Don't Tread on My Planet

A Research Paper in STS 4600

Presented to the Faculty of the School of Engineering and Applied Sciences
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering, Aerospace Engineering

Author

William McNicholas
May 01, 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

Signature ____ Date __________

Approved ____ Date __________
Rider Foley, Department of Engineering and Society

Introduction

On October 4th, 1957, mankind's access to space burst open with the launch of Sputnik. Sputnik, a small 23-inch diameter sphere, represented the beginning of a new, breakthrough industry (Sputnik, 2007). In addition to igniting the space race of the 1960s, humanity's newfound access to space has had profound implications on the everyday lives of people around the world. Whether it be TV or GPS, the nearly 5,000 satellites in orbit provide a wide range of services, including special capabilities for scientific research. Additionally, orbiting spacecraft can offer invaluable insight into the global behavior of the earth's weather and climate (Dunbar, 2015).

The overarching problem that motivates the technical project is the study of air pollution in the atmosphere. Specifically, the technical project seeks to study nitrogen dioxide levels over cities around the world with scientific instruments from an orbiting spacecraft. According the World Health Organization, high nitrogen dioxide levels are linked to impaired lung function 2018). Additionally, NO_2 levels are linked to wheezing bronchitis in children, as NO_2 reduces lung function and is referred to as a deep lung irritant (Pershagen, Rylander, Norberg, Eriksson, and Nordvall, 1995). Constructing an accurate model of NO_2 levels throughout the atmosphere will help further our understanding of the characteristics and behavior of NO_2 levels.

Studying nitrogen dioxide levels from space has several advantages. An orbiting spacecraft can cover wide areas of the earth's atmosphere at once, allowing for the development of a large-scale, global model of the atmosphere. Additionally, an orbiting spacecraft can identify pollution levels throughout different levels of the atmosphere. Because NO_2 is chemically reactive, the levels of the gas can vary widely throughout the atmosphere. Thus, measuring these levels with a spacecraft can "resolve spatial gradient at sub-kilometer scales, representing an order of magnitude higher spatial resolution that current space-based instruments" (Goyne, Skrutskie, and Pusede, 2019). The data acquired by the spacecraft will help to improve our understanding of the behavior and chemistry of the pollutant. In the technical project, a preliminary design review and critical design review will be conceived for a 3-unit (3U) spacecraft, which measure 10 cm x 10 cm x 10 cm, to study the levels of nitrogen dioxide from low-earth orbit.

As humanity continues to capitalize on the capabilities offered by earth-orbiting satellites, deep space exploration lies on the horizon, with preliminary plans for a manned Mars mission in the 2030s (Foust, 2019). Should humankind establish permanent bases or colonies on a celestial body, such as Mars or the Moon, several questions arise regarding the role of governments, corporations, and international organizations to regulate or control such endeavors. This paper will focus on the implications of these plans, with specific focus on the planetary protection concerns of space exploration, as the relationship between actors in the space industry and the concerns of planetary protection require further research and reflection.

Case Context

According to NASA, planetary protection is the practice of protecting the solar system from contamination by Earth life, and the practice of protecting Earth from possible life forms in the solar system. Contamination of other bodies by Earth life is known as forward-contamination, whereas contamination of Earth of foreign life forms is known as back-contamination. The NASA office of Planetary Protection oversees NASA's planetary protection policy. Most of the policy is adopted from the Committee on Space Research (COSPAR) guidelines (Planetary Protection, 2020).

The scientific practice of ensuring planetary protection involves providing concrete steps ensuring minimal contamination and threat within the architecture of a mission. For example, NASA states that "the probability that a planetary body will be contaminated during the period of exploration to no more than 1×10^{-3}." Additionally, NASA takes the necessary steps to avoid impact of celestial bodies during the entire lifetime of the mission and to minimize the probability of contamination, through the use of clean rooms, sterilization of spacecraft parts, and aseptic assembly (free of contamination) of the spacecraft. While these practices have not yet been implemented for a manned mission to Mars, they have been implemented for Martian rovers, orbiters, and deep-space probes (Planetary Protection, 2020).

