REMOTE-SENSING-ENHANCED NON-DESTRUCTIVE EVALUATION OF ROADWAY INFRASTRUCTURE

INDUCED TORPOR IN LONG DURATION SPACEFLIGHT

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

By
Khamal-Karim Saunders

November 2, 2020

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.

Signed Khamal Saunders Date: 10/28/20

Approved: Date:
Chris Goyne, Department of Mechanical and Aerospace Engineering

Approved: Date:
Catherine D. Baritaud, Department of Engineering and Society

Engineering is something we see everywhere in our lives. Whether it be houses, cars, or electronics, we are surrounded by and familiar with many different kinds of technology. One aspect of technology that is usually overlooked, is the engineering that happens for outer space. Spacecraft can take the form of a satellite that performs different operations, a rocket that carries things to space, or a habitable station like the ISS. Satellites are crucial in collecting data for large areas of Earth. This can be seen in weather satellites, GPS, or cell phone service satellites. Rockets and space stations are needed to expand our knowledge of the universe. These reasons are part of the bigger motivation for research, which is discovering more about space. Any research in the topic will aid in the use and exploration of space, increasing our understanding of it.

The two topics to be discussed are related to spacecraft. The technical project is to design a non-destructive, remote-sensing test for Virginia road infrastructure. The STS research will investigate the current diffusion process of induced sleep or hibernation in astronauts during long spaceflights. As the technical project will focus on a space-based solution, these topics are loosely related through engineering in space. Technologies in space may vary in what they do, but they all need to have similar components and teams to deal with space related problems. For the technical project, the UVA team consists of undergraduates Isaac Burkhalter, Andrew Curtin, Cooper Dzema, Shane Eilers, Kevin Fletcher, Jalen Granville, Dorothea LeBeau, Colin Purcell, Anisha Sharma, Naja Tyree, Bailey Roe, and myself. Chris Goyne of the MAE department at UVA is overseeing the project as the technical advisor. Cj Rieser and Michael A. Balazs of the MITRE Corporation are also helping in the design solution. In regards to the timeline for the technical project, the solution requirements, identification of data streams, and solution approaches will be completed by November 4, with a presentation given to MITRE on

November 11. The needed systems and technologies for the solution will be chosen next semester, along with possible prototyping and further refinement. For the STS deliverables, further research and refinement will continue through the end of this semester, with the final paper due the following term.

REMOTE-SENSING ENHANCED NON-DESTRUCTIVE EVALUATION OF ROAD INFRASTRUCTURE

According to the Virginia Department of Transportation (2019), there are over 57,000 miles of roadways that need to be maintained in the state of Virginia. These roadways are crucial for transportation efficiency and the daily lives of the public. Currently, national regulations only enforce the inspection of roadways every 5 years and the inspection of bridges every 2 years (Gee, 2007). Current methods such as visual inspection, acoustical techniques, and infrared or thermal imaging of roadway infrastructure inspection are inefficient inspection processes. These methods use ground-based systems which have drawbacks, including traffic buildups, lane closures, and intensive labor (Vaghefi et al., 2012). They have limitations such as invalid assessment of interior infrastructure, inaccurate testing, and limited usage (McGuire, 2020, para. 1-3). To improve the inspection process, a new solution that includes remote-sensing enhanced nondestructive evaluation through the combination of the state-of-the-art that includes spacecraft, aircraft or a combination will be designed. With an advanced evaluation solution, a satellite could send data to VDOT and allow them to focus on maintaining worn roads instead of repairing broken roads. This will create a more efficient system for the state’s roadways with cheaper cost, less labor, and fewer transportation infrastructure delays.

Maintaining transportation infrastructure is vital for the wellbeing of the state and public. The collapse of bridges is extremely dangerous, as shown by the death of 13 people when I-35W collapsed in Minnesota in 2007 (Vezner, 2015). Although the collapse has led to reform in how infrastructure is inspected, those methods are outdated and could be improved for more efficient and less costly methods of inspection. Research indicates that as road conditions deteriorate, there are more collisions and accidents tend to be more severe (Alhasan, 2018, Crash Records section). By remote sensing transportation infrastructure continuously, it would be possible to identify which roads are deteriorating faster. This would allow more time and effort to be put into these problematic areas.

