Lunar Surface Habitation as Preparation for Mars Exploration and Scientific Advancement

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Abstract

This thesis is the result of research and analysis of the upcoming human missions to the Moon, particularly the efficacy of the mission architecture both in completing scientific goals and as preparation for future human missions to Mars. A discussion follows of the international agreements pertaining to lunar surface operations and opportunities for amendments. The proposed Lunar surface habitat mission architecture is compared to research stations on Antarctica and the international agreement which governs those stations.

Introduction

The scientific community has had its sights set on Mars for decades. After many landers and rovers (the newest of which touching down earlier this year), the clear focus of the past few decades has been sending humans to Mars. President Bush set the goal of sending humans to Mars in the "next 30 years" in a 1990 speech.[1] While not on as tight a schedule as President Kennedy's goal to land on the moon, this is a serious goal with science and technology development already underway and a feasible mission on the horizon. One important aspect of these prospective missions will be the human factors. There have already been and continue to be analog Mars missions on the surface of the Earth in which human volunteers enter and live in a fake Mars habitat and live as if they are actually there. These includes an accurate communication delay, accurate accommodations, and accurate surroundings The location of these simulations are chosen to match Martian landscapes and the participants must treat the outside world as the hostile atmosphere of Mars because even though they could safely step outside when they need a break from their "crewmates"; the astronauts on a Mars mission certainly cannot.

Before Mars, we will return to the Moon with the Artemis missions set to begin in 2024. The Moon still offers a wide variety of scientific interests and has been the subject of study since humans last left it. However, the Moon and Mars are not completely separate missions. The upcoming Artemis missions can also be used as technology and procedures development. The technology that will be used for the Artemis campaign will be the baseline for that used on a Mars mission. The EVA suits redesigned for the Lunar surface conditions will be the starting point for what humans will wear on the surface of Mars. Beyond that, the types of rockets and the protocols for crew life during the missions will also likely be based on what was successful

[1] Wilford, 1990

in the Artemis missions. These missions are a chance to practice and perfect situations that the first Martian crews will face in a situation most similar to Mars with the safety net of closer proximity to Earth and more familiar terrain. However a large amount of focus, and therefore budget, for these missions revolves around a Lunar space station, a mission element which NASA and its partner national space agencies have already demonstrated success in with the International Space Station over the past two decades. A heavier focus should be placed on permanent Lunar surface structures to better advance both the scientific capabilities of the Artemis missions and the technological capabilities of future Mars missions.

Focus on Human Spaceflight and the Artemis Missions

Human spaceflight is a clear priority for NASA as human missions to the Moon and to Mars are planned in the coming decades. These missions will be huge economic expenditures for the agency, they will be large projects with many teams of employees and contractors, and they will be the spectacles that the public will base their opinion of NASA's competency on. No mission can be free of risk, however, choosing when to take those risks can decrease the level of danger. Humans have not lived on the surface of another planet for a substantial amount of time, our lack of experience in this mission type will mean that the first time it is utilized, there may be unforeseen problems. The risk that astronauts will be enduring when they undergo this new mission style would be much greater the further they are from Earth. Extended surface stay risks are minimized on the Moon compared to on Mars due to the proximity to Earth.

The Artemis missions are designed to rely on Gateway, the Lunar orbiting space station. This will be the first space station orbiting anything other than Earth so it will be an achievement. However, Gateway is similar to the International Space Station; a mission which

has been successfully underway for nearly 20 years. The later phases of the Artemis missions should be more focused on extended surface stays instead of surface visits with extended stay on Gateway. The new mission structure of extended surface stays will be challenging, and proficiency should be gained in this model on the Moon before going to Mars to lower the risk to astronauts. The money and time spent with Gateway at the focus is time not spent on gaining a level of skill in a new aspect that a mission to Mars will surely rely on. The demonstrated proficiency in space station based human space habitation is appealing because it offers a higher chance of success for the Artemis missions, but it does so by sacrificing the opportunity to gain proficiency and practice with a new and challenging form of off-world human habitation.