Specific to a Mars mission, the key planetary protection guidelines proposed by COSPAR involve assessing the potential bioburden of manned missions to the Martian surface and safeguarding the Earth from samples brought back from Mars. COSPAR states in its report that astrobiological exploration of Mars is only possible if human-associated contamination is controlled and understood. This means that studying potential life forms on Mars, something scientists and biologists have dreamed about for years, will only be possible if astronauts take the necessary steps to mitigate human contamination of the Martian environment. COSPAR acknowledges that while it will be impossible for human mission operations to exist in entirely closed systems, and that crewmembers will inevitably be exposed to some Martian materials, putting infrastructure in place to manage these conditions is imperative. This includes providing quarantine capability for the crew members (both for the entire crew or a single crew member), conducting evaluation of any potential landing site with robotic missions, and treating all Mars sample return material with extreme caution. COPSAR also believes it is critical to study the weather/meteorology of Mars with a Mars orbiter and a weather station network on Mars. Mars is known to have strong storms and high winds, which could facilitate the spread of both human contamination and pose contamination threats for crew members (COSPAR 2019).

While these COSPAR guidelines appear rigid and comprehensive, the main topic of interest will be to study how these policies are upheld against an actual Mars mission. NASA, which works closely with COSPAR and historically has implemented their guidelines, is likely to take Planetary Protection concerns very seriously. But what if a private company, such as SpaceX, or an adversarial nation, such as China or Russia, is the first to conduct a manned mission to Mars? They may have vastly different philosophies on the importance and implementation of planetary protection.

Planetary Protection in the New Era of Space Exploration

According to Jim Bridenstine, the current NASA Administrator, NASA is planning to send humans to Mars in the 2030s (Foust, 2019). Additionally, private companies like SpaceX proposed plans to visit Mars as soon as 2028 (Wall, 2018). These timelines are aggressive, and given historical delays associated with spaceflight, it will likely take much longer to achieve the goal. Nonetheless, exploration of Mars by humans appears to be on the horizon. When people think of the challenges of Martian exploration, most think of the technological hurdles, such as surviving the long journey, radiation shielding, landing on Mars, and sustaining long-term life support systems. While technical constraints offer big challenges, distinctly challenging questions also surround the geopolitics of a Mars mission.

The primary framework that governs the politics of outer space is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, commonly referred to as the Outer Space Treaty of 1967. The main provisions in the treaty is that it bans the placement of nuclear weapons in space, and it limits the use of the moon and other celestial bodies for exclusively peaceful purposes. In addition, the treaty defines astronauts as the “envoys of mankind”, and that all parties of the treaty shall offer assistance in the event of an accident or emergency. If an astronaut makes a landing on the territory of another State Party, that state shall return the astronaut promptly and safely to their home state (1967). The Outer Space Treaty is the most significant existing legal framework regarding the role of government in outer space. But would the treaty be of any use for a Martian colony? How could such a treaty be enforced?

For example, the physical logistics of Mars itself pose major hurdles for governance on Mars. The average distance between the Earth and Mars is a whopping 225 million kilometers. At this distance, it would take approximately 9 months to travel to Mars (NASA, 2019). As a result, a Martian colony would have tremendous autonomy. Mars is so far that even communication between Earth and Mars would be affected. Delay times could reach up to 24 minutes, rendering real-time monitoring and control over Mars difficult.

To address these concerns, the framework of *responsible innovation* might prove useful. In their article, Richard Owen, David Maynard, Trevor Maynard, and Michael Depledge articulate some core concepts of responsible innovation. Due to rapid innovation in the 21st century, society has struggled to keep up with the consequences of these changes. The framework of responsible innovation advocates for greater foresight in innovation. The article introduces the idea of “horizon scanning”, which is an approach for “identifying emerging issues, such as innovations, associated impacts, risks and benefits… and then synthesizing this through knowledge management” (Owen et al., 2009, p. 6903). Mars exploration has not begun yet. However, it certainly is on the horizon. According to the framework of Responsible

Innovation, now is the time to address the consequences of a potential Mars mission, rather than wait until the arrival of the actual missions. Researchers and analysts on space exploration cannot predict the future implications of Mars exploration. But by paying attention to the horizon, they can anticipate events, circumstances, and future contingencies.

Additionally, the framework of actor network theory (ANT) can be used to describe the network of governments, corporations, independent organizations, and individuals that would influence the geopolitics of a Mars mission. The ANT can be used to describe nonhuman artifacts, such as the spaceship, habitation module, and physical base itself on Mars. Further, ANT can offer insights about the infrastructure of the actor-network for a Martian colony and can help describe the network of organizations that make decisions regarding planetary protection (Latour, 1992).

