USING INDUCED TORPOR AS A METHOD TO REACH MARS

A Research Paper submitted to the Department of Engineering and Society
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical and Aerospace Engineering

By

Khamal-Karim Saunders

March 25, 2021

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

ADVISOR
Catherine D. Baritaud, Department of Engineering and Society

LONG DISTANCE SPACEFLIGHT TO MARS

Engineering is present everywhere in our lives. All throughout the world, people rely on and use engineered technology. One aspect of engineering that cannot be overlooked is outside our world. Space technologies impact us every day, although it may not be direct. Global Positioning Systems (GPS), phone calls, and the internet all rely on satellites in outer space.

The technical and STS topics look into different aspects of these space technologies. The technical project looks to improve on real-time weather data collection. The task is to design a satellite system that can collect current weather data and distribute it to drivers with minimal delay. This will increase road safety, as drivers will know the road conditions as they drive on them. The STS project looks to find a way to successfully have astronauts travel long distances in space. These are related in the use of spacecraft. Every operation that involves outer space needs to have similar components to address orbits, zero gravity, and other space phenomena.

For the STS project, the situation that created interest in researching the topic was the realization that sending humans to Mars is becoming more likely. Major space organizations are starting to seriously look into our neighboring planet. Loff (2018) notes how The National Aeronautics and Space Administration (NASA) has sent the new Perseverance rover to Mars, and missions are being planned to send astronauts there. Elon Musk's SpaceX company has had Mars as a goal for a while, and testing the spacecraft for the mission is progressing quickly (SpaceX, n.d.). With this new goal comes complications. The biggest issue arises from how far away Mars is. The planet is about 67.77 million km from Earth, which means it would take about eight months to reach the planet with current technologies ("Mars One", para. 2). Eight months would be an extremely long time for someone to sit in a compact vehicle, isolated from everything except a few fellow astronauts. It will be an uncomfortable journey, and psychological or physical problems may occur. Some of these physical dangers include increased acceleration and radiation, while the psychological issues arise from confinement, remoteness, and isolation (Doarn & Shepanek, 2019, para. 8). This leads to the research question. Is there a way to make this long journey easier in order to send humans to Mars? The following research on induced torpor is a hopeful answer to this question.

INDUCED TORPOR

Induced torpor is an idea brought up by SpaceWorks (Bradford et al., 2018) to induce sleep in astronauts as they travel in space. The immediate benefits of using this as a solution is that it seemingly solves many of the problems of an eight-month long journey. Astronauts that are asleep would not experience the phycological issues of confinement, or remoteness as they will be unconscious. They also would not feel the discomfort that comes from being unable to move in a small area while asleep. One example of the benefits of torpor can be seen in radiation protection. Our solar system is full of radiation. An astronaut is exposed to 50 to 2,000 Milli-Sieverts of ionizing radiation, which is equivalent to 150 to 6,000 chest x-rays (Perez, 2019, para. 6). Beyond Low Earth Orbit, there is an increased risk for things like radiation sickness, cancer, central nervous system effects, and degenerative diseases (para. 5). A round trip to Mars, which is beyond Low Earth Orbit, will take over a year to complete, and that will expose the astronauts to these dangers. Research by Hisanori Fukunaga (2020) suggests that induced hypothermia can help with protection from radiation. This stems from the amount of oxygen tissues get. The tissues in the body are sensitive to radiation, and this sensitivity is dependent on the amount of oxygen they receive, so with reduced oxygen from a hypothermic state, it follows that the effects of radiation are lessened (p. 4). With many solutions to the problems a long space journey brings, induced torpor is a legitimate option for future missions.

This STS paper will be a research paper. The majority of the points made will be research and evidence based with details provided to back up the points made. Induced torpor is a good solution for the human problems in traveling to Mars, but it is far from a complete answer. Because this is an active area of research, there is not much information on induced torpor in space flight. The research on human torpor is scattered, with most of the information being on the scientific and medical aspects of it. There is little on the current progress the technology is making. Along with that, there is also a lack of research into the ethical considerations of using torpor. NASA declined to fund a proposed international conference on torpor that would have brought experts together to discuss deep-space applications (Emmet, 2017, para. 16). One possible reason for turning down the conference idea was the lack in research.