There are a variety of remote sensing options available on either drones or satellites that allow sensing from air and space. A paper published by Devin Harris, a Civil Engineering Professor at the University of Virginia, and other contributors, mentions that remote sensing is already used in non-destructive evaluation methods when inspecting bridges, and it has proven to be more efficient (Vaghefi et al., 2012, p. 887). The paper discusses the wide variety of sensors: Synthetic Aperture Radar (SAR), Interferometric Synthetic Aperture Radar (InSAR) on satellites, and a sensor called Light Detection and Ranging (LIDAR) on drones (Ma, 2019). Another popular sensor is three-dimensional optics, which is a technology that can provide depth and height information that cannot be obtained from one image. This can be done by overlapping two images of an object at least 60% from different angles.

There are several examples of remote sensing technologies being used for road infrastructure. Different Uninhabited Air Vehicles (UAVs) used include the tethered blimp, a small imaging quadcopter, a micro quadcopter, and a hexacopter. Drones are being sent into areas that might be dangerous for human inspectors, or in areas with moving heavy machinery (Danielak, 2019, Drones Support Workforce Safety section). Satellite systems, like InSAR, are being used to monitor the sinking of the Millennium Tower in San Francisco (Hsiao, 2015).

These examples and the research on the specific technologies will serve as a starting point for the final design solution. Designing a system that will be able to see all Virginia roads and accurately determining which roads and bridges have damage will come with various challenges. Satellites are limited by the resolution they are able to detect, as more resolution leads to higher costs. Current and affordable technology might not be within reach and an outside company may be required to fund the project. Drones are also limited by Virginia laws requiring them to be manually piloted, which greatly decreases the range they can cover in a day. Despite these challenges, camera systems installed in ground vehicles through companies like MobilEye and Tesla could provide insight into transportation infrastructure usage and quality. The hope for the final solution is to design a system with an overarching satellite that collects daily information on Virginia roadways with drones or UAVs that can be used in areas to increase detail. The use of ground systems will be utilized when UAVs need more coverage. This will cover the greatest area in the most effective way.

Figure 1 on page 5 illustrates how each part of the solution will be connected. The larger arrows show the order of detail a user would get from the three technologies, with satellites being the broadest and ground systems the most detailed. Each of the technologies will collect transportation data and give that information back to whoever is using the system, in this case VDOT. The user can then use that data to send out the technologies accordingly.