Research Question and Methods

The following question will be addressed in the research: what is the relationship between different actors in the arena of space travel and the planetary protection concerns of Mars exploration? Landing people on Mars would be a game changing opportunity to study the planet and learn more about its past, and additionally would force humanity contemplate the best way to responsibly explore outer space.

To study these problems, two methods will be used. First, the current Mars planetary protection policies from COSPAR will be analyzed to establish the existing approach to handling planetary protection concerns. Studying present planetary protection policy will provide valuable insight into the potential implementation of planetary protection guidelines for a manned Mars mission. The following questions will be addressed in the analysis. What is the framework of COSPAR's forward-contamination policy? How rigorous are the steps taken to prevent back-contamination of the Earth? And lastly, how does COSPAR propose to safeguard astronauts on Mars from contamination? Answering these questions would provide critical insight into the role of planetary protection policy on space missions and a potential manned mission to Mars.

Additionally, a case study on the launch of a Tesla Roadster by SpaceX will be evaluated on the basis of planetary protection concerns. In the development of a new rocket system, named the Falcon Heavy, SpaceX opted to use the flashy Tesla Roadster as a dummy payload in place of a block of concrete as is typically used for dummy payloads (Zacharias, 2018). The Tesla Roadster served no scientific or practical purpose, but did attract lots of attention and interest in the space community. This launch is important because it was the first time SpaceX had ever sent an object beyond Earth orbit, and consequently is the first-time planetary protection concerns have ever arisen for a SpaceX mission. Because SpaceX is leading the efforts to bring humans to Mars, this mission offers a unique opportunity to study the company's use of (or lack thereof) planetary protection in its mission. To evaluate the planetary protection concerns in the mission, the interagency deliberations between SpaceX, NASA, and the FAA will be studied to reveal the role planetary protection guidelines played in the mission.

Results

The main takeaway from the analysis of COSPAR's guidelines for a Mars mission reveal that manned missions to Mars will require more lenient planetary protection policies than robotic missions currently require. Life support systems, habitation stations, and Martian weather will all make it difficult to avoid contamination of Mars, and as a result some amount of contamination risk will have to be assumed during a manned mission to Mars. Additionally, the Tesla Roaster case study found that SpaceX payed little attention to planetary protection concerns prior to launch and likely sent the most contaminated object ever beyond Earth orbit. Additionally, while regulatory bodies such as NASA and the FAA raised concerns, they ultimately dismissed these planetary protection concerns with little analysis, raising questions about their willingness to defend planetary protection policies against ambitious and influential companies such as SpaceX. These findings detail a microcosm of a battle between ambitious exploration and responsible science that is starting to take place. While COSPAR is attempting to represent responsible science, it admits that ambitious space missions will require more lenient planetary protection. SpaceX is on the frontier in leading this ambition and threatens to erode planetary protection in the process.

Policy Review: COSPAR's Vision for Mars

An analysis of the latest COSPAR documentation from its workshop in 2018 reveals detailed and meticulous steps that need to be taken prior to human spaceflight to Mars. COSPAR makes a list of bioburden assessments, with bioburden being the number of bacteria living on a surface that has not been sterilized. The main bioburden assessments that need to be made are of existing spacecraft environments, new spacecraft, and the Martian environment. COSPAR then lists planetary protection principles and implementation guidelines for human missions to Mars. It states that safeguarding the Earth from contamination from Mars back to Earth (back contamination) is the most important aspect of planetary protection. To mitigate this risk, COSPAR lists several specific guidelines. First, quarantine capability for both the entire crew and for individual crew members shall be provided in the event of potential contact with

Martian life forms. Second, neither robotic systems or human activities should contaminate "special regions" on Mars, with special regions referring to any area on Mars of special interest, such as a gully where flowing water once existed. Third, any uncharacterized Martian site will first be evaluated by robotic missions prior to any human access to the site. Forth, all Mars sample returns will be treated as category 5 material, the highest category level for inter-planetary protection missions (See table 1 for planetary protection categories). And lastly, an onboard crewmember will be primarily responsible to maintain and implement the planetary protection provision (COSPAR, 2019).

