a gravitational field very similar to that of Earth. Astronauts aboard the ISS experience what is known as weightlessness, zero g, or microgravity, which mean that there is a balance of forces which leave the astronauts "weightless." This phenomenon occurs because the ISS is in freefall, meaning that it is continuously falling towards the Earth because of the Earth's gravitational pull. The ISS's horizontal movement in conjunction with its freefall keeps it in an orbit around the planet without falling to the surface of Earth. This balance of forces leads to the weightlessness that we see in astronauts aboard the ISS. Although astronauts in the ISS experience 90% of Earth's surface gravity, they do not feel it due to this phenomenon, which makes the ISS a better model for low gravity environments like the Moon and Mars despite it experiencing 90% of the Earth's gravity. The ISS, however, is not a good model for determining the health effects if radiation on astronauts. The ISS is within the Earth's magnetic field and atmosphere, which protects it from most of the radiation from space. Although astronauts aboard the ISS to experience higher exposure to radiation than humans on the surface of Earth, the current findings regarding radiation's effects on human health are likely to be much smaller than for a human population traveling to Mars in deep space.

To better understand the health effects that astronauts experience in space, NASA performed a first-of-its-kind study, the Twin Study. Francine E. Garrett-Bakelman et al. (2019) studied Scott and Mark Kelly who are twin retired astronauts. Mark Kelly stayed on Earth as a control subject while Scott Kelly was aboard the ISS for 340 days, the longest any astronaut has been in space consecutively. This experiment studied human health before, during, and after exposure to space and human health for long-term space travel while comparing the subject to a nearly genetically identical control subject as opposed to the previous 6-month long studies of individual unrelated astronauts. The study consisted of ten different categories of interest, biochemistry, immunome, epigenomics, gene expression, cognition, integrative omics, telomeres, proteomics, microbiome, and metabolomics studied over a period of 25 months.

The results showed that many processes within the body remained the same, however, there were a few notable findings in each of the ten different categories studied that display the differences in physiology and regulation in the body between preflight, early inflight, late inflight, and postflight stages.

Immunome:

The higher stress levels experienced by the subject preflight, inflight, and postflight led to varying effects on cytokine levels. Cytokines are molecule excreted by specific cells of the immune system for the purpose of leading to an immune effect on other cells. Some cytokines levels rose significantly in the subject's blood plasma during and following the return to Earth and continued to increase after 6 months. Other cytokines were found to be relatively high preflight and continued to be high during the inflight stages and subsequently decreased after return to Earth. After return there was an 8-fold increase in a few select cytokines which is hypothesized to occur due to the stress of a return mission on the body. Flu shots administered over a span of two years, one before flight, one during flight, and one after flight, all produced the typical immune response with no significant differences.

Genomics:

Many genes were differentially expressed while in the early and late inflight stages as compared to preflight stage and the control subject. This can mean that some genes are expressed in the body in higher levels (upregulated) or lower levels (downregulated). There are 481 differentially expressed genes (DEGs) between inflight and preflight in lymphocyte depleted cells specifically. 23.2% of these DEGs remained differentially expressed in the postflight stage and did not return to normal expression levels during the duration of the study. Across all cell types there were 811 DEGs that remained differentially expressed during the post flight stage. Differential expression levels of genes have been linked to a number of diseases and cancer types. Many DEGs were also determined to be involved in immune related pathways which is likely linked to the increased stress put on the body in space. The failure for these DEGs to return to normal expression levels after postflight indicate a significant health risk for humans in space and also may point to potential semi-permanent or permanent genetic material damage.

In addition, mitochondrial genetic material, mtRNA, expression levels increased significantly between the preflight stage and inflight stages. The increase in mtRNA expression levels and the abundance of DEGs also continued to increase between the 0-6 month period of early inflight stage and the 6-12 month period of late inflight stafe. This shows that the genomic changes in humans in space is further exacerbated by the duration of the stay in space. These studies were done in peripheral blood mononuclear cells (PBMC) as were many of the other studies to decrease the number of samples needed from the astronaut.