Getting humans to Mars is a goal for many reasons. Scientifically, it can hold many answers to questions of the universe: it can help with the search for life, and understanding the surface and evolution of the planet. Learning about the Martian surface and its evolution as a planet can uncover details of the evolution and history of Earth, as well as other planets (European Space Agency, para. 5). Reaching Mars may seem like an inessential desire that wastes money, but in reality, it could be quite vital for the survival of the human race as we may need to live there one day. With climate change, carbon emissions, and the mass of nuclear weapons on the planet, Earth may not be habitable one day, and a back-up plan may be needed. (Fecht, 2017, para. 1-2). Mars is convenient in that it is the planet in the solar system most similar to Earth and is relatively nearby, so it is the designated back-up.

In order to examine the option of induced torpor as a solution in traveling long distances in space, three topics will be discussed: plausibility, ethical considerations, and logistics of the idea. The section on plausibility will look into the science of induced torpor in humans to see if it will be possible to use. The ethical implications will be studied to assess whether or not the technology should be used as a means to travel in space. The final section on logistics will focus on how soon torpor can be incorporated in space travel.

PLAUSIBILITY

Using induced torpor on humans is not a senseless idea. Although using the method for space travel has not been done on people before, there is promising research. There are two main ways to possibly induce sleep in humans for a mission to Mars. These are inducing hypothermia and forcing hibernation.

The hypothermia method involves cooling the internal body temperature to around 35 degrees Celsius or less. While in hypothermic conditions, oxygen consumption in humans is greatly decreased. With less oxygen, cells and tissues cannot function at a normal speed. While this may seem dangerous, this affect can help the body protect from further injury causes and prevents the progression of an injury (Nordeen & Martin, 2019, para. 4). Usually, if there is an interruption of oxygen and nutrients, there will be major destructive events that occur at the cellular level in minutes to hours. If the demand for the oxygen and nutrients is decreased in preparation of a reduced supply, the destructive events can be avoided (para. 4). In addition to preventing the destruction of the cells or tissues, hypothermic treatment can lead to preservation (para. 5). Preservation of the body with no damages to it is the ideal state for astronauts to be in on their way to Mars.

The use of hypothermia as a means of medical treatment has been around for a while. The first recorded instance of this dates back to the fourth century BCE. During this time, Hippocrates is said to have suggested this practice to treat the disease tetanus, and recommended packing the wounds of soldiers with snow and ice (Nordeen & Martin, 2019, para. 3). More recently in the 1950s, surgeons started using hypothermia for open-heart surgeries in order to halt circulation to the heart (para. 3). This practice caused many patients to survive lethal conditions, and is still in use today.

Hibernation is similar to hypothermia in that both involve a sense of falling into unconsciousness. Many animals, like bears, squirrels, and chipmunks, hibernate in the winter as a means to survive. The cold weather cases a shortage in resources and these animals rely on hibernation to avoid the struggles. They survive because while in hibernation, the metabolic rate in animals plummet (Nordeen & Martin, 2019, para. 14). The metabolic rate is the rate at which chemical processes occur in a living organism. These processes can be understood as converting food into energy for cells or eliminating metabolic wastes like carbon dioxide or water. Although hibernating animals have a much lower metabolic rate, they are strangely still protected from tissue damage and organ dysfunction. Their survival is possible due to the stores of excess nutrients in the body that allow them to not eat or drink for months at a time (para. 14). Humans may not have the ability to store excess fat or nutrients to hibernate like animals, but there are two ways to induce the condition: with a chemical or drug, and through brain synapses.

Adenosine is a part of the central nervous system in humans and animals. When it binds to its receptors, neural activity slows down and a sense of drowsiness occurs (Dubuc, n.d.). Using certain drugs, scientists at the University of Alaska successfully induced hibernation in arctic ground squirrels by activating these receptors (Bradford et al., 2018, p. 5). There were mixed experimental results, but pairing this with lowered temperatures proved to increase the likelihood of success. One chemical that can be used is hydrogen sulfide. This has been used to induce hibernation in mice by binding to their cells and reducing their demand for oxygen (p. 5). In this case, the hibernation works in a similar way to the hypothermia method.

