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Effects and Solutions on the Human Body After Long-Duration Space Flights

Jose Jaime Esquivel Patricio
San Jose State University

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***Jose Jaime Esquivel
Patricio***

Major:
Aerospace Engineering

Mentor:
Taylor-Dawn Francis

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Biography

Jaime is a first-generation student pursuing a B.S. in Aerospace Engineering with a Minor in Astronomy. His research focuses on the effects of microgravity on astronauts in order to find solutions for long-duration space flights to Mars. After graduating, he plans to attend graduate school to continue his dream of making humans an interplanetary species. He believes the purpose of engineering goes beyond making people's lives easier. When used sensibly, human history demonstrates engineering can propel humanity into unimaginable new boundaries. He developed his mission to promote higher education among underrepresented groups in his community and advocate for more students to pursue a career in STEM. His belief is that if we only have one life; to make our lives more meaningful, we should strive to make this world better and to serve the community.

Effects and Solutions on the Human Body After Long-Duration Space Flights

ABSTRACT

During the Cold War, President John F. Kennedy made it a mission for the National Aeronautics and Space Administration (NASA) to accomplish a lunar landing and return to Earth. The final lunar landing and the last time humans left Low Earth Orbit (LEO) was in December, 1972. However, 47 years have passed and the fascination with traveling into deep space remains alive and flourishing. A major problem with future human missions to Mars is the effects of microgravity and Mars' 0.38g environment. Unfortunately, space medicine is limited and little is known about the effects of microgravity on the human body after one year in space. Is it possible for astronauts to survive long spaceflight missions to Mars? To help address this question, my research focuses on the effects of microgravity on astronauts in order to find solutions for long-duration space flights to Mars. Bone and muscle loss are factors that could lead to severe, unknown consequences on an astronaut's health. My methods included doing an analytical interpretation of historical and contemporary research on long-distance spaceflight. In the future, longer missions are going to require more permanent solutions for humans to be an interplanetary species. The current solutions being used in the International Space Station (ISS) are only to treat individual symptoms separately. Only theoretical permanent solutions were found, such as artificial gravity; therefore, further research is needed. Centripetal acceleration has shown great promise to eliminate microgravity effects but more research is needed to understand the health consequences and the limitations of rotation that humans can sustain.

Nomenclature

F	=	Force
m	=	Mass
ω	=	Angular velocity
r	=	Radius

I. Introduction

A. Background

Space exploration in the United States began with tensions between the United States and the Soviet Union. Dwight Eisenhower initiated the National Aeronautics and Space Administration (NASA) in 1958 as a way to keep the Soviet Union distracted while the Department of Defense (DOD) focused on a militaristic approach to secure space [11]. As tensions grew between the nations, a competition to reach the moon intensified. In a momentous speech by John F. Kennedy in 1962 that continues to echo in the modern day, he said, “We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills.” [9]. This speech helped to energize the United States to put a human on the Moon and bolstered a movement for space exploration.

In contrast, the Richard Nixon administration (1969-1974) reduced the funding from NASA and actively made efforts to cancel a return to the moon, as well as stop the management of the Saturn V rocket [11]. Although funding was cut from NASA, Nixon wanted the human spaceflight program to continue, so he laid the foundation for the space shuttle program that would be later developed by many presidents after him [11]. With no new mission to return to the moon, George H.W. Bush wanted to reignite the flame for space exploration again so he pushed his plan forward – known as the Space Exploration Initiative (SEI) in 1989 [11]. SEI was a plan to return to the moon and many scientists and engineers pushed for the opportunity to create a plan known as the 90-day report [1, p. 58]. The 90-day report included a summary to start a base on the moon and build a spaceship in orbit for Mars, but it gained scrutiny due to the 450-billion-dollar cost of the project [1, pp. 58-59]. In the end, the SEI efforts died with

no progress made in returning to the moon [11]. The reason for its demise was its high cost and the United States' dwindling focus on space exploration. Without the support of the people, an expensive plan was difficult to justify.