There were also changes in DNA methylation that were found to not be significantly different, but notable. There was genetic damage detected, however. Cytogenetic damages were detected, likely from galactic cosmos rays, and DNA damage, likely from ionizing radiation

(IR). The subject's chromosomal inversion frequency also increased due to exposure to IR and continued to increase in the postflight stage which points to genetic instability. DEGs were enriched in pathways for DNA damage repair in many cell types showing that some of the DEGs may have been caused in response to DNA damage instead of the environment of space itself.

Telomeres:

Real time PCR (qRT-PCR) was used to determine telomere length. Telomeres are found at the end of chromosomes to protect genetic material on the terminal end of the chromosome. As cells divide, telomeres shorten, which is why shortening of telomeres is associated with aging and the increased risk of certain diseases. Stress and radiation can also lead to shortening of telomeres. Telomere length increased by 14.5% during the inflight stage compared to preflight in a variety of cell types and maintained this level throughout early and late inflight stages which indicates that the lengthening will most likely level off at some increased length during an even longer mission. Upon returning to Earth, telomere length shortened rapidly within 48 hours and mostly stabilized to preflight levels. This likely occurred due to the stress of a return mission. However, a concerning finding is that some telomeres became critically short. In addition, less telomeres were detected during the postflight stage which indicates that there was an increase in critically short telomeres and that some telomeres may be completely gone. These effects can lead to cardiovascular disease or cancer. Telomere fluorescence in situ hybridization, Telo-FISH, was performed to confirm this surprising finding. In addition, upregulation of DEGs that are specifically associated with packaging of telomere ends and maintenance of telomeres was detected.

Weightlessness and physiology:

The weightlessness experienced by astronauts leads to increased fluid shift towards the head. This increase in cephalad fluid flow plateaus after 2 weeks indicating that it likely will not worsen on a longer mission. This change in fluid movement in the body can lead to various cardiovascular and eye issues. Cardiovascular adaptations to space led to left ventricular mass increase which worsened during the late inflight stage showing that this issue may be exacerbated by longer missions. In addition, there was a 10% increase in cardiac output and a decrease in systolic and arterial pressure. Carotid artery dissension which is the expansion of the artery occurred throughout the inflight stage. Carotid intima-media also thickened and remained thick after a few days of return. Vascular wall dimensions were also increased due to the increased abundance of two collagen proteins which was discovered during the proteomic studies.

Spaceflight-associated neuro-ocular syndrome (SANS) is a syndrome that has been known to space agencies and was further studied in this experiment. It is caused by increased cephalad fluid shift which can also cause optic disc edema, hyperopic shifts, globe flattening, and choroidal folds. The subject developed SANS and retinal edema formation during the inflight stage and has worsening choroidal folds. There is no current counter-measure for this syndrome due to the little understanding of this phenomenon.

Proteomic and metabolomic studies showed that there was in increase in leucine-rich alpha-2-glycoprotein (LRG1) in the subject's urine which has been linked to retinal vascular pathology. Lower levels of serum folate, part of the b vitamin family, were also detected which has previously been shown in low levels in astronauts with ophthalmic issues.

Lastly, weightlessness leads to loss of muscle mass and strength, slower bone formation, and decreased in bone density, which are partially mitigated through regulated exercise. These effects worsen with longer time and are not fully solved through exercise or dietary changes.