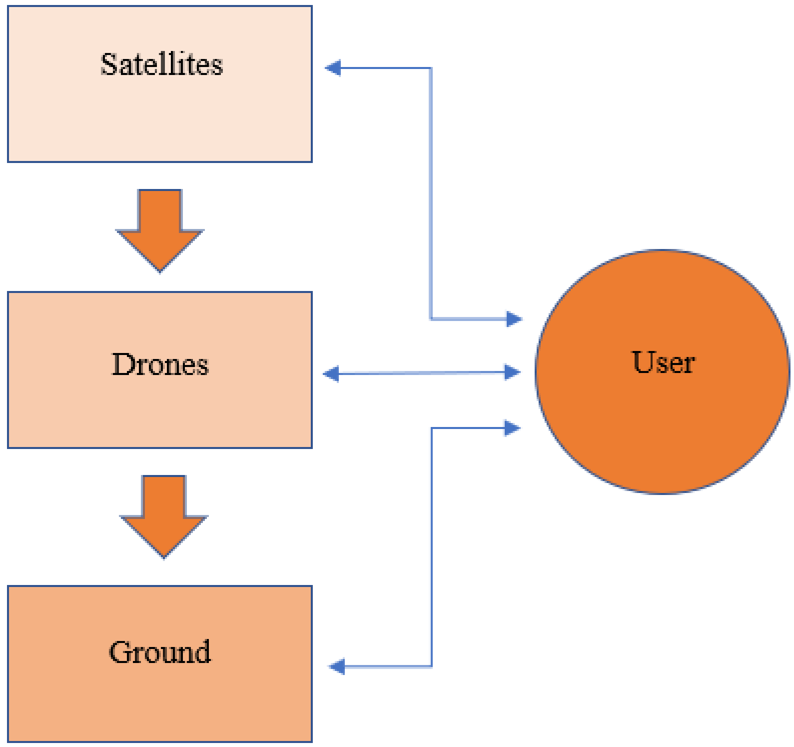

Figure 1: Remote Sensing Flow Diagram with Connectivity. Shows the flow in technology based on detail, starting with the least detail in satellites. Data is sent to user and user decides which technology to send. (Saunders, 2020)

Aside from the project hopes, the team expects to learn the process of designing a solution to a real-world problem. There are different stakeholders who want different designs and there are many constraints imposing certain ideas. In a conference-like paper, the research and final solution will be presented in a way to appease the stakeholders as much as possible.

The following research takes a step away from infrastructure, and focuses on a problem about spacecraft.

INDUCED TORPOR

This paper focuses on the possibility of inducing sleep in astronauts as they travel long distances in space, otherwise known as induced torpor. Scientists have been trying to land people on Mars for long time. This hope has been revitalized with NASA's new Artemis program. The plan is to first land people on the moon again, and then start looking towards Mars (Loff, 2018). Elon Musk is also planning to send people to colonize Mars and is focusing a lot of SpaceX's research to that topic (SpaceX). Reaching Mars may seem like an unimportant desire that wastes money, but in reality, it could be quite vital. Humans may need a new planet to live on in the not-so-distant future. With climate change, carbon emissions, and nuclear weapons threatening civilization, it makes sense to have a back-up plan (Fecht, 2017, para. 1-2). Mars is the planet most similar to Earth, thus it is designated as the back-up, although this landing will likely not happen in our lifetime.

The problem with travelling to Mars is that it is extremely difficult to reach, and it has never been done with humans on board. Mars is about 67.77 million km from Earth which means it would take about eight months for a space vehicle to reach it (Mars One, para. 2). This is where the challenge lies; astronauts have never spent that amount of time in space. They will have to keep themselves entertained for eight months in a confined area with limited communication which leads to mental and physical health concerns. Induced torpor is a possible way to combat this challenge by having the astronauts sleep the majority of the journey.

This is a relatively new area of research, as an official outline on the possibilities of this was reported by the company SpaceWorks in 2018 (Bradford et al., 2018). Because this is an active area of research, there isn't much information on induced torpor in space flight. Most of the research is in the medical or aerospace field, with a lack in an analysis from an STS perspective. NASA has already rejected SpaceWorks' initial proposal for induced torpor as a way to get to Mars, and a possible reason for this is a lack of research (Emmett, 2017). They have decided to look at other ways to get humans to Mars. Figure 2 shows some of these alternative solutions and gives a sense of where they are in development. In the figure, red

