Analyzing Apollo Program Failures and Their Applications to Future Mars Missions

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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.

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Introduction: Why Mars?

Plans for manned Mars missions go as far back as 1991 starting with Mars Direct, continuing today with SpaceX's plan of landing humans on Mars in the near future (*Mars Direct,* 2019). Buzz Aldrin described it best, "Mars is there, waiting to be reached." This recent revival of Mars missions in the media has spurred interest in the final frontier once again and should be capitalized on as the Apollo missions did with the space race between the United States and Soviet Union. While all space missions are complex and expensive in nature, a manned Mars mission adds a magnitude of difficulty, cost, and danger to the astronauts partaking in the mission when compared to lunar missions.

While a manned Mars mission may not seem productive on the surface, there are many unknowns about the mission itself and the Martian planet to be uncovered. Investigation of the planet may yield valuable materials, a second home for humans if a catastrophe occurs to the Earth, allow for more information to be collected on the universe, and the technology developed for the mission can benefit life on Earth (Dallas, 2020). If a manned mission to Mars does not occur soon, it is possible that humans may never engage in interplanetary travel and our knowledge of the universe will be limited. Furthermore, technology and economies on Earth will suffer from a lack of research being performed towards the betterment of the human species (Inclan, 2020).

To answer the question of how to apply failed Moon missions to plan Mars missions better, I look at the shortcomings in the Apollo missions and see if these shortcomings are applicable to the plans of current Mars missions. A few topics are common for the failed moon missions, specifically cost cutting, safety and design issues, and overlap between mission plans. The Apollo 13, 18, 19, and 20 missions are the failed American Moon missions that this question can draw information from (The Planetary Society, nd). In this paper, I argue that using information from previous failed missions can in turn lead to a safe and effective manned mission to Mars by prioritizing safety, applying technological culture appropriately, and maintain relevance in the public sphere.

Defining Lunar failures and Possible Martian Failures

Of the Moon missions, twenty were planned specifically in the Apollo program (Mann, 2020). Apollo missions were numerically named in ascending order, starting from one and going up to twenty. Of these twenty missions, two of the missions had failures and three later missions were scrapped having their resources used for other missions. Apollo 1 had a catastrophic failure when fire swept through the command module killing the astronauts onboard (Loff, 2019). Apollo 13 had an oxygen tank catch fire and burst on route to the moon, leading to an emergency aborting of the mission with the safe return of the onboard astronauts being the top priority. This mission is where the infamous "Houston, we've a problem here" comes from said by astronaut Lovell (Woods et al, 2020). Apollo Missions 18, 19, and 20 were the cancelled Lunar missions due mostly to budget constraints and bad planning.

Failed Moon missions

These failed missions revealed the inherent danger of space travel. While it was obvious to the engineers who designed the rockets and missions the level of danger, the public had no idea. Even after lots of rigorous testing, Apollo 1's catastrophic failure on the launch pad left a terrible precedent for the following Apollo missions and cost the lives of the three astronauts on board (Loff, 2019). This event led to a pause on all other Apollo missions and led to intensive investigations into all the root causes of the failure, which led to the later Apollo missions being designed better (Loff, 2019).

Furthermore, Apollo 13 was a widely televised event. Shortly after the oxygen tank exploded, employees at NASA feverously developed a return trip for the stranded astronauts who could no longer finish the mission. While all the astronauts were able to make it back to Earth, alive it was a monumental task that garnered help from all around the world, even the Soviet Union offered its help in spite of the tensions between them and the United States (Dunn, 2020). The astronauts on board had to use the lunar module to return to Earth which was only meant to sustain two people for two days, but was adapted by the astronauts to support three people for four days. It is worth noting that this situation of using the lunar module as a lifeboat was anticipated, but was considered unlikely.

Engineers at NASA were able to devise a plan to allow the lunar module to sustain all the astronauts for the emergency return trip by jerry-rigging a carbon dioxide adsorbing air filtration system. However, this was not their only problem as the new trajectory for reentry to Earth was in the Indian Ocean where NASA had few recovery forces. Along with these challenges, the whole world was watching. An estimated 40 million Americans and 30 million other people were watching as the astronauts returned. While the mission was a failure, it also succeeded in returning all the astronauts. Lovell said it was a "successful failure" and Mike Massimino, a space shuttle astronaut, said it "showed teamwork, camaraderie and what NASA was really made of" (Garber, 2006; Dunn, 2020). The failure of these missions reveals that mistakes can be made. These mistakes must be analyzed so that they do not occur again, such as with the Apollo 1 mission.