A synapse is a site of transmission of electric nerve impulses between two nerve cells in the brain. With synapses come dendritic spines, which are protrusions that can transmit electric signals (Lodish et al., 2000, Section 21.1). Research shows that there is a decrease in dendritic spines in hibernating creatures (Bradford et al., 2018, p. 5). It is currently unclear whether or not the spines can be used to initiate hibernation, but more research is being completed on the topic. If it is possible to use the synapses for hibernation, it may be necessary to alter the nerve impulses in the brain. This can lessen the functions of the brain which would lead to a decrease in the functions of the body, allowing for a hibernation state.

Besides the use of hypothermia in medical practices, there has not been any human testing to induce hypothermia or hibernation. That being the case, there are some promising accidents that occurred which provide examples of these states. In 1999, a 29-year-old woman was submerged under ice wile she was skiing. Her body temperature dropped to 14 degrees Celsius and she entered a torpor state, but she still was revived after her heart stopped for three hours. Another example of this was seen when a man from Japan was found on a snowy slope unconscious, but alive, after 24 days. Finally, there was an incident where a 1-year-old baby survived after her heart stopped beating for over two hours after being left out in -20-degree Celsius weather (Bradford et al., 2018, p. 6). These cases show that humans can survive having their body temperature lowered with limited function, which resembles what induced torpor would do.

ETHICS

The ethical considerations of induced torpor also need to be discussed to see if the solution should be implemented. A trip to Mars would be a grand procedure to undertake, and there would be a lot of risk to human lives. Mission planners, engineers, executive leaders, and many positions within the organizations involved will all have a moral responsibility to protect the lives of the astronauts. Induced torpor is not yet a perfected procedure, so there is still much risk in its use. This section will look at the risks involved and analyze them from an ethical and moral viewpoint.

One moral concern is testing. Because this is a new technology in its development stage, it will inevitably need to undergo testing to make sure it will function properly. Testing on smaller animals may not seem that bad at first, but eventually larger animals will need to be tested on before humans. Animals being tested for science experiments already angers people who support the animal rights movement, so this will only add to that. Forcing hibernation in non-hibernating organisms has not been done, so it could prove dangerous. Not being able to reverse the condition may lead to the death of the animals or people being tested.

Another concern involves the state of the individuals under induced torpor conditions. Research has shown that animals in hibernation may not actually be completely unconscious. "According to data collected in animal studies, the cortical activity recorded during this state resembles a sort of 'slowed wakefulness', more than a state with a small degree of consciousness…" (Cerri, 2017, p. 6). A state where one is vaguely aware of what is happening, but cannot move is a frightening thought for someone in space. If an astronaut was even a little conscious for the 8-month journey, many of the benefits of induced torpor would not occur. The astronaut would be stuck and unable to do anything, leading to extra psychological issues that are meant to be avoided.

The final ethical issue is the limited control humans will have on the actual journey to Mars. The use of induced torpor and subsequent monitoring of the individuals will rely heavily on computers and robots. Due to the distance from Earth, there will be too much of a communication lag for the computers or machines to be controlled by people back on Earth. That means they will have to rely on preprogramming in order to make sure the astronauts stay safe. NASA missions have a history of computer malfunctions and mistakes that have caused missions to fail. In 1988, one missing character in a software program drained the life out of a Martian probe, and in 2006, a software bug ended the mission of the surveyors on Mars (Johnson, 2013). These are just two of many mechanical issues that have arisen. If there were to be a malfunction during induced torpor, this could lead to astronauts not waking up or death, with no way to help. This brings up the dilemma of possibly relying too much on computers. The mission fully leaves the lives of humans to computers.