The Columbia space shuttle disaster of 2003 was the first of its kind where there was an engineering problem that led to the explosion of the vehicle eventually killing the passengers aboard. This event influenced George W. Bush to stop space shuttle development because of the increasing cost and to prevent another disaster from happening [11]. However, Bush pushed for an alternative project to replace the space shuttle and gave his approval for the Commercial Space Launch Amendments Act of 2004. This amendment played a critical role in boosting commercial spaceflight for the future and inspiring entrepreneurs to start companies that would change the future of spaceflight. Pappalardo describes that the amendment, "Establishes an experimental permit for reusable orbital rockets. This opens an entire door for spaceport development and a boom in space projects" [12, p. 58]. Without their own active space shuttle, the United States relied on the Russian Soyuz to take them to the ISS until the United States developed a new way to take its own astronauts to the ISS [12, p. 27].

After these events, Barack Obama canceled the Constellation Program started by George W. Bush and moved all the funds to support the deep space capsule called Orion and the Ares rocket [13]. The space capsule Orion and the Ares rocket would be used to leave earth's orbit to return to the moon. Following the lack of leadership and continued reliance on the Soyuz, there was a need for a new competitor to further expand space flight development. In 2014, there was a major push by NASA to increase commercial spaceflight and awarded SpaceX and Boeing billions of dollars to develop their own space capsules to LEO [14]. Elon Musk, the founder of SpaceX, has been a major leader in pushing the limits of space exploration and has successfully made reusable rockets to decrease the cost of sending payloads to space.

Although SpaceX and many other private companies are introducing new ways to travel in space, we still have yet to combat the effects of long-duration spaceflight on the human body. To date, humans have conducted constant research in the ISS to further understand the effects of

weightlessness and find solutions. In 2015, Scott Kelly and Mikhail Kornienko were one of the first people to complete a one-year mission in the ISS, implying that more extended missions will take place in the future.

B. The reason for NASA's Failure to go to Mars

In Robert Zubrin's book, *Mars Direct*, he criticizes the path NASA took after the Apollo Era, which began in 1961 and ended in 1973 [2, p. 47]. During the Apollo Era, NASA was focused on reaching the moon and many projects were successful, such as the Apollo space program and the first U.S. space station Skylab [2, p. 50]. After 1974, NASA altered their resources to accommodate the new Shuttle Era, which was focused on improving technology for future space missions [2, p. 47]. However, Zubrin points out that instead of making focused technological improvements, scientists wanted to push their favorite technologies without a strategic purpose [2, p. 48]. Zubrin states:

To make this distinction completely clear, a metaphor may be useful. Imagine two couples, each planning to build their own house. The first couple decides what kind of house they want, hires an architect to design it in detail, and then acquires the appropriate materials to build it. That is the Apollo Mode. The second polls their neighbors each month for different spare house-parts they would like to sell, and buys them all, hoping eventually to accumulate enough stuff to build the house. When their relative inquire as to why they are accumulating so much junk, they hire an architect to compose a house design that employs all the knickknacks they have purchased. The house is never built, but an excuse is generated to justify each purchase, thereby avoiding embarrassment. That is the Shuttle Mode. [2, pp. 48-49]

Here, Zubrin uses a metaphor describing NASA in two-time eras where one was focused and driven while the other half was disorganized and lacking a clear direction. Throughout history, we can infer that each United States president had a different agenda and chose to remove funding or cut ongoing projects that delayed any real progress to return to the moon or go to Mars.

In 2001, the NASA Administrator, Sean O’Keefe, was not focused on a destination outside of Earth [2, p. 52]. After the 2003 Columbia Disaster, O’Keefe was prompted to cancel future space missions, including one that was meant to repair the Hubble Space Telescope [2, p. 71]. To prevent another space shuttle tragedy, O’Keefe was willing to sacrifice an extraordinary piece of equipment that was important to understanding the universe. Zubrin ends with, “Leadership is required – and for the last four decades, there has been almost none” [2, p. 53]. The Challenger and Columbia disasters were unfortunate in the history of NASA but these challenges are unknown and have always been risky. To continue making progress in unknown territories, risk should not be the stopping factor.