Artemis III will be the first Artemis mission to return astronauts to the surface of the Moon. The NASA Artemis plan says that, "In addition to two crew, the HLS [Human Landing System] will carry up to 220 lbs (100 kg) of science tools and equipment to the surface, with the goal of returning up to 87.5 lbs (35 kg) of samples."[2] For reference, the Apollo 12 mission was able to return 34 kg of samples to Earth for study.[3] These weight allotments limit the science that can be done both on the surface and back in labs on Earth or Gateway because of how much material can be returned. The surface operations detail that, "While on the surface, crew will live in the cabin of the ascent vehicle—the upper part of the landing system that they will use to get back to lunar orbit when the surface expedition concludes."[4] These missions will still revolve around living in the ascent vehicle on the surface and taking a few EVAs out before heading back to the Gateway station. This aspect of the mission again demonstrated a mission archetype that NASA already proved sufficiency in with the Apollo missions. These missions are a combination of Apollo and ISS architectures, and offer a limited amount of innovation in mission design that

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[2] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020
[3] Lunar and Planetary Institute
[4] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020

will be needed for a successful Mars mission. The plan for Artemis III continues, “Outside on the Moon, the two crew members will spend about 1.5 hours on set-up tasks including configuring the lander for contingency return, and unpacking tools and equipment for the objectives of the day.”[5] This takes time, effort, and oxygen. The more oxygen astronauts need to bring to the surface, the less room they have in the HLS for equipment. Operating out of a base research station with its own oxygen supply would make every EVA more efficient, this plan requires astronauts to land a spacecraft and set up camp before they can begin working. These short surface trips are not compatible with long term scientific goals because they will always have an intensely limited scope.

Before the mission has even begun there are already concerns over mass allotments, “NASA requires a minimum of two moonwalks during the Artemis III surface expedition, and is currently working to drive down HLS vehicle mass to allocate more resources to spacesuit life support systems.”[6] The economic efficiency of this mission model is a concern. Phase 1, which spans from the start of the missions through Artemis III, will cost nearly 28 billion dollars.[7] The amount of science completed for this money needs to be maximized in order to guarantee adequate funding for the remainder of the Artemis missions which contain much more expensive plans. The nature of these EVAs limits their scope and therefore their payoff. Astronauts would get more scientific return per launch if they operated out of an extended surface stay instead of short visits. The efficacy of these missions will also affect the funding that any potential Mars mission campaign can secure. Not only would a permanent research station be beneficial in science goals, it would also be a public display of proficiency and success.

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[5] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020
[6] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020
[7] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020

The Artemis mission plan does include a base camp at the Lunar south pole, “The additional infrastructure at the base camp will support one- to two-month expeditions on the surface to learn more about the Moon and the universe at large”.[8] This is still a fairly temporary set up which will only be housing astronauts for 30 to 60 days; comparable only to the shortest possible Mars missions. Because the Base Camp at the South Pole is proposed for the end of the campaign, it may be altered before actually being built. The Artemis missions are a focus for the agency, however not every aspect of these plans is guaranteed. Like the Apollo missions, missions later in the campaign could be outright cancelled. This base is not nearly as planned out as Gateway and the early missions.

Gateway will be used to conduct scientific research of the Moon from orbit as well as a lab for returned surface sample analysis; however, in terms of mission capability development it is redundant to the ISS and therefore largely irrelevant to Mars mission preparedness. The ISS has offered an experience much more similar to that of a spacecraft orbiting Mars because Mars is far more similar to Earth than the Moon in terms of orbital conditions. It is true that the vehicle that astronauts take to Mars will likely stay in orbit until they return to Earth. The Artemis phase 1 reliance on Gateway will offer sufficient practice in orbital capture of a spacecraft which remains beyond the atmosphere. Continued reliance on Gateway through the end of th3e Artemis missions will limit the lunar base development possible and therefore limit new technology development.

Not only does a greater focus on surface living help prepare NASA for the human factors related to a Mars mission; it also offers a more analogous way to test and prepare and develop instruments and systems that will be utilized on those missions. It also allows for more efficient scientific study of the Moon on the Artemis missions. At least in the early phases of the Artemis

[8] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020

missions, astronauts will only be on the surface for short periods of time to conduct science and because these will involve landing at a target point on the surface from the orbiting Gateway station they must be planned in advance. Surface habitation offers a much faster response time to on-surface events of interest. A surface lab also allows more samples to be examined without the pressure to minimize the mass of collected material because it does not need to be taken back to Gateway or Earth. Long-term experiments could be set up and eventually telescopes that could take advantage of the lack of atmosphere and the ability to be serviced easier than a space-based telescope. A surface base would be a much more sustainable mode of scientific investigation than a continuous stream of short trips.

Mars Mission Architectures

While some Mars missions consider the idea of a transit vehicle which orbits the Earth first and then Mars with separate ascent and descent vehicles are used to reach the surface; all include some permanent structure on the surface which crew members would habitate. Because of Mars' distance from the Earth and the two planets' orbits the shortest possible surface stay would be 30 days and the longest would be around 600. Even the shortest possible mission would be a significantly longer surface stay than any human mission in the past. Living on the surface of another planet is the next hurdle in advancing the human space exploration program.