	Type and Goal of Mission				
	Category 1	Category 2	Category 3	Category 4	Category 5
Requirements providing interplanetary protection	Transiting orbiting space-craft, landing modules (LM): Venus, the Moon, some asteroids, other bodies, TBD	Transiting, orbiting spacecraft, LM: comets, carbonaceous chondrite asteroids, Jupiter, Saturn, Uranus, Neptune, Pluto, Charon,	Transiting, orbiting spacecraft: Mars, Europe, TBD	Missions with LM: Mars, Europe, TBD. Subcategories 4a, 4b and 4c	Any missions with return to Earth. Subcategories: 1. Restricted Earth return (possible danger when returning to Earth): from Mars, Europa, TBD. 2. Unrestricted Earth return (no danger when returning to Earth): from Moon, TBD
Categories for the bodies of Solar system and types of missions	No	Report on the proposed probability of collision, and some possible measures to control microbial contaminant	Limiting the probability of abnormal collision of spacecraft or passive control of the bioload	Limiting the probability of collision of spacecraft. Limitation of the bioload (sterilization and decontamination) for spacecraft	In the case of possible danger when returning to Earth: -avoiding collision with the Earth of the Moon; -sterilizing returned equipment

Table 1. Categories of planetary protection for space missions. (Image Source: Khamidullina, 2012)

From the executive summary of the report, COSPAR states that "the main finding of the COSPAR Work Meeting on Natural Transport of Contaminants on Mars is that a dedicated meteorology mission in the area of planned human landing site is needed (2)." COSPAR emphasized that it would be critical to study Mars weather and meteorology in order to gain an accurate understanding of the bioburden risk of a human mission. It recommends a Mars orbiter and weather station network dedicated to studying and documenting the Martian climate. The main takeaways from the COSPAR workshop is that, while there is still a strong interest and dedication to protect Mars from forward contamination, there remains a significant knowledge gap for the necessary measures that need to be taken for manned missions. Consequently, this report signals that manned missions to Mars will require more lenient planetary protection policies than robotic missions.

Case Study: SpaceX Raises Red Flags

On February 6th, 2018, SpaceX conducted a demo-launch on its new rocket system, the Falcon Heavy. As a demo mission, the rocket had no functional payload, such as a satellite or spacecraft. SpaceX opted to use a red Tesla Roadster as the payload for the rocket, and launched it into a heliocentric, Mars-crossing orbit. In short, this is an orbit about the sun (i.e. heliocentric) that crosses over the orbital path of Mars (Figure 1). This raises several planetary protection concerns. First, the roadster was not sterilized before flight, and may have been "the largest load of earthly bacteria to ever enter space" (Zacharias, 2018). Additionally, given its orbit path, the Roadster could one day collide with an astronomical body in the solar system and consequently contaminate it with any microorganisms that are still alive. While solar radiation will sterilize most of the Roadster, microorganisms deep within the car could still survive in a dormant state.