C. Why Mars?

In order to have a settlement and a thriving society, certain requirements are necessary, such as food, fuel and raw materials to build a colony. Growing food is important because it has the potential to reduce the cost of sending supplies to future inhabitants in different planets. Using artificial light to grow crops is economically unfavorable because generating enough sunlight to power a football size of plants requires four thousand kilowatts [1, p. 237]. Zubrin points out that solar and wind power are unable to generate the power necessary to grow crops because at best, only hundreds of kilowatts could be produced [1, p. 237]. If these methods can only generate a limited supply of power, then it would be difficult to grow food for a space colony.

One proposed solution is creating a colony on the moon. Although there have been numerous proposals for this solution due to its proximity to Earth, placing a colony on the moon has significant disadvantages. One factor that makes the moon unattractive is that it has different phase changes; this makes it difficult for plants to grow there [1, p. 211]. It is difficult for plants to grow because there is a constant change in light that is not healthy. The added difficulty is that artificial light to grow plants would not be able to sustain a large colony. The idea of having a colony on the moon is difficult and can cost more money to send supplies. Also, since the moon does not have an atmosphere to defend itself from solar flares, it requires a thick shield to protect the plants from radiation [1, p. 237-238]. Having a thick wall would shield the plants from cosmic radiation except it

would complicate the mission and add more weight to existing spacecraft, making it costly to implement.

In contrast to the moon and the other eight planets in our solar system, Mars is the only one that has the capacity to harbor and sustain life. Mars resembles Earth because it has a thin atmosphere and has an abundance of raw materials that could be used to build a future colony [1, p.211, 236]. Mars also contains precious metals that were made from its past volcanic activity [1, p. 236]. Since Mars has a thin atmosphere, it is able to block solar flares, allowing plants to grow without a thick shield on its greenhouse [1, p. 238]. Mars has a perfect environment for human survival because it can shield humans from radiation and the raw materials could be used to build a new habitat. A possibility in the future is sending robots to Mars to construct the shelter and by the time humans arrive everything will be ready to be used. The cost would decrease and the new base would not rely on Earth for supplies. Zubrin argues that Mars also has all the building blocks to sustain life and has an abundance of hydrogen, nitrogen, carbon and oxygen [1, p. 236]. These important elements could be used to refuel a spacecraft stationed in Mars and launch itself out after the mission is complete. Water is another important resource that has been found on Mars (frozen) and can be extracted [1, p. 236]. To have a sustainable colony, power is also another important consideration. It is gained by harnessing geothermal energy though deuterium [1, p. 237]. What makes deuterium important on Mars is that it is five times more likely to be found there in comparison to Earth, and it can produce 10,000 kilowatts for power [1, p. 237]. Accessing this large amount of energy could open doors to power more tools or vehicles. This is important because solar and wind power cannot generate enough power to grow plants; therefore, another source of power is needed.

Zubrin stresses the importance of living off the land on Mars [2, p. 15]. Because Mars is the only planet that can sustain human life outside of Earth and has all the necessary building blocks to sustain a colony, this would save money in the long run because there would be fewer resupply missions needed to bring food and supplies when the inhabitants could use their surroundings to build a new base.

II. Effects of Weightlessness

Astronauts in the ISS do not feel earth's gravitational force acting on them since they are on constant freefall orbiting around Earth. Since no force is acting on them, they are under the effects of microgravity. Similarly, when Astronauts leave LEO to the Moon or Mars, they experience the same effects of weightlessness. The human body on earth has adapted to the constant gravitational force pulling them down but when gravity is removed the body reacts negatively.

This research was undertaken because longer space missions are going to be required in the future and current space medicine research is limited. In Gilles Clément's book, *Artificial Gravity*, he details the history of space medicine and conveys that research is limited to only six months of travel in space; little is known after the one-year mark [3, p. 25]. According to Clément, the ideal space mission will take two and half years with a maximum surface stay on Mars of a year and a half [3, p. 6]. Another option to travel to Mars is an opposition class mission because it reduces the mission time by half but also reduces the surface stay on Mars by thirty to ninety days [3, p. 6]. Zubrin criticizes opposition class missions because it limits the amount of research that could be done on the surface of Mars [1, p. 94]. Zubrin states that if mission planners reduce the time, it is also actively hurting the crew because they would be consistently exposed to radiation and microgravity [1, p. 93]. Although Mars is not Earth's twin, it is still able to reduce radiation and microgravity exposure which can help a long-term mission be successful. Crafting giant spaceships and developing propulsion systems is an important engineering problem, but we have overlooked the factors of human challenges that have not changed over the past forty-seven years.