Cancelled Moon missions

Apollo missions 18, 19 and 20 were all cancelled. Budget constraints had limited the number of rockets that could be commissioned for the Apollo program (Garber 2006). Only fifteen Saturn V rockets had been commissioned for the program. Apollo 20 was cancelled so its Saturn V rocket could be used to lift the Skylab space station into low Earth orbit. Thus, the Apollo 20 mission had been determined to be less important than other missions, mostly due to budget constraints.

Apollo 18 and 19 were cancelled after the Apollo 13 incident as these were the last planned manned missions to the moon (Woods et al, 2020). The risk of losing more astronauts was too high along with Congress cutting NASA’s budget after the incident led to these missions attempting to have their goals achieved by previous Apollo missions, but fell short due to the vast geographical distances between the goals of the missions. In particular, Apollo 18 had planned to reach the far side of the moon and Apollo 19 had planned to land at the Hyginus Rille region (Wade, n.d.). Their Saturn V rockets are now on display at Johnson Space Center and can be seen in Figure 1 (Boyle, 2011).

Figure 1. Saturn V rocket on display at Johnson Space Center (*Mission Apollo minute, 2020)*

The cancellation of these last Apollo missions reveals a shift in public appeal and the view of space travel as being important. While the Apollo missions did allow for lots of data to be collected on the moon, the benefits of the missions do not end there. Technologies used for the astronauts trickled into daily life. Things taken for granted such as athletic shoes, memory foam, scratch resistant lenses, and the cameras used in cell phones were all developed for the Apollo missions (Inclan et al. 2020). Furthermore, NASA contributes hundreds of thousands of jobs nationwide while also returning seven dollars to the American economy for every dollar spent on the Apollo program. By reducing investment into the space program, the United States could pay for it in the future for not investing into themselves and furthering technology and knowledge (Inclan et al. 2020).

Finally, useful resources were found on the Moon. Helium-3 which is a rare isotope on Earth is much more abundant on the Moon. Helium-3 has a great application as one of the best fuels for fusion reactors. While this material is not applicable yet with current technology, it will become valuable once fusion reactors are developed. Although, it is worth mentioning that fusion reactors have been perpetually "30 years away." Regardless, many countries have made plans to return to the moon once that technology becomes available for the sole reason of mining helium-3. Thus, materials such as helium-3 may not have been discovered on the Moon if the Apollo missions had not occurred, which is important as helium does not bleed off into space on the Moon like it does on the Earth. (*Helium-3,* n.d.)

The data and experience gained from the Moon missions, failed or successful, will be paramount in designing a Mars mission. All the challenges of the Moon missions will be present in the Mars missions with more specific problems for the Mars missions such as, needing much more fuel for a return, more materials for a longer journey, and significant coordination between all teams working on the mission. Safety considerations and failures, goal planning, and engineering knowledge from the Apollo missions will help with the design of the mission.

Current Mars mission plans

NASA's current plans for a manned mission to Mars falls under the Artemis program. While this program focuses on plans for moon missions, its overall emphasis is on getting humans to Mars. The initial moon missions serve to expand sustainability and operational capabilities in space and ensure that all the proposed technology for Mars missions will be viable for those missions. Sustainability of lunar and interplanetary missions is based on in-situ resource utilization and having all materials and equipment be as long lasting and robust as possible to reduce costs. Furthermore, the Moon gives a safer alternative to test the technologies for the Mars mission in a very similar environment to that which will be experienced on Mars (Bridenstine, 2020).