Metabolomics and Proteomics:

Mass spectrometry (MS) was used for metabolomic and proteomic studies. These experiments showed changes in the abundance of 245 metabolites between the subject and the control with 39 metabolites different preflight. Many metabolites that increased in abundance are linked to pathways for genotoxic stress, inflammation, and altered amino acid metabolism. 32 urinary metabolites involved in energy production and macromolecular metabolism were also impacted. This is likely linked to the changes in mtRNA. RNA-seq data showed higher levels of mtRNA inflight and more time led to increased mtRNA inflight which was validated by qPCR on DNA in blood plasma and qRT-PCR in RNA from PBMC. An extracellular flux assay tested mitochondrial oxygen consumption rates which measured oxidative phosphorylation. Muscle cells were treated with plasma from the subject and the control and showed that there was an increase in ATP-linked respiration and a decrease in non-mitochondria respiration which is related to the increased mtRNA levels and the increase in urinary metabolites involved in energy production such as citric acid cycle intermediates. Lastly, DEGs were found for genes related to oxygen usage, mitochondrial transport, hypoxia, glycolysis, and lactic acid production.

Microbiome:

Shotgun metagenome sequencing was used to determine microbial diversity. Data showed no significant difference between the preflight, inflight, and postflight stages.

Metabolomic studies showed that metabolites from microbes that have anti-inflammatory properties were found in lower abundances than normal which may have an affect on the body's inflammation response.

Physical Health Risks:

While many factors resolved themselves by returning to normal during the postflight stage, such as the carotid artery size, choroidal thickness and peripapillary total retinal thickness, and many blood serum metabolites, the most risk inducing factors are the ones that do not return to normal upon return or ones that pose a danger while in space. The paper states that the mid-level risk factors include collagen regulation, intravascular fluid changes, and critical shortening of telomeres. High risk factors include SANS, changes in vascular physiology from fluid shifts, genomic instability and increased translocation and inversion frequencies, and continuously differentially expressed genes (Garrett-Bakelman et al., 2019).

Garrett-Bakelman et al. (2019) is the most comprehensive study of human health in space to date, but it does have weaknesses when using this paper to establish if a journey to Mars will be safe for humans. The duration of this study is one year in comparison to the proposed three-year journey to Mars and radiation effects will be much more pronounced on a journey to Mars due to the fact that the ISS is protected by the magnetosphere of Earth and does not experience as much radiation as astronauts in deep space would. Lastly, this paper did not mention that another potential risk factors for human health in space is the distance between Mars and the Earth which increases the time needed for travel and communication between two celestial bodies and will not allow for immediate response when medical supplies are needed. Current studies on radiation predict that increased radiation levels can lead to central nervous system damage, radiation sickness, and degenerative tissue diseases (NASA, 2020a).

Mental Health:

The Twin Study studied cognition throughout the preflight, inflight, and postflight stages. They found that cognitive speed increased across all domains in early inflight relative to preflight, spatial orientation increased throughout all stages, and accuracy of visual object learning decreased. Emotional recognition declined from early inflight to late inflight and all areas of cognitive sped decreased except for spatial orientation during the six months of postflight which may have occurred as a post-stress reaction to the full year in space (Garrett-Bakelman et al., 2019).

Other studies have displayed that isolation and confinement have been shown to lead to depression, loss of motivation and cognitive performance, as well as sleeping disorders. These effects are further exacerbated by a lack of key nutrients in astronauts' diets which can be mitigated through the advancement in crop harvesting aboard the ISS. (NASA, 2020b)

In a study by Dr. Jack Stuster, ten journals from astronauts that span five Earth years were analyzed to determine the psychological effects of the humans on the ISS. Stuster found that interpersonal issues increased by 20% during the second half of their stay in space which affected the astronauts' teamwork. In addition, physical jobs became easier over time, and problem-solving skills remained constant. These increases in interpersonal issues faced by the astronauts could lead to severe problems that require teamwork and collaboration on a longer mission such as the journey to Mars (Stuster, 2010).

Many of the health effects and challenges discussed in this section are not fully understood and do not have treatment or mitigation plans. In terms of physical and mental health support, humans are not ready to colonize Mars. Human health in space, however, is a very active field of research and is of top priority to many space agencies. This field of science may develop to enable humans to successfully and safely travel to, and live on, Mars.