Louis Friedman discusses that human spaceflight ends on Mars because robotic technology has surpassed humans and continues to evolve further [10, p. 4]. Robots will replace humans in deep space missions, and virtual reality will take its place because human adaptation in space has not changed [10, pp. 7-9]. Significant microgravity effects are plaguing human exploration. Although radiation is another factor that poses a substantial problem for human safety during spaceflight, this research will focus on the significant effects of microgravity which include bone loss, muscle loss, cardiovascular, and sensory-motor deconditioning.

A. Bone loss

With the absence of gravity in space, there is no constant force acting on the bones, which affects their strength. Bone loss is important because according to Clément, “40% decrease in bone mass might occur for a spaceflight lasting two years” [3, p. 8]. A six-month journey to Mars would be dangerous because the astronaut would not be in their top physical condition, like they would be on Earth. If the future of human spaceflight requires missions longer than six months, there could also be an increased risk of bone fractures [3, p. 8]. Possibilities of fracturing bones could occur during a reentry back to earth or an accidental fall. They will not have the same strength they had before they left earth due to being in space for a long time. There will also be a limited number of surgical devices that would be taken and the added difficulty is that the blood will not behave the same way outside of a 1g environment. Another challenge is that not enough is known if the 0.38g Mars environment will be strong enough to halt further bone loss, decreasing the health of the astronaut’s bones [3, p. 8]. Bone loss is challenging to treat because there are no known solutions [3, p. 8]. Simply intaking calcium will not prevent the effects.

B. Muscle loss

Since there is no acting force on the human body in space, the muscles are also affected. The main way an astronaut moves around the ISS is by using fingertips, which decreases the number of times they use their legs [3, p. 15]. As the muscles become weaker, the fibers within the muscles change [3, p. 9]. There are slow and fast fibers within the muscles [3, p. 9]. Slow fibers are resistant against gravity and fast fibers are used with vigorous movement [3, p. 9]. According to Clément, “Studies reveal that about 15-20% of the slow fibers in a tight muscle convert to fast fibers during a 14-day spaceflight” [3, p. 9]. With a progressive increase of fast fibers in space, it also increases the probability of injury [3, p. 9]. When astronauts return to Earth, the change in gravity weakens their muscles, making it difficult for them to move due to the fatigue [3, p. 9].

In a hypothetical, worst-case scenario, Dana Carpenter and his team explored what would happen to the human body during a two-year mission to Mars without exercise. The result of their research was surprising; they found loss in knee strength by 15% on a six-month mission to Mars, 18%

in the 18 months on the surface of Mars, and an additional 15% loss on a 6-month trip back home [4]. The total muscle strength loss in the knee and ankle would be 48% and 32% [4]. The amount of damage raises concerns because astronauts coming back home could develop permanent damage. Also, the surface of Mars may not be safe for a permanent colony because humans would slowly lose their strength with Mars's 0.38g environment.

C. Cardiovascular deconditioning

Cardiovascular deconditioning is fluid shifting through the human body [3, p. 11]. On Earth, the heart pumps fluids and blood throughout the body, but in space, those fluids travel to the head and chest due to the microgravity [3, p. 11]. This can cause a higher heart rate and a sensation of fullness in the head [3, p. 11]. These effects are dangerous because astronauts returning from a mission or arriving on Mars can experience lightheadedness and fainting [3, p. 11]. This is a huge problem for astronauts because as they arrive on Mars, they will not be able to move until they can adapt to Mars's environment. Additionally, we are also unaware of the damage their bodies will sustain for a full two-and-a-half-year mission and the amount of time needed to recover. The 0.38g environment that Mars has is different from Earth and this can prove to be a problem.