Recent discoveries and current experiments have also helped increase the viability of a Mars mission. Discovery of ice underneath the Martian surface will allow for less materials to be sent to Mars as the resources are already available there, albeit with some work involved (*Exomars*, n.d.). With nearly 20 years of human habitation on the International Space Station (ISS) it was discovered that future Mars-class life support systems could see a reduction in mass by 36% due to more resilient systems and equipment. This means less maintenance and spares will have to be sent and will also make the newer operating systems safer than the current ones on the ISS (Bridenstine, 2020). These findings make planning a Mars mission significantly easier as the water on Mars provides a multitude of benefits like not having to bring water reclamation systems, and safer life support systems could reduce the likelihood of failure during the mission.

How the Missions Will be Analyzed

Explaining Bijker's Method

For the approach to resolution, Bijker's approach in his article "Differences in Risk Conception and Differences in Technological Culture" is utilized (Bijker, 2007). Bijker compared and contrasted the history and heritage in coastal engineering for both the Netherlands and the United States through two independent case studies, where he focuses on two points. First, he focuses on how the United States had a risk tolerant style of engineering, allowing for an estimated flooding every 100 years while the Netherlands are risk averse, allowing for an estimated flooding every 10,000 years. Bijker also focuses on the culture of each country, citing that the United States views the risk as a risk to the individual living on the coast and favoring individuals over the government. The Netherlands' governmental role is different, focusing on protecting all of its people, keeping the flooding to a minimum for everyone.

When Bijker writes about risk perception, he acknowledges that both groups know about the danger of flooding. One difference is the Netherlands' and United States' geographical situations. The Netherlands is a much smaller country with a much larger ratio of coastline to land with much of their land below sea level, meaning that they perceive the risk of flooding much more readily than an American who lives in the Midwest with no bodies of water nearby. Here, Bijker analyzes the underlying causes for the difference in risk perception rather than claiming one is wrong. Through this, Bijker reveals that risk perception is often based on personal experience rather than accepting calculated numbers for circumstances that often have nothing to do with that individual.

He also argues that the difference in the United States' approach and the Netherlands' approach is due to their technological culture. Technological culture as used by Bijker, is the attitudes and use of existing technology for a better society. Bijker cites the United States as focusing on research into sand erosion around the coast while the Netherlands focuses on hydrologic engineering activities. Furthermore, he also mentions the views of each group, where Americans favor individual freedoms over the government meaning that individuals living at the cost have knowingly accepted that risk. The Netherlands view is that government protects everyone, and that it is the goal of everyone to reduce flooding. This analysis of technological culture demonstrates that a focused and united team has more success than a fractured group, as the Netherlands more effectively stops flooding than the Americans who have diverse views about the flooding of New Orleans. These findings in Bijker's paper are summarized in Figure 2.