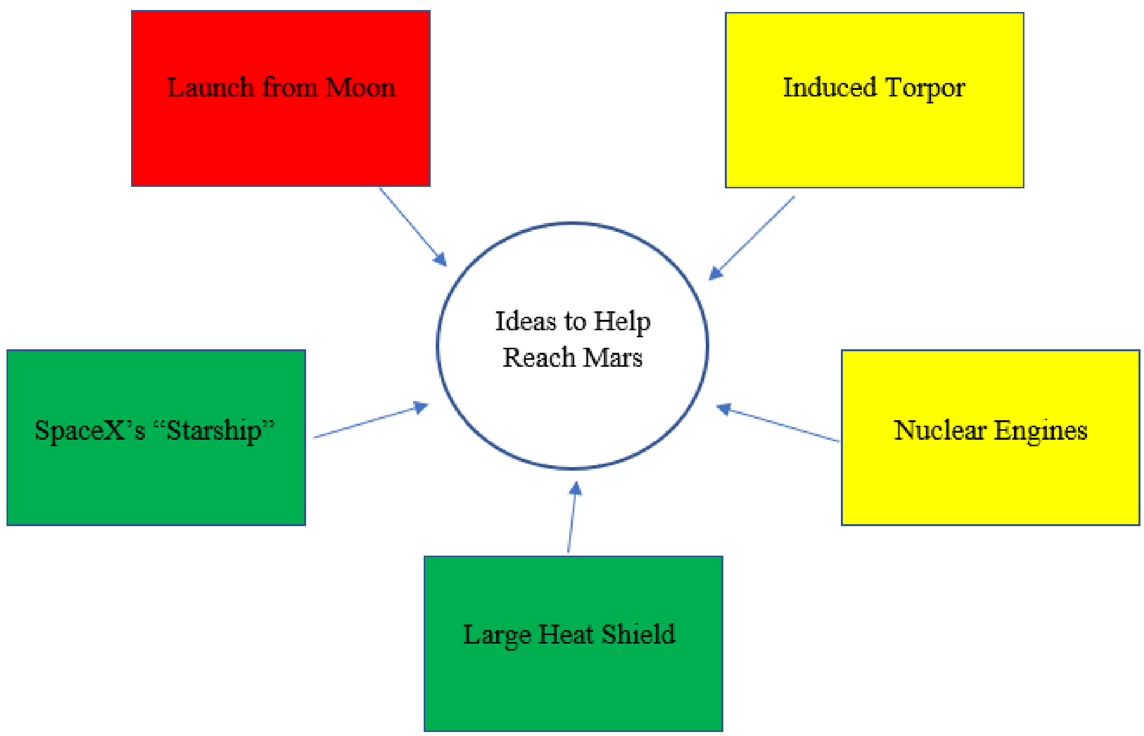

Figure 2: Alternate Solutions to Reaching Mars. Shows other possible ideas for reaching Mars and where they are in development phase. (Saunders, 2020)

depicts the furthest from development with no research being 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 isn't 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.

There are several objectives the research will look for. The first is to find out where torpor is in the development process. This will directly correlate to figuring out how soon this technology can be implemented. This will be important to discover because if the completed technology is not ready by the time major space agencies plan to go to Mars, then they will look at other options. If this becomes the case, then the companies developing torpor technologies would be losing a lot of money and research would stop. Another research objective is to find out if the technology can actually be implemented. Due to the early stages of research, it is unknown whether it is possible to induce torpor in humans in a safe manner. This is clearly important, as it will never be used by companies if there is no guarantee in safety. The third objective of the research will examine if the technology should be used in traveling to Mars and other long-distance space flights. Induced torpor is not the only solution to the challenges of reaching Mars, and it is important to look at these alternatives. Each solution has its benefits and drawbacks. If using torpor has significantly more drawbacks than another method, torpor should not be used.

The STS approach taken will be Diffusion of Innovation by Everett Rogers (2003). The reason for this approach is due to the fact that 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. Already, technological homeostasis is seen with fear of the unknown through NASA's rejection of SpaceWorks' proposal. The adoption process will be analyzed and research into the technology will clarify where in the process induced torpor currently is and what needs to happen for it to diffuse. The process includes awareness, interest, evaluation, trial, and finally adoption. Figure 3 shows a handoff model of this process.