D. Sensory-motor deconditioning

Sensory-motor deconditioning in space motion sickness because the body is confused in the direction it is moving [3, p. 12]. Generally, it usually takes a few days for a person to adapt [3, p. 13]. A drug known as antihistamine promethazine is used to reduce the effect of motion sickness but there are negative side effects that come with it [3, p. 19]. After arriving back to earth, astronauts need time to recover because they are not able to walk due to loss of coordination [3, p. 13]. As stated by Clément, "After flights lasting six months or more, some crewmembers must be physically removed from the vehicle on lifters" [3, p. 13]. An extended time in space can make it difficult for Astronauts to walk and assistance will be needed to pick them up after they arrive. Unfortunately, when they arrive on Mars, there will not be assistance and they would have to rely on their own strength and teamwork.

In 2003, a Soyuz capsule did not land in the anticipated landing point, so the crew had to manually fix the antenna to update their location and get rescued [3, p.17]. Before leaving Earth, this assignment took them minutes; however, after they arrived back on Earth, it took them hours to accomplish [3, p.17]. This could be a scenario if humans arrived on Mars in a weakened state from weightlessness. The plan for Mars is unknown because we do not know if 0.38g is sufficient to stop the effects of bone and muscle loss.

III. Solutions to Weightlessness in Deep Space

In order to address a problem, we have to identify and analyze the issues to take the necessary steps to fix them. Zubrin states, “The point, however, is that an awful lot of research has already been done in this area, and we know what the effects are” [1, p. 134]. Hall makes a similar statement that instead focusing on the individual symptoms the root cause should be solved [14]. Zubrin makes another good argument that studying the effects of microgravity too long can potentially delay the continuation of trying to find solutions [1, p. 134]. Hall and Zubrin are effectively saying that focusing on the problem will not fix it and without seeking a permanent solution, there will not be progress. A significant amount of research has been conducted in the ISS to study the effects of weightlessness, but there has not been a breakthrough to find solutions. Zubrin has not been satisfied with the course NASA has taken because they are not undertaking efforts to go to Mars but have spent a lot of time learning about the problems. A larger effort should be made to find possible solutions to the effects of microgravity on the human body; if one focuses too much on the problem after the solution is found, it renders all previous research on the effects insignificant.

Currently, there are few possible solutions that can reduce the effects of microgravity on the human body. Hall says [14], “Current countermeasures to musculoskeletal degeneration and other ailments, that rely on diet and medication, are essentially chemotherapies that address only individual symptoms of weightlessness, not the root cause, and run the risk of unintended consequences.” Hall gives an example of consuming calcium can lead to urinary stones [14]. By trying to fix one problem, another one can arise. Astronauts in the ISS reduce the effects of muscle

loss by doing isotonic and isometrics exercises [3, p. 10]. Isotonic exercises depend on intense movements where weight lifting is involved, and isometric exercises involve pushing against surfaces [3, p. 10]. Exercise with rapid movement like cardio is used to reduce the effects of cardiovascular deconditioning [3, p. 9]. Anti-gravity suits compress the lower part of the body to force fluids to the upper part of the body, which helps the heart circulate the blood more efficiently [3, p. 20].

When astronauts return to Earth from the ISS, there is a rapid reduction of fluids, so they ingest water and salt tablets to reduce these effects. However, this effectiveness is reduced the longer they remain in space [3, p. 20]. When astronauts come back to Earth, they oftentimes have a loss of coordination. The only solution is to reintegrate them back into a 1g environment [3, p. 13]. The difficulty with this is that the 0.38g of the Mars's environment might take longer for them to recover from, or it will continue to pose a problem on their bodies. In the past, exercise has been the main solution to reduce bone and muscle loss in space, but it is not a permanent solution for missions that last longer than six months in space.

Hall makes a strong argument for when NASA will make a serious attempt to develop artificial gravity [15]. Will there be another disaster like challenger to finally consider artificial gravity as the best solution for long distance space flight [15]? There are solutions that are applicable in theory but without proper funding and support, they will not see the light of day.