LOGISTICS

This section focuses on how soon induced torpor can be incorporated. This information is important because if it takes too long to complete the technology, it will not be considered when the trip to Mars actually occurs. If that were to happen, it is likely that torpor technology would be abandoned for space travel, as NASA and other space agencies would reuse whatever method was chosen instead. The STS method of Diffusion of Innovation by Everett Rogers (2003) will be used to analyze the situation.

Diffusion of Innovation will be used because this technology is still in early stages. A major objective of this research is to see how soon induced torpor can be used, and Diffusion of Innovation incorporates time as one of its major factors. One aspect of the theory requires there to be a reason for innovation. This comes in the form of technological homeostasis, which can be understood as fear of the unknown or anxiety and adjustment. Already, this can be seen with NASA rejecting the funding of the torpor conference. Also, trying to reach Mars requires

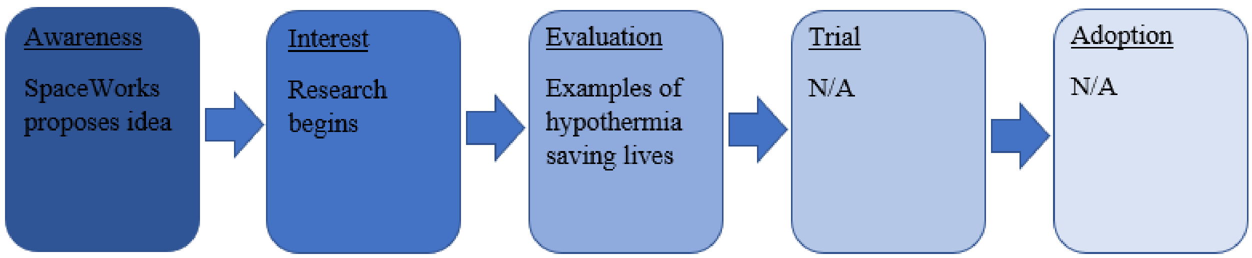

Figure 1: Current Adoption Process for Induced Torpor. This shows where torpor is in the adoption process and gives examples. The trial and adoption steps are empty because the technology is not in those phases. (Saunders, 2020)

adjustment, so that's why induced torpor is being considered. An adoption process of the theory identifies certain steps a technology has to complete in order to diffuse. The process includes awareness, interest, evaluation, trial, and finally adoption. Figure 1 shows a handoff model of this process.

Through this model, it is clear that induced torpor is on its way to be diffused into society, but it is far from being close. If getting to Mars was easy, it would have been done by now. There are many difficulties in reaching the planet, and space administrations understand that. SpaceWorks was aware of the problem of getting humans to travel the long distance and proposed the idea of torpor. Interest in the topic is also evident, which can be seen by the vast quantities of research done by parties outside of SpaceWorks. People are curious to see if torpor is a viable option, so they have looked into it in more depth. The technology is currently stuck on the evaluation step. Besides inducing hibernation in small animals, there has not been much testing. The examples of hypothermia saving lives also serves as a low-level evaluation, but that does not serve as a test of induced torpor. Once it has been decided which method will be used to induce the sleep, it needs to be tested on people to make sure it will work. Only then will the evaluation step be completed, and the trial phase can begin. The trial phase would likely consist of a simulation of induced torpor on the Mars mission. The computers and robot programs will be tested as if they were in space. After this succeeds, induced torpor would be able to enter the adoption stage.

Diffusion of Innovation also mentions adopter categories that a technology will have as it is diffused. These are innovators, early adopters, early majority, late majority, and laggards. Figure 2 shows a model of the adopter categories according to the Diffusion of Innovation theory. The model highlights how likely a group is to adopt or resist a new technology.