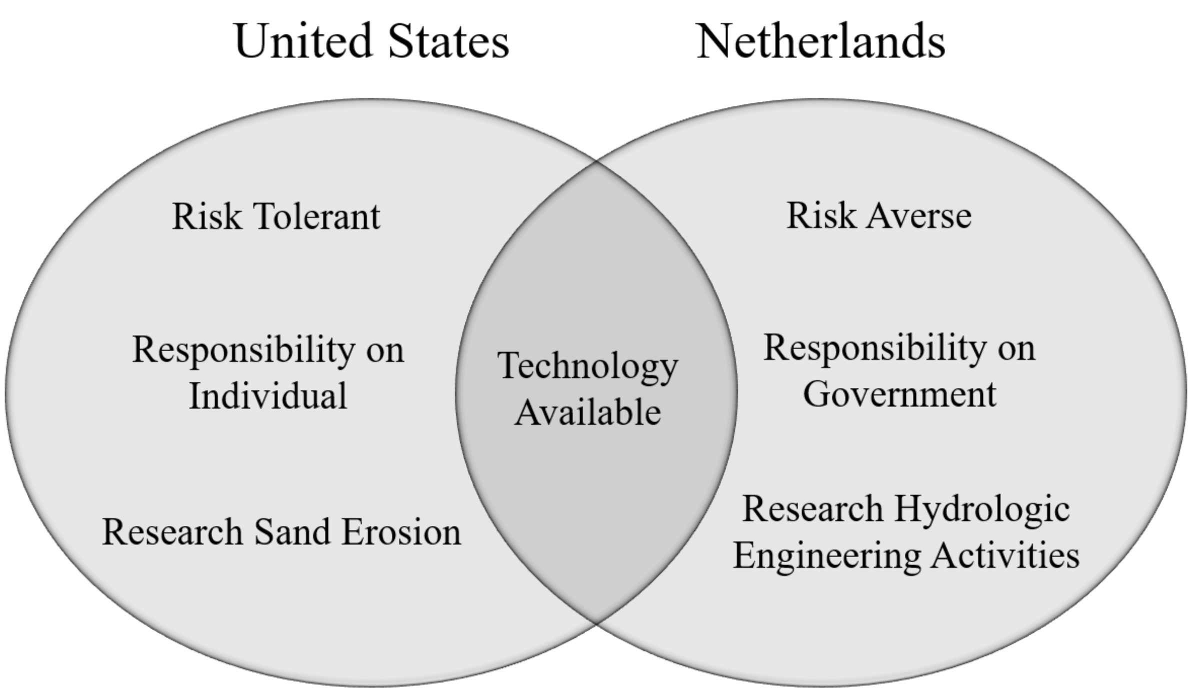

Figure 2. Bijker's Findings comparing and contrasting the United States approach and the Netherlands approach (Made by author; Bijker, 2007)

This framework is based around comparing two similar pieces of literature. While Bijker uses it specifically for risk conception and technological culture with an emphasis on how technology is applied, it can be applied to other aspects of a project. While many literature pieces exist for both the Mars and Moon missions, it is unlikely that two as similar as the two used by Bijker can be found. However, the method will still be applied through a comparison of what Bijker's writing emphasized and a couple other engineering virtues for this paper.

Applying Bijker's Method

Risk conception, acknowledgement of a possible danger and then how it is handled, is applicable for comparing the Mars missions to the failed moon missions as the difference in danger is measured in magnitudes rather than fractional increases. Technological culture is also applicable, but in a slightly different style as the technology has improved for the space missions rather than the same technology being available for both the Netherlands and the United States. Public perception and public usefulness are other characteristics that can be analyzed to ensure both the beginning of a Mars mission and the continuation of a Mars program once it begins. Finally, proper planning can also help the Mars missions accomplish their goals rather than be cannibalized to have its materials fulfill other missions.

Analysis of the Missions

Complexity and Risk of Missions

Given the complexity of a Mars mission, its length, and the communication barrier due to the distance between the planets, the astronauts sent on the mission will likely have to be more specialized and self-sufficient than the astronauts of the lunar missions. For example, a doctor would likely need to be sent along to monitor the health and apply treatments as necessary to other astronauts that either get sick or injured. Another example would be the life support systems running into issues. In either of these cases, a 15-minute response time, due to the vast distances between the planets, from the support team on Earth could be too late to save either the life or lives of the astronauts on Mars. However, to supplement this, computer technology has vastly improved which would allow for better simulating and more robust backup systems at fractions of the cost that were used in the lunar missions. Due to this requirement of specialization, more astronauts will be required to fulfill the mission requirements for each mission to be successful than was required for the Apollo missions.

As there is no plan B if something catastrophic were to happen, as much resiliency and replacements will still need to be designed into the mission. As the Artemis plans expected a reduction in 36% of the mass of the life support system due to information learned from the ISS, sending extra parts is absolutely essential for a Mars mission again due to the lack of other options if something were to go wrong as parts are now lighter (Bridenstine, 2020). Small items such as pumps must be doubled up on with spare parts to keep the systems running even when one fails, allowing for a broken pump to be repaired while the spare pump is running. This follows the same safety principles learned through chemical plants and their process controls and analysis.

It must also be ensured that, should the system fail, it fails in a safe manner. This could be something as simple as leaving extra room in pipes for water to freeze if the heating fails and the water becomes stagnant in a pipe on Mars. Another example could be a pressure lock failing shut rather than open. While it is a danger that an astronaut would not be able to access the door, it is much safer than opening up a habited space to the environment on Mars. Thus, NASA should expect systems to fail, and design them so that they fail into an advantageous state that is repairable if possible.