A. Nuclear Thermal Propulsion

One solution to reduce the effects of microgravity on the human body is minimizing the time astronauts are exposed to microgravity. Chemical rockets have been used throughout human history, but an alternative approach is to use Nuclear Thermal Rockets (NTR). Rocket efficiency is based on seconds of specific impulse, meaning the amount in seconds that 1 pound of propellant gives of 1 pound of thrust. Nuclear rockets can produce a specific impulse of 900 seconds compared to chemical rockets that produce a specific impulse of 450 seconds [1, p.114]. According to Robbins, using a nuclear solid core reactor would save 100-days round trip instead of a conventional chemical propulsion system [5]. Instead of taking eight months to reach Mars, there would be reduction to

six months that could be beneficial in reducing the adverse effects of microgravity.

To test the theory and make it practical the U.S. undertook a project called the Nuclear Engine for Rocket Vehicle Applications (NERVA) to test the efficiency of nuclear rockets. A fission reaction is when a neutron is absorbed by an isotope—like Uranium 235—and splits the nucleus, releasing more neutrons [6]. NERVA uses fission as its primary source of generating heat by using a continuous chain reaction inside its solid core reactor [6]. To control the chain reaction within the reactor, a moderator is used to reduce the speed of the neutrons and stop the fission reaction [7]. The preferred propellant is hydrogen because of its lightweight properties [6]. As the hydrogen passes through the solid core reactor, it gets heated and expels itself through the nozzle, pushing the vehicle into space [6].

These concepts for nuclear rockets are not mere science fiction; and they were attempted with great results. For example, Zubrin states that, “These engines really worked, and really delivered specific impulses of over 800 seconds, far beyond the wildest dreams of any chemical rocket engineer” [1, p.115]. Although great progress was being made, the NERVA project was terminated due to budget cuts by the Nixon Administration [1, p.115].

B. Linear acceleration

Another likely solution is to create artificial gravity. Artificial gravity is the sensation that mimics Earth's' gravitational force and has the potential to remove the effects of weightlessness. One way to make artificial gravity is through linear acceleration. When astronauts are launched from a space shuttle, they experience a few seconds of an opposite force pushing in the opposite direction they are facing [3, p. 35]. This method of transportation could be used to have a 1g force similar to that of gravity by pushing a rocket with a constant speed [3, p. 35]. This method sounds simple but it is costly because of the fuel requirement needed to have a constant speed [3, p. 35]. Hall also discusses the disadvantage of linear acceleration because it would require a constant energy input [14]. Linear acceleration is a solution to eradicate the effects of weightlessness but has shown to be costly.

C. Centripetal acceleration

The most popular method to develop artificial gravity is through centripetal acceleration. Figure 1 is an example of centripetal acceleration by having particle rotate around the center with the acceleration pointing inward and always being perpendicular to velocity.

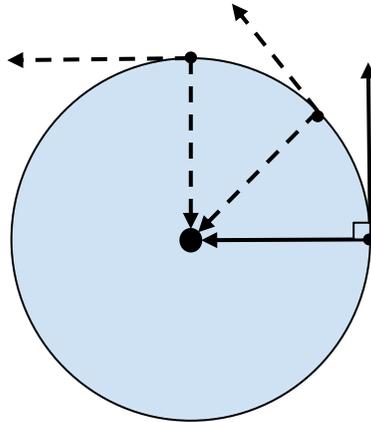


Figure 1: Visual representation of the centripetal acceleration

Centripetal acceleration happens in our daily lives; for example, when a bucket of water is circulated in a circle with a constant speed [1, p. 135]. The water within does not fall because it is being pushed outside at a constant rate [1, p. 135]. Two methods to use centripetal acceleration in space is by revolving the spacecraft or making a centrifuge inside of the spacecraft [3, pp. 33-34]. Essentially the big goal will be to have humans inside a rotating centrifuge to feel a sense of a 1g environment. The difficulty with this idea is the size of the centrifuges. This leads to Equation 1 which is a force equal to mass times its radius and angular velocity squared.