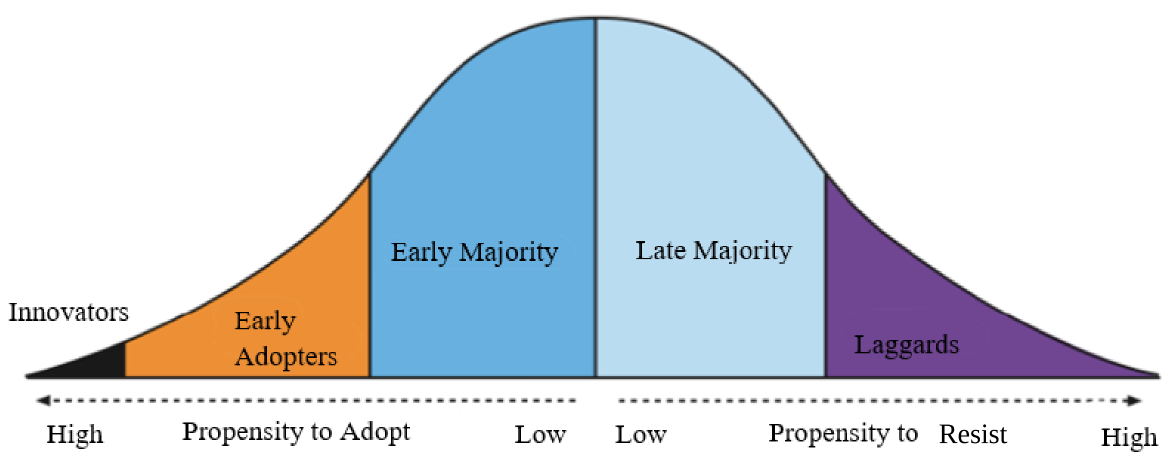

Figure 2: Adopter Categories in Diffusion of Innovation. The five adopter categories mentioned in the theory are shown in a bell curve. The size of the area indicates the group size for that category. The likeliness to adopt a new technology is given if the curve is followed left to right. (Adapted by Khamal Saunders, 2021, from C. Baritaud, 2020)

As induced torpor has yet to be completed, there are not many adopter categories that can be filled. SpaceWorks can be seen as the innovators, as they introduced the idea, but that is the only group. The idea was proposed to NASA, and as they will likely lead a mission to Mars, they can be a candidate for early adopters. If the first Mars mission uses torpor and is successful, other space agencies may use the technology in the future, placing them in the early majority category. It is too soon to assume which companies may be placed in the late majority or laggards.

A successful technology will have certain qualities that will help it spread. If it has a relative advantage over other ideas, and is compatible with existing values and practices, then it will likely succeed. Additionally, the technology must be simple and easy to use, be able to be tested, and have observable results. The big advantage in using induced torpor is that it minimizes many of the physical and mental problems that other solutions cannot by having astronauts be unconscious. Reaching Mars is a very complicated thing to do, so there are no current practices to be compatible with. Along with that, no solution will be simple because it is not simple to get to Mars. Trial runs have yet to be seen, but it is possible to complete tests before using the technology in space. The examples of people surviving hypothermia and animals being put to sleep are observable results, but more results on humans will need to be completed.

Induced torpor has to beat out the other options of reaching Mars in order to be used. Figure 2 shows some of these alternative solutions and gives a sense of where they are in development. In the figure, red depicts the furthest from development with no research being