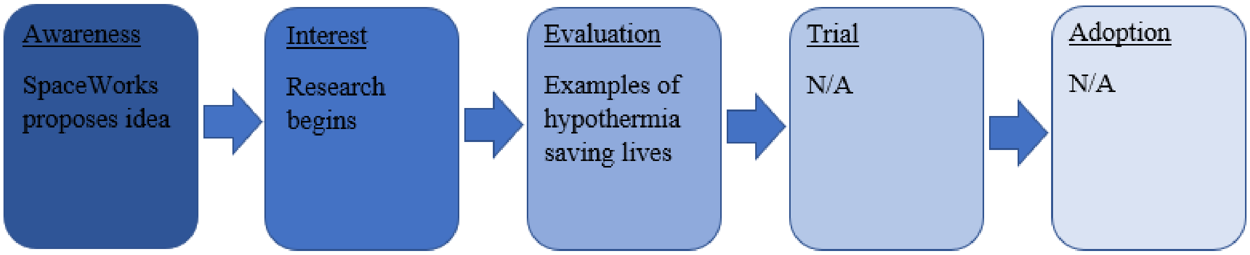

Figure 3: Current Adoption Process for Induced Torpor. This shows where torpor is in the adoption process and gives examples. The trial and adoption steps are empty because the technology is not in those phases. (Saunders, 2020)

The fact that the idea has been introduced and research has occurred shows an awareness and interest in the topic. There is little testing that has occurred, and the only evaluation that can be considered is an example of hypothermia being used to treat and save patients (Nordeen & Martin, 2019, para. 5-6). More evaluation in the field will lead to trial and adoption in the future. The social groups will be analyzed and placed in the adopter categories mentioned in the diffusion theory: innovators, early adopters, early majority, late majority, and laggards. Specific qualities mentioned in the diffusion theory will guide the research in the analysis of the spread of innovation. The qualities to be analyzed include the relative advantage, compatibility with existing values and practices, simplicity and ease of use, trialability, and observable results. Combining the analyses of the adoption process, adopter categories, and mentioned research points will shape the diffusion of induced torpor.

The anticipated and hoped-for outcomes come directly from the objectives. It is expected that this technology will not be ready to use for quite some time. With COVID hitting this year, additional delays are expected to set this technology back. SpaceWorks has done a decent amount of research and it seems like testing is to happen soon. If the tests are successful, it is possible induced torpor can be used by the end of the decade, which is the set timeframe for reaching Mars. STS research hopes to discover that the technology will be safe enough for humans to use and that it is a good solution for long distance space travel. Traveling in an enclosed area for months at a time cannot be great for the astronauts physical or mental health. Sleeping the majority of the way can help alleviate these problems. If there are not any major problems then this would seem like a great option.

This will be a research paper that outlines a background on induced torpor and studies the benefits and drawbacks. Possible alternatives will be studied and compared to the chosen technology. The STS discussion on diffusion will be a different, non-technical study on torpor that will cover holes in the current research. By the end of the paper, it is anticipated that induced torpor will be researched enough to decide if it is a possible and beneficial solution to reaching Mars.

TECHNOLOGY IN SPACE

Space-based technology impacts our everyday lives. It is present through the internet, cellphones, and GPS, some common things in the world today. This usefulness is why space-based solutions are becoming popular. Virginia has a large road system, and only using grounded technology to assess the infrastructure is inefficient. A solution using satellites with supplemental drone and ground systems will improve roadway evaluation. 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 is a viable option, but it is a new idea so it is far from being used. With a diffusion of innovation study, the development of the technology can be analyzed. It is unclear if torpor will be a legitimate option for reaching Mars, but research into the background and development of it will clarify this problem. Any research into space-based solutions will further the technology, leading to new possibilities and opportunities in our future.

WORKS CITED

Alhasan, A. (2018). Impact of pavement surface condition on roadway departure crash risk in Iowa. *Infrastructures*, 3(14), 14-32. Retrieved from https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1191&context=imse_pubs

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://strives-uploads-prod.s3.us-gov-west-1.amazonaws.com/20180007195/20180007195.pdf?AWSAccessKeyId=AKIASEVSKC45ZTTM42XZ&Expires=1604328925&Signature=EKqdnQ88Qt1NDOt1HRStIu2fX2M%3D

Danielak, M. (2019, September 16). Drones improve safety of infrastructure inspections. *Roads & Bridges*. Retrieved from https://www.roadsbridges.com/drones-improve-safety-infrastructure-inspections