ETHICS OF HUMAN COLONIZATION OF MARS

The successful political framework and sustainability efforts for colonizing Mars show how, in some aspects, humans are prepared for Martian colonization. The unknown extent of human health effects in space, however, question whether we are ready to colonize Mars. With more scientific, medical, and technological development, we may be able to fully understand the human body and how it is affected by space and implement countermeasures to ensure the safety and happiness of humans in space. Assuming that humans are prepared and ready to safely travel to, and colonize, Mars, it is important to question whether humans should colonize space.

To answer this question, the current reasons why humans want to colonize Mars and whether the planet can provide what humans are looking for will be considered. Colonizing Mars will be an exciting advancement of science and technology, and would serve as a testament to the resilience of the human race. Colonizing Mars also provides a new direction for the future of humanity and an expanded view of the human's place in the universe. Mars also provides a potential second-home for humans, which is especially important due to the growing concerns regarding global warming, overpopulation, resource depletion, and catastrophic events on Earth. While some of these dangers to the human race and to Earth may be far in the future, perfecting the journey to Mars and establishing a successful colony will take time. While there are many other reasons for Martian colonization, these represent some of the most common. These common reasons for human expansion to Mars each bring ethical concerns that must be overcome before developing and completing the technology needed to colonize Mars. In addition, this thesis will discuss whether these motivations will be met by successfully colonizing Mars.

Abandoning Earth: A Plan A versus Plan B Approach

Human civilization faces constant threats, including plagues and pandemics, global warming and ecological damage, natural disasters, depletion of natural resources, overpopulation, and collisions from space. Some of these threats are caused or exacerbated by humans and can thus be slowed or mitigated with proactive measures, however, others are inevitable. Human exploration and expansion into space serves as a scientific and technological feat and provides human civilization an escape from our planet in the case of a disaster.

Levchenko et al. (2019) state that the strongest arguments for colonization of Mars is Earth based. Fears surrounding global warming, imminent war, asteroid collisions, and other catastrophes that could wipe out the human race are catalysts for many people to want to colonize Mars. Human survival faces constant threats on Earth, and Mars presents the best possible safe haven due to its proximity to Earth and potential to support life. Szocik et al. (2019) bring up the idea of protecting Earth versus colonizing Mars. Szocik et al. explains that as we plan for safe haven on Mars, the challenges and hurdles that we face to make it a reality may show people how uncertain this plan is and may increase participation in the improvement and sustainability of our own planet. However, there is a risk that if a Martian colony becomes more and more possible, the importance of sustainability on Earth may diminish overtime as the population begins to look towards a life on a new pristine planet that does not need to be saved.

Alexey Turchin introduces the Plan A, Plan B model to this argument. Plan A seeks to get ahead of the catastrophe and prevent it, which can be aligned with the sustainability and protection of our Earth environment. Plan B represents the aftermath of a catastrophe and is a plan for survival. Turchin argues that Plan A should be the primary plan to prevent a catastrophe instead of preparing for its aftermath. However, some catastrophes cannot be prevented and some plans for survival cannot be done in the aftermath of a catastrophe and must be prepared for ahead of time.

Mars colonies would be heavily controlled and regulated to ensure that it is sustainable and balanced, and would provide a stable environment in comparison to an Earth that has undergone a catastrophe. Mars, however, presents challenges that would be completely new to the human race. There will be a steep learning curve, where the colonizers would be forced to come up with solutions for problems that could easily become disastrous, such as a loss of power, a disease outbreak, or the death of crops needed to sustain the population. Many of the catastrophes that are possible on Earth such as pandemics, asteroid collisions, war, and environmental change are also possible on Mars. If Mars presents many of the same possibilities for catastrophes, as well as increased challenges that can easily disrupt the delicate balance of the colony, then it suggests that Mars is not a viable Plan B.