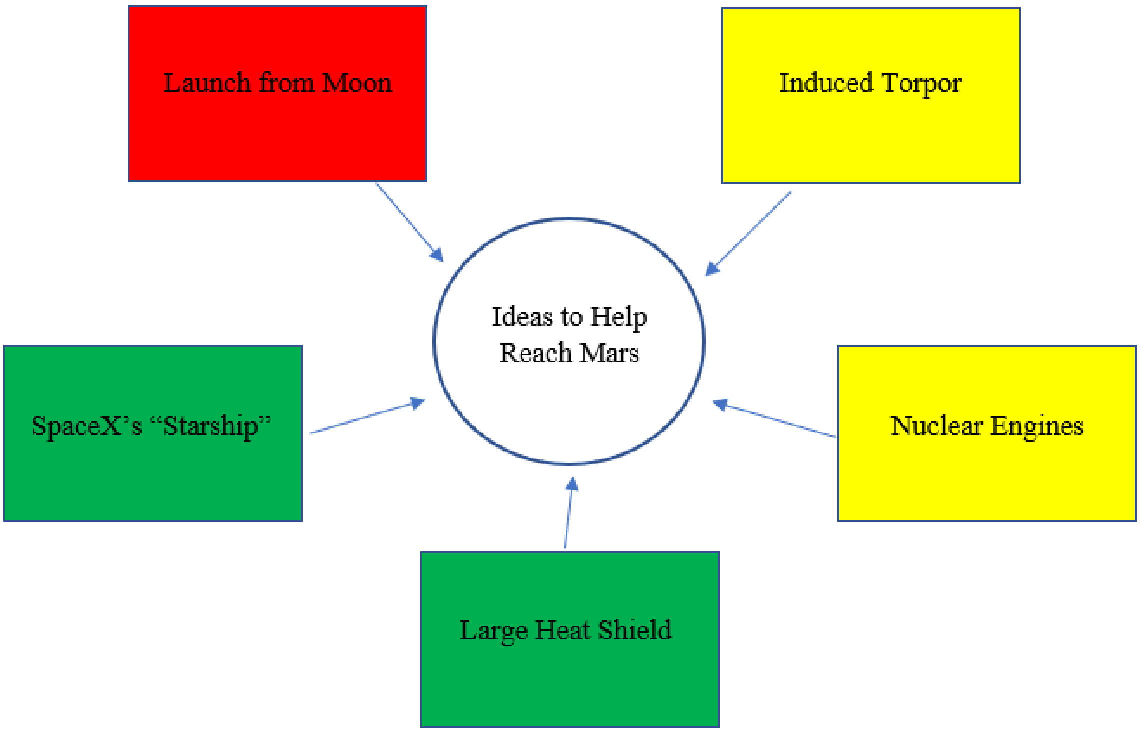

Figure 3: Alternate Solutions to Reaching Mars. Shows other possible ideas for reaching Mars and where they are in development phase. (Saunders, 2020)

done. Yellow signifies that the topic is being researched with no testing, and a green box means the technology is being tested. A technology in green means it is the closest to being implemented. Induced torpor is in the intermediate stage which means it is not necessarily close to being used, but it is still has a chance to be a viable option in the future. More research, and studies in STS fields could help this technology begin testing. This would bring it one step closer to the alternate solutions.

TECHNOLOGY IN SPACE

Space-based technology impacts our everyday lives. It is present through the internet, cellphones, and GPS, which are commonplace in the world today. This usefulness is why space-based solutions are becoming popular.

Virginia has many roads, and bad weather always poses a serious threat to safety. Satellites could help alleviate these problems, which is the main goal of the technical project. Delivering real-time weather data will help drivers make more educated decisions and allow extra caution to be used. An additional goal is to experience a real-world, space-based problem. This will allow the class to learn what goes into the design process of a space mission. This is a multi-year project, so continuation of the solution will continue past this year. The building of the satellite will be completed next year, and this will be based of the design plan of this year. Some of the plan may be altered due to budget or time constraints, but the general solution should stay the same.

Still related to space is the goal of reaching Mars. Mars is difficult to get to because of its distance, and innovation is required to solve this. Induced torpor seems like the best solution to the problems that stem from a journey to Mars, barring any negative test results. It is less expensive because unconscious people produce less waste, take up less space, and need less nutrients to survive. Induced torpor also effectively solves more problems than the alternatives. This paper was written to gather the scattered research of the technology in the hopes that this collection quickens the progress of the technology. Torpor is far from being completed, but a trip to Mars is also far away. There is a lot of scientific knowledge of induced torpor already completed, so the focus should be on testing and evaluation in order to continue the progression. If there is a safe way to test animals, then this should be done. It may even be possible to do human testing on clinically dead humans to look into some technical aspects of torpor (Cerri, 2017, p. 5). This would still need to be followed by testing on real people before being implemented. Any research into space-based solutions will further the technology, leading to new possibilities and opportunities in our future.