$$F = m * \omega^2 * r \quad (1)$$

If you have a small radius in the centrifuge, you will have to rotate it quicker to make a gravity force adequate for the astronaut to counter the effects of microgravity. Another option is to have a large radius with slower

rotation in order for it to have the same effects as a small radius. The difficulty with a small radius is that the spin rate could harm the human inside and the large radius is complicated to implement. Hall has compiled the research of multiple scientists and found that humans can sustain two revolutions per minute to the limit of six revolutions per minute [14]. Anything beyond six revolutions per minute was uncomfortable to astronauts and made their task difficult to complete [14]. Zubrin also explains that if there is a faster rotation, it produces a Coriolis force which makes it difficult for the astronauts to walk in a straight line when the habitat is constantly moving. Hall expresses that [14] ,“On the Soviet satellite Cosmos 936 in 1977, the lifespan of rats exposed to centrifugation during 18.5 days of space flight was significantly greater than that of non-centrifuged control animals.” The research that has been done in centripetal acceleration has been positive and tests have proved that artificial gravity is a permanent solution against microgravity. Even though this is the best solution, Clément also points out gaps that still need to be researched that include: rotation speed, length of exposure, Coriolis and the 0.38g Mars effects on the human body, and if the research done on earth will be the same in space [15].

IV. Conclusion and Discussions

The U.S. has proven to be a world leader in space exploration and NASA has been on the forefront to solve the challenges we have to bring humans back to the Moon and travel to Mars. However, everyone has continued to ask the same question - when will we go to Mars? And why haven't we returned to the Moon? It has been 47 years since the U.S. left LEO or made any real plans to make another trip like the Apollo Space Program. There have also been inconsistencies with each president pushing a different agenda and cutting funds from NASA expecting a larger outcome. Every time they get defunded, it makes it difficult for the organization to execute plans and delays their projects. For example, when the Richard Nixon Administration cut the funds from NASA they had to retire the Saturn V rocket that took humans to the Moon. Without any real vehicle that could return to the Moon, the Apollo Era ended and there has not been a real push since then. Even though NASA has taken a detour and made the best with existing funding, private companies have started to move

in and prioritize space flight. Commercial spaceflight is the future of the U.S. and will be a key player for humans to go to Mars in the future.

Commercial spaceflight has been pushing the boundaries in reusable rockets and Elon Musk has energized the movement of making humans interplanetary species. The push for Mars is getting the U.S. exhilarated but there are many problems that have to be addressed before taking flight. A large amount of progress has been made in improving spacecraft development, but microgravity continues to be a substantial problem for human survival due to the deteriorating effects it has on the human body. There is a significant amount of bone and muscle loss on missions to Mars that increases the chance of an accidental bone fracture. Astronauts will not have the same medical equipment we have here on Earth, complicating the mission even further. After a six-month journey to Mars, astronauts will not have someone to take care of them to recover from their journey. There is also the ambiguity of the length of time it will take to recover from an environment that has 38% of Earth's gravity. They will be facing multiple challenges on their own without the assistance and tools they have on Earth.

Will humans be ready for a voyage to Mars in this decade? The current answer to this question is, “no.” A Mars mission will require three years and the effects of weightlessness is catastrophic in the human body. The current solution to fight these effects has been traditionally exercising on the ISS but if longer missions are going to take place there needs to be a permanent solution. NASA has been trying to treat the symptoms of weightlessness individually when there is an obvious solution that can solve everything. The best method that needs to be taken more seriously is having centripetal acceleration on a spacecraft. Movies like the *Martian* offer the idea of having a rotating part of the spaceship to have a 1g environment while traveling. This could potentially remove all the effects that come from bone and muscle loss and eliminate sensory motor deconditioning. A centrifuge could be made for the whole spacecraft or shorter to have a small one inside the spacecraft. The idea would be to expose the astronauts to artificial gravity through centripetal acceleration.

V. Future Research

This report was meant to serve as a building block for a more advanced research project to find out if we can travel to Mars and find solutions to combat the effects of microgravity. The longer humans are in space, the more negative side effects will occur, mainly, microgravity weakening their muscles and bones.