A split population on Mars and Earth may provide a longer survival for the human race in the case that Earth does get affected by a catastrophe because the Martian populations would survive. This separation, however, will likely be decided on classist principles because only the most fortunate will be able to fund a journey to Mars (Schwartz et al., 2021). In addition, the population left on Mars would then be forced to make sustaining Mars their top priority and may look to colonize another planet as a secondary Plan B, which will lead the human race into an unending cycle of escape and colonization

This cycle questions whether humans have a right to colonize other planets and utilize their resources. Schwartz et al. (2021) discusses whether the universe is a human right for use and exploitation. Various belief systems are likely to answer this question differently based on their individual view of the uniqueness of humans in the universe and where humans lie on their respective hierarchies of life. Abrahamic religions have a deity who creates the universe for humans, who are unique to other forms of life. In this belief, it would seem that the uniqueness of humans and the creation of the universe around them allows humans to use and exploit their universe for their own use and benefit (Schwartz et al., 2021). Conversely, in the Buddhist value system, all life is connected, related, and interdependent on one another and with their surroundings. In this view, the universe is not many parts, but rather one whole system where exploitation of one ecosystem or planet hurts everything connected to it (Schwartz et al., 2021). These are just two examples, however, the breadth of human thought on our place in the universe implies that we may never come to a conclusion, and it is unlikely that there will be agreement on the degree that humans may use other planets and resources for their own gain.

These claims show that Mars will not be a perfect safe haven for all humans to travel to in the case of a catastrophe on Earth, and that a split population on Earth and Mars to protect the future of the human race will only enforce further division and classism between populations. In addition, it is unlikely that there will be an agreement on the usage of space and its resources, which will lead to future conflict and the need for stronger regulations that dictate how humans may utilize space and other planets. Lastly, Martian colonization may entrap humans in a cycle of destruction and further colonization. These conclusions show that human colonization of Mars will not meet two of the most common reasons for why it should be done in the first place unless the human attitude towards their environment changes.

The Martian Environment

Other significant motivations for colonization of Mars are the current state of our Earth's environment and the scientific opportunity that living on Mars provides. Earth is experienced increasing climate change, depletion of resources, and overpopulation. Human expansion has been the answer to some of these challenges in the history of the human race, and many believe that it is still the answer. Increasing climate change on our planet has been shown to be heavily impacted by human activity. In addition, long-term colonization of Mars will lead to permanent change and damage to the environment from human settlement. It is likely that human settlement on Mars will lead to many of the same problems that we face on Earth unless humans change the way that they interact and affect their environment. While global warming is unlikely to occur on Mars due to the lack of atmosphere and magnetic field, resource depletion and overpopulation is possible. Many of the resources humans will need on Mars will either need to be sourced from Earth, further depleting our planet, or will need to be synthetically derived.

Terraforming of Mars is a common answer to the eventual resource depletion of a human colony on Mars. Terraforming is a process that changes an environment to be suitable for human life. Examples of this process include increasing the amount of oxygen on Mars, synthetically altering the temperature of Mars by changing the chemical composition of its thin atmosphere, building a thicker and denser atmosphere, or introducing microbial and plant life to the Martian environment. While it may seem like terraforming is a solution to the depletion of resources, it will also lead to permanent environmental change and damage. If humans terraform Mars and damage the environment in the same was as Earth, then the cycle of environmental destruction and colonization, as mentioned in the previous section, will always continue. To prevent having to re-colonize new planets, humans should reinforce better relationships with the environment, and should minimize the level of terraforming used to make Mars a more habitable planet for humans. If these changes are not implemented, then Mars will not provide a long-term solution to the environmental damage of Earth. In addition, damage to the environment of Earth and terraforming will prevent the study of a “scientifically pristine” Martian environment. These conclusions show, once again, that common motivations for colonizing Mars will not be met unless the human relationship with their environment changes. While the political framework mentioned in previous sections protects the environment from resource exploitation and environmental damage, the language is vague and must be expanded to be more specific to Mars and its environment.