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/

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/

Gee, K. W. (2007, October 23). *Highway bridge inspections.* Testimony before the Committee on Transportation and Infrastructure Subcommittee on Highways and Transit, United States, House of Representatives. Retrieved from https://www.transportation.gov/testimony/highway-bridge-inspections

Hsiao, V. C. (2016, November 7). Using interferometric synthetic aperture radar for network-wide transportation infrastructure monitoring. Retrieved from http://onlinepubs.trb.org/onlinepubs/webinars/161107.pdf

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

Ma, P. (2019, June 3). Eyes in the sky: How satellites can monitor infrastructure health. *The Conversation*. Retrieved from https://theconversation.com/eyes-in-the-sky-how-satellites-can-monitor-infrastructure-health-117216

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

McGuire, S. (2020, May 29). *An analysis of modern bridge inspection technologies*. Giatec Scientific. Retrieved from https://www.giatecscientific.com/education/bridge-inspection-technologies/

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

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

Saunders, K. (2020). *Remote sensing flow diagram with connectivity*. [Figure 1]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Saunders, K. (2020). *Alternate solutions to reaching mars*. [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Saunders, K. (2020). *Current adoption process for induced torpor*. [Figure 3]. *Prospectus* (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-spaceflight/mars/

Vaghefi, K., Oats, R. C., & Harris, D. K. (2012). Evaluation of commercially available remote sensors for highway bridge condition assessment. *Journal of Bridge Engineering*, 17(6), 886-895. Retrieved from https://ascelibrary.org/doi/10.1061/%28ASCE%29BE.1943-5592.0000303

Vezner, T. (2015, November 14). I-35W bridge collapse / 13th, final victim recovered. *Twin Cities Pioneer Press*. Retrieved from https://www.twincities.com/2007/08/20/i-35w-bridge-collapse-13th-final-victim-recovered/

Virginia Department of Transportation. (2019). *Virginia's highway system*. Retrieved from http://www.virginiadot.org/about/vdot_hgwy_sys.asp

Wilson, J. (2018). *The 3 types of road maintenance*. Everything Roads. Retrieved from https://everythingroads.com/2018/the-3-types-of-road-maintenance/

BIBLIOGRAPHY

Ahlmer, A., Cavalli, M., Hansson, K., Koutsouris, A. J., Crema, S., Kalantari, Z., KTH, & Stockholms universitet, Naturvetenskapliga Fakulteten, Institutionen för Naturgeografi. (2018). Soil moisture remote-sensing applications for identification of flood-prone areas along transport infrastructure. *Environmental Earth Sciences*, *77(*14*)*. Retrieved from https://eds-a-ebscohost-com.proxy01.its.virginia.edu/eds/detail/detail?vid=0&sid=e2c0caed-7382-4ac7-ac17-78fecec49420%40sessionmgr4006&bdata=JnNpdGU9ZWRzLWxpdmU%3d#AN=edsswe.oai.DiVA.org.kth.232784&db=edsswe

Alani, A. M., Tosti, F., Ciampoli, L. B., Gagliardi, V., & Benedetto, A. (2020). An integrated investigative approach in health monitoring of masonry arch bridges using GPR and InSAR technologies. *NDT and E International*, *115.* Retrieved from https://www-sciencedirect-com.proxy01.its.virginia.edu/science/article/pii/S0963869520303121?via%3Dihub

Alhasan, A. (2018). Impact of pavement surface condition on roadway departure crash risk in Iowa. *Infrastructures*, *3*(14), 14-32. Retrieved from https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1191&context=imse_pubs

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://strives-uploads-prod.s3.us-gov-west-1.amazonaws.com/20180007195/20180007195.pdf?AWSAccessKeyId=AKIASEVSKC45ZTTM42XZ&Expires=1604328925&Signature=EKqdnQ88Qt1NDOt1HRStIu2fX2M%3D