The increased risks don’t end there as the climate of Mars is more inhospitable than the Moon. Martian dust storms can destroy structures and materials along with possibly burying others. Furthermore, the length of time the astronauts would be exposed to radiation usually stopped by the Earth's magnetic field is a danger not experienced by the Moon missions as they were significantly shorter than the minimum 26 months overall time for a Mars mission (Bridenstine, 2020). All these factors make the risk of a Mars mission significantly harder than a Moon mission, requiring a better understanding of risk perception. Just like in Bijker's article, the mission must be risk averse. While the Moon missions were risk adverse, the Mars missions must be so even more as there will not be any second chances.

Improvements from Previous Missions

Technology has improved since the Moon missions. A computer with 4kb of RAM was sent on the Apollo missions while modern laptops can have upwards of 16 GB of ram installed as an example of technological advancement (Fisher, n.d.). Another large-scale improvement in technology directly applicable to Mars missions would be SpaceX's Falcon 9, which serves as a reusable lift off rocket replacing the consumable Saturn-V rockets used in the Apollo missions. While the technology today is better, it can still be improved further. The technological culture of the Mars missions should still embody that of the Moon missions where lots of research and development occurred, deciding to improve efficiency and optimize rather than being complacent in what was available as is expected from the Artemis program (Bridenstine, 2020).

Some further avenues for improvement of technology required for the Mars mission would include reliability, electrical efficiency, and the study of human health sciences. All machines fail eventually, however if their reliability is increased to the point where a replacement is not required, that can significantly reduce costs for the mission and increase the safety of the mission for the astronauts. Electrical efficiency is important as Mars is significantly energy scarce, likely requiring the transporting of a small nuclear reactor to power a Mars mission. Finally, studying human health from diet to psychology can help the mission prevail by both reducing the food requirements to sustain the astronauts and ensuring they do not go mad throughout the long and stressful mission. The demands of the Mars mission will be higher than those of the Lunar missions, requiring the improvements mentioned above when comparing the two mission requirements.

Public Perception and Planning

Public perception is key in getting and keeping a Mars program running like the Apollo program. While ethics, international law, and current world affairs play a large role, they are out of most of the world's control and are out of scope for this paper. Focusing on the United States, communicating how the Moon missions developed technologies we utilize everyday would gain the public support for an interplanetary mission. Furthermore, promoting the estimated seven to thirty dollars returned to the United States economy for every dollar spent on the Apollo missions would likely generate the most support for the Mars missions (Inclan et al, 2020). However, the first Mars mission has to both be successful and allow for a decent size discovery. Unlike the Moon missions, there likely cannot be a test run due to the cost and complexity of an interplanetary mission. These factors paired with the length of the mission means that public perception will be a tough battle as the mission won't stay within the public perception as long as it would have in the past due to how social media algorithms work along with current media practices.

Planning for the unknown is challenging, especially when it is the equivalent of throwing a football to the moon in terms of challenges. However, unlike the moon missions, robots have been sent to Mars to collect information on the red planet allowing for more informed planning for mission objectives. This should allow for more accurate planning leading to higher mission success rates and lower costs for said missions with a greater return on investment per dollar spent.

While this paper mainly focused on NASA, it would be best if all the best and brightest minds could be used, and not just those at NASA. For comparison, India is currently putting its own version of the ISS into space with China attempting to do the same (Tiwari, 2022). Given these technological advances and similar goals across the world, it would be more advantageous if more teams could work together to pool resources and knowledge to design the most effective missions for Mars.

It must be noted that this would introduce another level of complexity of human factors that would lead to more moving parts and therefore more avenues for failure. This addition of complexity was seen with NASA and the European Space Agency (ESA) working together and having a miscommunication about units, leading to a robot hurtling into Mars leading to the mission ending in failure. Furthermore, other international issues such as the Russian-Ukraine War have led to reallocation of resources and have delayed some current extraterrestrial missions. Russia also destroyed a satellite using a missile which led to tons of particles being introduced to low earth orbit and the astronauts on the ISS having to wait in escape pods just in case the ISS was struck and suffered catastrophic failure. International issues like these make it harder to work with other agencies on top of human factors when introducing more moving parts and demands.