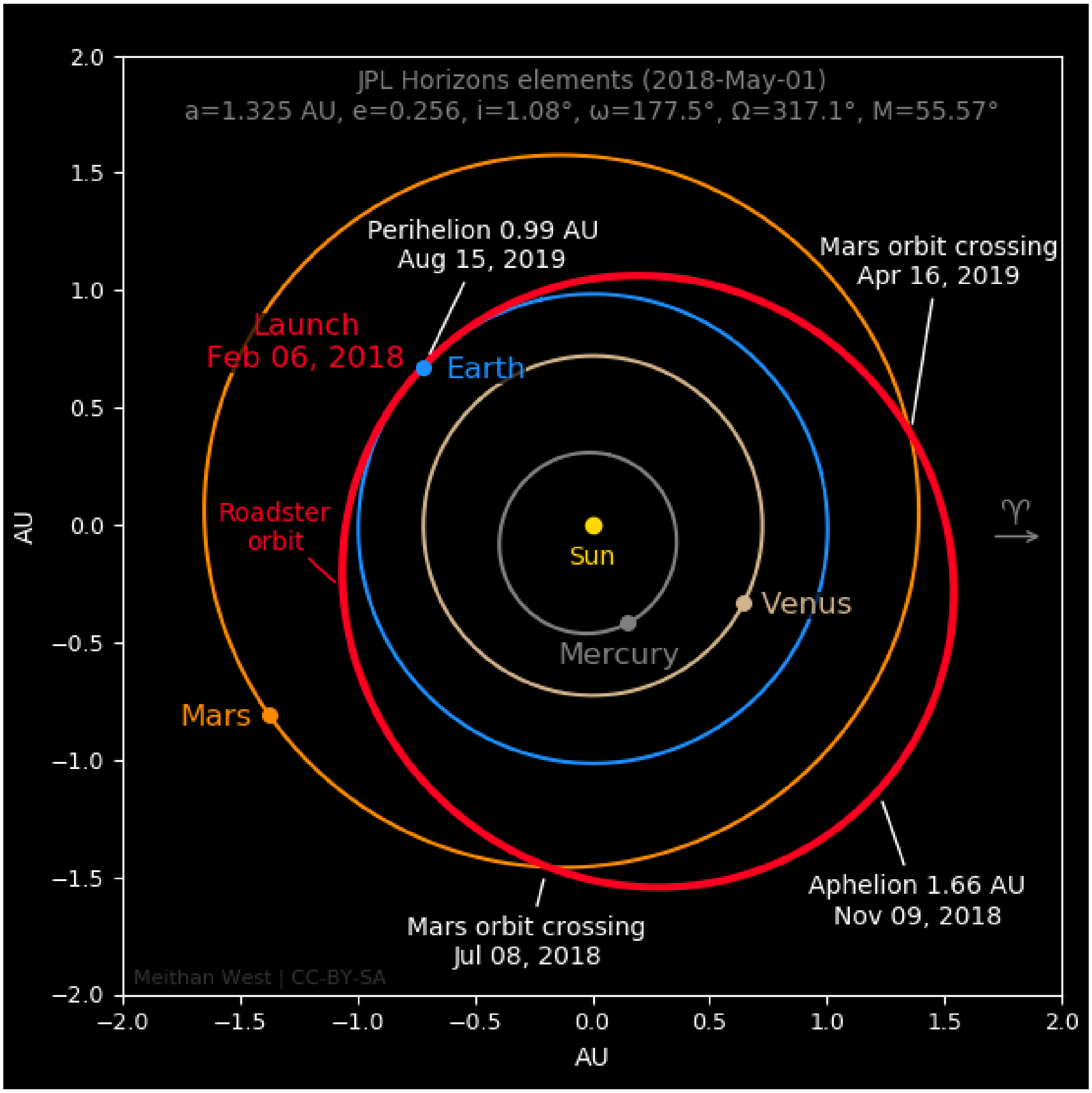

Figure 1. Orbit of the Tesla Roadster about the sun. (Image Source: Tesla Roadster orbit from JPL elements, 2018)

Interagency deliberations between SpaceX, NASA, and the FAA reveal that planetary protection was considered prior to the FAA granting the launch license for the mission. On December 1, 2017, SpaceX CEO Elon Musk posted a statement on twitter stating that the "destination is Mars orbit", referring to the destination of the Tesla Roadster (Musk, 2018). In response, NASA queried both SpaceX and the FAA for more information of the mission, as the mission raised red flags about a potential planetary protection risk. Because COSPAR regulations only apply to spacecraft that encounter a planetary body, the mission would consequently not be subject to planetary protection guidelines. NASA, however, still wanted to analyze the trajectory information of the spacecraft to determine if the spacecraft posed any risk to "NASA's scientific assets", which presumably refers to astronomical bodies of interest such as Mars (National Academies of Sciences, Engineering, and Medicine, 2018**)**. According to Dr. Betsy Pugel of NASA's Office of Planetary Protection, NASA attempted to simulate the orbit of the Roadster but was not able "to assess longer-term risks to scientific assets beyond the immediate launch window," and that "NASA was not in a position to confirm the probability of an impact on Mars." Nonetheless, in a formal response to the FAA, NASA noted that the information SpaceX provided "implied a consistency with international guidelines on planetary protection (Pugel 2018, p. 124**)**." The mission was approved by the FAA eleven days later on February 2, 2018.

The mission demonstrates a clear divide between COSPAR, NASA, and the private space company. SpaceX appeared content to go ahead with the mission with little analysis on the long-term orbit of the Roadster, and with no interest in sterilizing the car prior to launch. Additionally, NASA and the FAA were reluctant to thoroughly investigate the planetary protection concerns of the mission. NASA simply took SpaceX at its word that it had no intention of a rendezvous with another planetary body, did some quick calculations based on the orbital parameters of the Roadster, and then approved the mission soon thereafter. While the probability of a collision with Mars or some other astronomical body appears low, what if the rocket malfunctioned in some way and put the Roadster onto the wrong trajectory? SpaceX would risk crashing a hunk of metal, chock-full of Earthly microorganisms, into the planet that astrobiologist have hoped to study for generations. The risk would go against everything that COSPAR and planetary guidelines in general stand for. The Roadster mission could very well foreshadow SpaceX's eventual erosion of planetary protection as we know it.