CONCLUSION

This thesis adds to the current discussion on whether humans should colonize Mars by discussing the current framework for politics in a Martian colony, sustainability research, human health in space, and ethical concerns regarding the colonization of Mars. These discussions ultimately help determine whether it is feasible to colonize Mars and if colonization of Mars meets the current motivations behind it. The findings from this literature review highlight strengths in human preparedness for colonizing Mars, such as the broad foundation for a Martian colony’s political framework and the success of plant growth in space for sustainability efforts. Further research is needed to determine the variety of crops that can grow in space and to expand on the current political framework to be more specific to Mars and the colony inhabiting it. Weakness, such as the current lack of understanding of how the human body will react in space for three years and the concerning health deterioration of astronauts in space, were also discussed. These weaknesses, however, may be solved through further scientific advancement and understanding of the human body in space. Lastly, this thesis states that concerns surrounding Martian colonization undermine the motivations behind it. While this thesis cannot make a definitive conclusion on whether humans should colonize Mars, I argue that the most pressing concern is that current common motivations for colonizing Mars may not be met by successfully accomplishing this goal, which ultimately questions why we should do it.

Current media attention and scientific discussion focuses on both the scientific and technological aspects of this feat, however, I argue that motivations for colonizing Mars as well as the ethics surrounding the environmental usage of Mars should be at the forefront of the current discussions of human expansion and colonization of space. In addition, while this thesis focuses on Mars, many of the pressing concerns that arise in terms of the reality of Martian colonization are related to the relationship between humans and their environment. Care for Earth's environment will prevent the need for a Plan B motivation to colonize Mars, and will foster healthy interactions between humans and the environment which will mitigate issues related to resource exploitation and environmental destruction of Mars. This will enhance the preservation of a scientifically pristine Mars and will allow Martian colonization to better meet the common motivations behind it.

REFERENCES

Cockell, C. S. (2016). The Ethical Status of Microbial Life on Earth and Elsewhere: In Defense of Intrinsic Value. In J. S. J. Shwartz & T. Milligan (Eds.), *The ethics of space exploration.* (pp. 167-179). Springer. https://doi.org/10.1007/978-3-319-39827-3

European Space Agency. (2020). *International Space Station legal framework.* https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/International_Space_Station/International_Space_Station_legal_framework

Garcia, M. (2020) *NASA Station Astronaut Record Holders.* National Aeronautics and Space Administration. https://www.nasa.gov/feature/nasa-station-astronaut-record-holders

Garrett-Bakelman, F. E., Darshi M., Green, S. J., Gur, R. C., Lin, L., Macias B. R., McKenna, M. J., Meydan, C., Mishra, T., Nasrini, J., Piening, B. D., Rizzardi, L. F., Sharma, K., Siamwala, J. H., Taylor, L., Vitaterna, M. H., Afkarian, M., Afshinnekoo, E., Ahadi, S.,…Turek, F. W. (2019). The NASA Twins Study: A multidimensional analysis of a year-long human spaceflight. *Science, 365*(6436). DOI: 10.1126/science.aau8650

Levchenko, I., Xu, S., Mazouffre, S., Keidar, M., & Bazaka, K. (2019). Mars colonization: Beyond getting there. *Global Challenges*, 3(1), 1800062. doi: 10.1002/gch2.201800062

Lockhart, L. (2021). *Seed Film Brings New Way to Grow Plants in Space.* National Aeronautics and Space Administration. https://www.nasa.gov/feature/seed-film-brings-new-way-to-grow-plants-in-space

Losch, A. (2020). Developing our planetary plan with an 18th United Nations Sustainable Development Goal: Space environment. *Teologiese Studies Theological Issues, 76*(1). doi: https://doi.org/10.4102/hts.v76i1.5951

Manzey, D., Lorenz, B., & Poljakov, V. (2010). Mental performance in extreme environments: Results from a performance monitoring study during a 438-day spaceflight. *Ergonomics, 41*(4), 537-559. https://doi.org/10.1080/001401398186991