While robots have been sent to Mars for reconnaissance and to collect information, a lot is still not known about the planet. The current information available is not much and means that the first mission will likely be a near shot in the dark to confirm suspicions of data about Mars. However, even these small steps of information collection will still lead to following missions being more successful than the first. This must be emphasized to keep the program alive as most people will likely be expecting a breakthrough, fascinating information, or some valuable material to be discovered considering the high monetary investment into the missions. Furthermore, by utilizing materials left behind by older missions, the newer Martian missions can reduce their cost.

Even if the first mission does lead to a crazy discovery, the ability to leave things behind like telescopes and other remote-controlled devices that cannot be assembled by robots would be invaluable to discovering more about the universe as a whole. Due to the Martian planet having a very thin atmosphere, nearly no humidity, and no light pollution it would allow for clearer telescopic pictures than those achievable on the Earth. These pictures could rival those of the Hubble Space Telescope and allow for more precise calculations on the universe due to there being two points collecting data that can be compared against one another.

Given these possibilities, and again the complexity of the missions, work would not stop once the astronauts land on Mars. The organizing group on Earth can still provide expertise that cannot be accounted for by specialization in the astronauts. While the communication delay would be a problem in emergencies, the team on Earth can help optimize processes once the conditions of Mars are truly known by the astronauts. Furthermore, they can run processes remotely once setup by the astronauts, allowing the astronauts to use their time on the Martian planet more efficiently, rather than just worrying about keeping everything running so they have a chance at returning to Earth.

While all these plans and simulations are good, it will not matter until an actual plan begins to put humans on Mars. It cannot be understated that a Mars mission is truly more complex than the lunar missions. The investment into the mission will be higher with likely the same return on information learned from the lunar missions. Lunar missions are likely more viable and useful in terms of the future than it is to work towards Mars while also being a fraction of the cost. Some of these realizations are shown in Figure 3, including other differences between Lunar and Mars missions. This is realized by the Artemis program as the first missions are actually set to return to the moon rather than head towards Mars. However. all these plans, simulations, and estimations will go to waste if there never actually is a Mars mission. It cannot be known what is out there unless astronauts actually land there and prove our hypothesis of the red planet and the Universe.

Lunar Missions	Mars Missions
• Risk Tolerant initially • Risk Adverse later on • Cheaper • Less Complex • Has been done before • Lots Known about Moon • Have had Mission failures • Lots to Gain	• Must be Risk Adverse • Magnitudes More Expensive • Significantly More Complex • Only Landed Rovers • Have had Mission failures • Not much Known about Mars • Unlikely That There is Much to Gain

Figure 3. Factors influencing missions going to the Moon rather than Mars.

Conclusion: Is Humanity Ready for Mars?

Landing astronauts on Mars and returning them to Earth is a monumental task. However, it is one that is already being designed. Utilizing the shortcomings of the Apollo missions taught space programs that they must be risk averse, utilize technological culture properly to ensure the mission can run smoothly, continue to stay relevant and useful in public's perception of the missions, and plan the missions carefully to ensure as little waste and overlap of mission objectives as possible. Mars missions will be more costly, complex, and dangerous than any of the lunar mission, but these missions have the benefits of better technology and more information to plan on from previous non-human Mars missions.

The largest implication of this claim is that humanity may not be ready for an interplanetary mission to include astronauts. While technology has improved by magnitudes, the cost and demands of an interplanetary mission compared to that of a lunar mission are also magnitudes higher. The information likely gathered from the Mars mission would likely not be useful in the meantime, but may be more useful once things like land become so in demand that its viable to move into space. Even given this though, it is likely the Moon is an easier target first. All this to say that the goal of humanity should be to explore the moon further and be patient in exploring the other planets.

This paper in scope was limited to the Apollo program when examining failed and scrapped missions. Due to this, it is somewhat outdated by almost five decades; however, it is still the closest comparable example to a manned Martian mission. Given the time difference and the advancements in both technology and other non-manned missions in the solar system, this paper likely misses out on other issues that could be fixed to help streamline Mars missions. However, it is applicable through the prioritization of safety and being risk adverse rather than tolerant. Finally, it serves as an outsider perspective to the whole mission schemes as someone who did not specialize in anything space related, but was also still fascinated by the topic regardless. Putting all the criticism on the table is important, even from those who are not as keen to the topic to ensure the problem can be seen from all angles and perspectives, reducing the likelihood of failure.

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