Discussion

The analysis of planetary protection reveals a complex network of actors. COSPAR is the central authority figure in planetary protection, setting the international guidelines and policies for planetary protection as permitted by the Outer Space Treaty of 1967. The implementation of the guidelines is carried out by governmental space agencies around the world, such a NASA, the European Space Agency, or Roscosmos. Private space companies have also entered the arena of planetary protection. Lucrative NASA contracts, deals with telecommunication providers, and breakthroughs in modern technology has allowed for private companies make great developments in their own rockets, spacecraft, and their own ambitious missions. Private companies are still subject to regulation by agencies such as the FAA and FCC, which grant the proper certifications and licenses prior to any rocket blasting into space.

The analysis of planetary protection reveals the need to use the framework of responsible innovation in order to gain foresight into the future conflicts that may arise in planetary protection. By scanning the horizon of the next decade or two, one observes ambitious plans by both NASA and SpaceX to land people on Mars. Rather than just wait for potential planetary protection conflicts to arise, responsible innovation seeks out the potential conflicts before they occur, so that we can responsibly decide on the best way to proceed with technological innovation. In the context of a manned mission to Mars conducted by NASA, one can anticipate several planetary protection conflicts that may arise. In order to create a sustainable outpost on Mars, significant infrastructure will be needed, consisting of habitation modules, life supports systems, and spacecraft for ascent and descent onto the surface of Mars. Each one of those elements pose a challenge from a planetary protection point of view. It will be close to impossible to create a system that results in no contamination of the Martian surface. COSPAR, NASA, and SpaceX will need to decide what level of contamination is acceptable.

There are some limitations to the findings of the research. The biggest limitation is the uncertainty about the specifics of future manned missions to Mars. While COSPAR has outlined detailed guidelines for manned missions to Mars, much could change between now and whenever the eventual mission takes place. Many dynamics are at play, such as technological improvements that could take place, as well as the politics associated with the management and funding of these projects. Additionally, the international landscape of space exploration could be vastly changed. Nations may decide that the Outer Space Treaty of 1967 is outdated and in need of reform or even replacement. Were the Outer Space Treaty to dissolve, the entire framework of COSPAR and modern planetary protection would dissolve with it, drastically changing the planetary protection policy of a manned mission to Mars.

In the future, I would want to include an analysis of public attitudes toward planetary protection in addition to the policy/case studies presented in this report. NASA, while given significant autonomy and discretion to make its own decisions, is ultimately, as a public agency, responsible for acting in the public interest. If the public were to signal that planetary protection is of little concern, then NASA may be swayed to significantly roll back its planetary protection policy. To gauge public opinion, I would likely conduct surveys to judge people’s attitudes across a wide variety of planetary protection issues.

I will use this research to help inform me of the ethics of pushing the boundaries and frontiers of science and engineering. Should I one day find myself in the position to make some of the decisions regarding Mars exploration or colonization, this research will help inform those decisions to ensure that the exploration of the solar system is done safely and ethically.

Conclusion

Human exploration of Mars would be a monumental milestone for our species. It would captivate the world, offer opportunities for scientific breakthroughs, and inspire the next generation of explorers, scientists and engineers. Underneath the excitement and awe, however, lie profound implications of the role our species plays in the cosmos. When the first astronaut puts footprints on the surface of Mars, Earth-bound life will officially make its presence known on other planets, and consequently will force humanity to act responsibly in its exploration.

The next steps to take on this subject is to continue to study the role planetary protection plays in the space mission engineering process, especially for ambitious missions in the near future such as Mars sample return missions or deep-space probes to other planets. Additionally, public opinion towards planetary protection needs to be gauged to determine how NASA, COSPAR, and SpaceX can help act on behalf of the will of the people.

In short, a mission to Mars raises the question of humanity's role in cosmic stewardship. NASA, COSPAR, SpaceX, and all of the other participants in the arena of space exploration will need to make critical decisions regarding both the contamination of Mars and potential back-contamination of Earth. There is much work left to be done before a human can make yet another giant leap for humankind.