McAllister, M. (2018). *Giving Roots and Shoots Their Space: The Advanced Plant Habitat.* National Aeronautics and Space Administration. https://www.nasa.gov/mission_pages/station/research/Giving_Roots_and_Shoots_Their_Space_APH

McMahon, S. (2016). The Aesthetic Objection to Terraforming Mars. In J. S. J. Shwartz & T. Milligan (Eds.), *The ethics of space exploration.* (pp. 209-218). Springer. https://doi.org/10.1007/978-3-319-39827-3

National Aeronautics and Space Administration Johnson Space Center. (2006). *The human place in space*. https://www.nasa.gov/centers/johnson/pdf/160399main_human_place_fact_sheet.pdf

National Aeronautics and Space Administration. (2013). *Variable Gravity Plant Biology Spaceflight Research*. https://www.nasa.gov/sites/default/files/files/PB_FS_8-26-13.pdf

National Aeronautics and Space Administration. (2020a). *The human body in space*. https://www.nasa.gov/hrp/bodyinspace

National Aeronautics and Space Administration. (2020b). *Veggie*. https://www.nasa.gov/sites/default/files/atoms/files/veggie_fact_sheet_508.pdf

Paikowsky D., Baram, G., & Israel I. B. (2015). Trends in space activities in 2014: The significance of the space activities of governments. *Acta Astronautica, 118*(January-February 2016), 187-198. https://doi.org/10.1016/j.actaastro.2015.10.007

Schwartz, J. S., Wells-Jensen, S., Traphagan, J., Weibel, D., Smith K. C. (2021). What do we need to ask before settling space? *Journal of the British Interplanetary Society.* 2021-2023.

Skelly,C. (2021). *Nuclear Propulsion Could Help Get Humans to Mars Faster.* National Aeronautics and Space Administration. https://www.nasa.gov/directorates/spacetech/nuclear-propulsion-could-help-get-humans-to-mars-faster

Smith, K. C. (2016). The Curious Case of the Martian Microbes: Mariomania, Intrinsic Value and the Prime Directive. In J. S. J. Shwartz & T. Milligan (Eds.), *The ethics of space exploration.* (pp. 195-208). Springer. https://doi.org/10.1007/978-3-319-39827-3

Stuster. J. (2010). *Behavioral issues associated with long duration space expeditions: Review and analysis of astronaut journals. Experiment 01-E104 (Journals): Final report. National Aeronautics and Space Administration.* https://lsda.jsc.nasa.gov/lsda_data/dataset_inv_data/ILSRA_2001_104__1740256372_.pdf_Expedition_8_ILSRA-2001-104_2011_31_010100.pdf

Szocik, K., Norman, Z., & Reiss, M. J. (2019). Ethical challenges in human space missions: A space refuge, scientific value, and human gene editing for space. *Science and Engineering Ethics, 26*(3), 1209-1227. doi: 10.1007/s11948-019-00131-1

United Nations Office for Outer Space Affairs. (2015a). *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.* https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/intromoon-agreement.html

United Nations Office for Outer Space Affairs. (2015b). *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space.* https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introrescueagreement.html

United Nations Office for Outer Space Affairs. (2015c). *Convention on International Liability for Damage Caused by Space Objects.* https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html

United Nations Office for Outer Space Affairs. (2015d). *Convention on Registration of Objects Launched into Outer Space.* https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introregistration-convention.html

United Nations Office for Outer Space Affairs. (2015e). *Space Law Treaties and Principles.* https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html

United Nations Office for Outer Space Affairs. (2015f). *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.* https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html

Author Biography

Divya Kolli was born and raised in Coppell, TX and is an Astronomy and Biochemistry undergraduate student at The University of Texas at Austin. She served as a member and mentor in the Accelerated Research Initiative – Virtual Drug Screening Stream and as a Membership Officer for Showtime, a committee under Campus Events and Entertainment. She will be attending The University of Michigan, Ann Arbor in the fall of 2021 as a graduate student pursuing a Ph.D. in molecular, cellular, and developmental biology.