Danielak, M. (2019, September 16). Drones improve safety of infrastructure inspections. *Roads & Bridges*. Retrieved from https://www.roadsbridges.com/drones-improve-safety-infrastructure-inspections

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

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/

Eskandari Torbaghan, M., Li, W., Metje, N., Burrow, M., Chapman, D. N., & Rogers, C. D.F. (2020). Automated detection of cracks in roads using ground penetrating radar. *Journal of Applied Geophysics, 179*. Retrieved from https://www-sciencedirect-com.proxy01.its.virginia.edu/science/article/pii/S092698511930477X?via%3Dihub

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

Gee, K. W. (2007, October 23). *Highway bridge inspections.* Testimony before the Committee on Transportation and Infrastructure Subcommittee on Highways and Transit, United States, House of Representatives. Retrieved from https://www.transportation.gov/testimony/highway-bridge-inspections

Hsiao, V. C. (2016, November 7). Using interferometric synthetic aperture radar for network-wide transportation infrastructure monitoring. http://onlinepubs.trb.org/onlinepubs/webinars/161107.pdf

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

Ma, P. (2019, June 3). Eyes in the sky: How satellites can monitor infrastructure health. *The Conversation*. Retrieved from https://theconversation.com/eyes-in-the-sky-how-satellites-can-monitor-infrastructure-health-117216

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

McGuire, S. (2020, May 29). *An analysis of modern bridge inspection technologies*. Giatec Scientific. Retrieved from https://www.giatecscientific.com/education/bridge-inspection-technologies/

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

Romero, E., & Francisco, D. (2020, October 1). The NASA human system risk mitigation process for space exploration. *Acta Astronautica*, *175*, 606 - 615. Retrieved from https://www-sciencedirect-com.proxy01.its.virginia.edu/science/article/pii/S0094576520302617?via%3Dihub

Saunders, K. (2020). *Remote sensing flow diagram with connectivity.* [Figure 1]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Saunders, K. (2020). *Alternate solutions to reaching mars.* [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Saunders, K. (2020). *Current adoption process for induced torpor.* [Figure 3]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Song, Y., Wright, G., Wu, P., Thatcher, D., McHugh, T., Li, Q., & Wang, X. (2018). Segment-based spatial analysis for assessing road infrastructure performance using monitoring observations and remote sensing data. *Remote Sensing*, *10(*11*)*. Retrieved from https://eds-b-ebscohost-com.proxy01.its.virginia.edu/eds/detail/detail?vid=0&sid=a26c1148-9016-460c-ba0b-98efd12245b8%40pdc-v-sessmgr04&bdata=JnNpdGU9ZWRzLWxpdmU%3d#AN=000451733800027&db=edswsc

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

Sreenath, S., Malik, H., Husnu, N., & Kalaichelavan, K. (2020). Assessment and use of unmanned aerial vehicle for civil structural health monitoring. *Procedia Computer Science, 170*, 656 - 663. Retrieved from https://www-sciencedirect-com.proxy01.its.virginia.edu/science/article/pii/S1877050920306384

Vaghefi, K., Oats, R. C., & Harris, D. K. (2012). Evaluation of commercially available remote sensors for highway bridge condition assessment. *Journal of Bridge Engineering*, 17(6), 886-895. Retrieved from https://ascelibrary.org/doi/10.1061/%28ASCE%29BE.1943-5592.0000303

Vezner, T. (2015, November 14). I-35W bridge collapse / 13th, final victim recovered. *Twin Cities Pioneer Press*. Retrieved from https://www.twincities.com/2007/08/20/i-35w-bridge-collapse-13th-final-victim-recovered/

Virginia Department of Transportation. (2019). *Virginia's highway system*. Retrieved from http://www.virginiadot.org/about/vdot_hgwy_sys.asp

Wilson, J. (2018). *The 3 types of road maintenance*. Everything Roads. Retrieved from https://everythingroads.com/2018/the-3-types-of-road-maintenance/