WORKS CITED

Bradford, J., Merrel, B., Schaffer, M., Williams. C., & Talk, D. (2018). *Advancing torpor inducing transfer habitats for human stasis to mars*. Paper presented to the National Aeronautics and Space Administration. Retrieved from https://www.nasa.gov/sites/default/files/files/Bradford_2013_PhI_Torpor.pdf

Cerri, M. (2017). Consciousness in hibernation and synthetic torpor. *Journal of Integrative Neuroscience*, *16*(5), 1-8. Retrieved from https://www.researchgate.net/publication/320913406_Consciousness_in_hibernation_and_synthetic_torpor

Doarn, C., Polk, J., Shepanek, M., Doarn, C. R., & Polk, J. D. (2019). Health challenges including behavioral problems in long-duration spaceflight. *Neurology India*, *67(*8*)*, 190-195. Retrieved from https://eds-a-ebscohost-com.proxy01.its.virginia.edu/eds/detail/detail?vid=0&sid=8efd3ddf-6a41-4095-8f14-eddc281da331%40sessionmgr4008&bdata=JnNpdGU9ZWRzLWxpdmU%3d#AN=000470267000013&db=edswsc

Dubuc, B. (n.d.) *Caffeine*. The brain from top to bottom. Retrieved from https://thebrain.mcgill.ca/flash/i/i_03/i_03_m/i_03_m_par/i_03_m_par_cafeine.html#:~:text=Adenosine%20is%20a%20central%20nervous,down%2C%20and%20you%20feel%20sleepy.&text=Caffeine%20acts%20as%20an%20adenosine,but%20without%20reducing%20neural%20activity

Emmett, A. (2017, March 21). Sleeping their way to mars. *Air & Space Magazine*. Retrieved from https://www.airspacemag.com/space/hibernation-for-space-voyages-180962394/

European Space Agency. (n.d.). *Why go to mars?* Retrieved from http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/Why_go_to_Mars

Fecht, S. (2017, April). Stephen Hawking says we have 100 years to colonize a new planet-or die. Could we do it? *Popular Science*. Retrieved from https://www.popsci.com/stephen-hawking-human-extinction-colonize-mars/

Fukunaga, H. (2020). The effect of low temperatures on environmental radiation damage in living systems: Does hypothermia show promise for space travel? *International Journal of Molecular Sciences*, *21(*17*)*. Retrieved from https://eds-b-ebscohost-com.proxy01.its.virginia.edu/eds/pdfviewer/pdfviewer?vid=2&sid=57aad4ca-9590-46d6-888d-208d808e3a26%40pdc-v-sessmgr04

Johnson, P. (2013, February). *8 famous software bugs in space*. CSO Online. Retrieved from https://www.csoonline.com/article/3404528/8-famous-software-bugs-in-space.html

Lodish, H., Berk, A., Zipursky, S.L., Matsudaira, P., Baltimore, D., & Darnell, J. (2000) *Molecular cell biology*. W. H. Freeman & Company. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK21535/

Loff, S. (2018). *Moon to mars*. National Aeronautics and Space Administration. Retrieved from https://www.nasa.gov/topics/moon-to-mars

Mars One. (n.d.). *How long does it take to travel to Mars?* Retrieved from https://www.mars-one.com/faq/mission-to-mars/how-long-does-it-take-to-travel-to-mars

Nordeen, C. A., & Martin, S. L. (2019). Engineering human stasis for long-duration spaceflight. *Physiology*, *34(*2*)*, 101-111. Retrieved from https://journals-physiology-org.proxy01.its.virginia.edu/doi/full/10.1152/physiol.00046.2018

Perez, J. (2019, October 8). *Why Space Radiation Matters.* National Aeronautics and Space Administration. Retrieved from: https://www.nasa.gov/analogs/nsrl/why-space-radiation-matters

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York: Free Press.

Saunders, K. (2020). *Current adoption process for induced torpor.* [Figure 1]. *STS Outline* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Saunders, K. (2020). *Alternate solutions to reaching mars.* [Figure 3]. *STS Outline* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Saunders, K. (2021). *Adopter Categories in Diffusion of Innovation*. [Figure 2]. *STS Outline* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

SpaceX. (n.d). *Mars and beyond*. Retrieved from https://www.spacex.com/human-spacefligt