My analysis of historical and contemporary research on long-distance spaceflight has shown the best approach to reduce the effects of microgravity will be to develop artificial gravity through centripetal acceleration. The next step is to dig deeper into centripetal acceleration and understand the engineering and design challenges it has to make it more feasible to implement in space. As Clément explains, we still do not know the health effects of different rotation speeds in the centrifuge and the time length of exposure recommended [15]. A future research project can thoroughly investigate who is continuing this research and if there are alternative ways to implement artificial gravity.

Another idea for future research is to explore exoskeleton research and how they can be used on missions to Mars. An exoskeleton would encompass the whole body and it will be an extra set of strength to keep them safe. Astronauts arriving on Mars will have a weak immune system and their bodies will require time to adapt to the new environment. The effects of microgravity would be recent and their poor balance can increase an accident of falling and injuring themselves. They will have to face the new environment on their own without the assistance they receive from Earth. An exoskeleton will help them reduce the stress on their body until they can recover. Exoskeletons are an emerging field in science and using them for space exploration could be a beneficial step for the first mission to Mars.

Additional research for the future is to explore how clothes could evolve to counteract muscle loss. The clothes will be meant for the purposes in the ISS because Astronauts are not using their muscles due to weightlessness. Astronauts have traditionally used comfortable clothes like shorts and shirts to move around but this could be an opportunity to develop clothing to grip the body and any movement they do would make them work. This idea needs to be further looked into but there is potential to use every moment they are on the ISS to reduce muscle loss.

VI. References

- [1] Zubrin, R., and Wagner, R., *The case for mars: The plan the plan to settle the red planet and why we must*, Free Press, 2011.
- [2] Zubrin, R., *Mars Direct: Space Exploration, the Red Planet, and the Human Future*, Polaris Books, 2013.
- [3] Clément, G., and Bukley, A., *Artificial Gravity*, Microsoft Press and Springer, 2007.
- [4] Carpenter, D. R., Lang, T. F., Bloomfield, S. A., Bloomfield S. A., Bloomberg, J. J., Judex, S., Keyak, J. H., Midura, R. J., Pajevic, P. D., Jordan S.M., “Effects of Long-Duration Spaceflight, Microgravity, and Radiation on the Neuromuscular, Sensorimotor, and Skeletal Systems,” *Journal of Cosmology*, Vol. 12, No. 26, 2010, pp. 3778-3780.
- [5] Robbins, W. H., and Finger H.B., “An Historical Perspective of the NERVA Nuclear Rocket Engine Technology Program,” NASA CR-187154, 1991.
- [6] Shane, R. D., “Nuclear Thermal Rockets: The Physics of the Fission Reactor,” 2001.
- [7] Gabrielli, R. A., and “Herdrich G., Review of Nuclear Thermal Propulsion Systems,” Elsevier, 2015.
- [8] Pempie, P., “History of the nuclear thermal rocket propulsion,” *AAAF 6th International Symposium Propulsion for Space Transportation*, 2002.
- [9] Kennedy, J. F., “John F. Kennedy Moon Speech -Rice University,” Available: <https://er.jsc.nasa.gov/seh/ricetalk.html>
- [10] Friedman, L., “The Human Future in Space,” *Human Spaceflight: From Mars to the Stars*, The University of Arizona Press, 2015, pp.4-8
- [11] Logsdon, J. M., “Ten Presidents and NASA,” Available: https://www.nasa.gov/50th/50th_magazine/10presidents.html
- [12] Pappalardo, J., *Spaceport Earth: The Reinvention of spaceflight*, Overlook Duckworth , 2017.
- [13] Malik, T., “NASA grieves over canceled program,” Available: http://www.nbcnews.com/id/35209628/ns/technology_and_science-space/t/nasa-grieves-over-canceled-program/
- [14] Hall, T. W., “Artificial Gravity in Theory and Practise,” *46th International Conference on Environmental Systems*, Vienna, Austria, 2016.

- [15] Clément, G., “International roadmap for artificial research,” Springer Nature Publishing AG, 2017. doi:10.1038/s41526-017-0034-8