References

Agam, Albracht, Shannon, Bajikar, Bridgeforth, Cano-Mejia, Choi, Day, Dunne, Feldman, Flaxman, Gallagher, Glassman, Good, Goss, Gupta, He, Kumar, Morgan, Nguyen, Oliphant, Palmer, Pantyuhin, Puckette, Rademacher, Suitt, Walters, Weeks, Wilson, Wilt. (2019, April 30). GLOBAL NITROGEN OXIDES MEASURING EXPERIMENT : A Technical Capstone in Spacecraft Design II. *University of Virginia*

Arnould, J., & Debus, A. (2008). An ethical approach to planetary protection. *Advances in Space Research*, *42*(6), 1089–1095. doi: 10.1016/j.asr.2008.02.001

Atlantic Ocean. (n.d.). Retrieved October 30, 2019, from https://www.pbs.org/benfranklin/.

COSPAR 2019. 2nd COSPAR Workshop on Planetary Protection Requirements for Human Missions and COSPAR Work Meeting on Addressing Planetary Protection Gaps on Natural Transport of Contaminants on Mars (Held in 2018)

Dunbar, B. (2015, June 16). What Is a Satellite? Retrieved October 30, 2019, from https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-a-satellite-k4.html.

Foust, J. (2019, July 16). Bridenstine says NASA planning for human Mars missions in 2030s. Retrieved October 30, 2019, from https://spacenews.com/bridenstine-says-nasa-planning-for-human-mars-missions-in-2030s/.

How Far is it to Mars? (n.d.). Retrieved October 30, 2019, from https://sservi.nasa.gov/.

International Committee Against Sending Mars Samples Directly to Earth: Petition. (2002, February 5). Retrieved October 17, 2019, from https://www.icamsr.org/petition.html.

Khamidullina, N. M. (2012). Realization of the COSPAR planetary protection policy in the Phobos-Grunt mission. *Solar System Research*, *46*(7), 498–501. doi: 10.1134/s0038094612070131

Musk, E. [@elonmusk]. (2017, December 01). Payload will be my midnight cherry Tesla Roadster playing Space Oddity. Destination is Mars orbit. Will be in deep space for a billion years or so if it doesn't blow up on ascent.. [Tweet]. Retrieved from https://twitter.com/elonmusk/status/936782477502246912?lang=en

National Academies of Sciences, Engineering, and Medicine. 2018. *Review and Assessment of Planetary Protection Policy Development Processes*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25172.

Latour, B. (1992) 'Where are the missing masses? The sociology of a few mundane artifacts', in Bijker, W. E. and Law, J. (eds) Shaping Technology/Building Society: Studies in Sociotechnical Change, Cambridge, MA, MIT Press, pp. 225-58.

Loff, S. (2015, July 22). CubeSats Overview. Retrieved from https://www.nasa.gov/mission_pages/cubesats/overview

Owen, R., Baxter, D., Maynard, T., & Depledge, M. (2009). Beyond Regulation: Risk Pricing and Responsible Innovation†. *Environmental Science & Technology*, *43*(18), 6902–6906. doi: 10.1021/es803332u

Pershagen, G., Rylander, E., Norberg, S., Eriksson, M., & Nordvall, S. L. (1995). Air Pollution Involving Nitrogen Dioxide Exposure and Wheezing Bronchitis in Children. *International Journal of Epidemiology*, *24*(6), 1147–1153. doi: 10.1093/ije/24.6.1147

Planetary Protection. (2020). Retrieved January 31, 2020, from https://sma.nasa.gov/sma-disciplines/planetary-protection

Sputnik. (2007, October 7). Retrieved October 30, 2019, from https://history.nasa.gov/sputnik/.

Tesla Roadster orbit from JPL elements (Feb 9, 2018).png. (2018, February 10). *Wikimedia Commons, the free media repository*. Retrieved 03:03, March 5, 2020 from https://commons.wikimedia.org/

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other Celestial Bodies. United States Department of State. January 27, 1967 2017. Retrieved October 17, 2019.

Wall, M. (2018, September 26). A Base on Mars? It Could Happen by 2028, Elon Musk Says. Retrieved October 30, 2019, from https://www.space.com/.

World Health Organization. (2018). *Ambient (outdoor) Air Quality and Health*. *Ambient (outdoor) Air Quality and Health*. Retrieved from https://www.who.int/news-room/fact-sheets/

Zacharias, K. (2018, February 27). Tesla in space could carry bacteria from Earth. *Purdue University* . Retrieved from https://www.purdue.edu/newsroom/releases/2018/Q1/tesla-in-space-could-carry-bacteria-from-earth.html