The Artemis mission plan states that the type of mission which is being pursued is the short-stay variety, "The concept of operations NASA is working toward for the first human mission to Mars is therefore one that reduces trip time significantly and minimizes time spent on the surface to around 30-45 days."[9] One of the factors listed in this decision is "complexity of

[9] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020

mission operations on the Martian surface" which can never be completely eliminated[10]. However, more preparation on the Lunar surface would decrease the perceived complexity of similar missions on Mars. A crewed mission to Mars will be the most complex mission ever attempted and it will come with natural constraints due to the geology of Mars, the biology of humans, and the orbits of Earth and Mars. Gaining proficiency in long-stay missions before these Mars missions are fully planned will relieve some artificial constraints which complicate the missions. As the NASA Human Exploration of Mars Design Reference Architecture states, “The long-stay mission architecture lends itself to a very robust surface exploration strategy. The crew would have approximately 18 months in which to perform the necessary surface exploration.”[11] Opening the possibility of long-stay Mars missions also opens up scientific possibilities on the planet. Long missions can also be more economical by maximizing the science done for each rocket launch.

No matter the mission duration, the Artemis mission model as it is now is not translatable to Mars. The Martian atmosphere is thinner than Earth’s but not negligible. Its escape velocity is approximately half of Earth’s but again not negligible. Trips to the surface and back up to a space station are not as easy as they are on the Moon. Mars has a weather system that must be accounted for but the Artemis model does not account for such delays. The amount of fuel and the much more massive Human Landing System that would be needed to carry out a short surface visit model on Mars make this mission impractical. This means that if Artemis is meant to prepare humans for Mars missions, it must be changed with Mars in mind.

[10] Artemis Plan: NASA's Lunar Exploration Program Overview, 2020
[11] Drake, 2009

Analog missions

Human preparation for Mars has long been underway. Before any specific plans had been crafted, it was clear that sending humans to Mars would require longer stays in space than humans have ever completed. Humans would be far enough away from Earth that even communication with society would be delayed; astronauts on a Mars mission would only be communicating in real-time with each other for likely a few years. So in preparation for this new level of isolation, NASA has been running analogous missions on Earth for longer than the ISS has been inhabited. One such mission is the Haughton-Mars Project located in northern Canada. This research station has been operational since 2000 and is designed specifically to mimic what a theoretical Mars mission setup could be.[12] Not only are Mars habitat set ups tested, the tools, technologies, and methods that may be incorporated into Mars missions are also tested here.

We now have renewed focus on the Moon with the upcoming Artemis missions. We may have been running a Lunar Science Station analogous mission for the past 60 years without realizing it. The permanent research stations on Antarctica can be used as a model for developing the framework for similar stations on the Moon. A Lunar Science Station would then be the most analogous mission to a Mars mission.

Antarctica as a Model

This new type of human space exploration will be just that, new. Current space law is outdated to such advancements, the language in the United Nations treated that designate international agreements could be improved to better fit this new mission type. One clear issue with these laws is their lack of clarity towards non-governmental actors. The Artemis missions will rely on private contractors, so any lunar surface base likely would as well. These contracts

[12] Mars Institute

will encourage private companies to develop the ability to travel to the Moon and they may have incentive to go on private business outside of their contracted involvement with NASA and partner agencies. These treaties are from a time before the possibility of private actors building crew vehicles was plausible and thus they do not account for that reality. While it could be argued that the regulations in these agreements apply to non-governmental organizations in the same way they apply to governmental agencies, the fact that it would need to be argued is troublesome. The gap in coverage of these treaties is obvious and could lead to an act first and debate legality later mindset due to their lack of specificity which could seriously damage scientific interests on the Moon and set a similar precedent for elsewhere in the solar system. Amendments to these treaties which include specific language applying the regulations included to any actor on the Moon, not just government agencies should be seriously considered to avoid exploitation and contamination of sites of scientific interest. Another glaring issue with the language not including non-state actors in provisions for the safety of astronauts. Commercial development in the ability to land on the surface could lead to private researchers paying for transport or even space tourism one day. While Article 10 of *the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies* says that "they shall regard any person on the Moon as an astronaut", there are still gaps in the language of other sections and of other treaties.

Some of the research stations on Antarctica have been abandoned despite a major purpose of the treaty being to preserve Antarctica as it is. Seeing how out of control the space debris problem has become in Earth's orbit, an agreement against abandoning waste on the Lunar surface should be considered. No such provisions were included in agreements on satellites and orbits because it was not considered common enough to be a concern, however looking back

now it is clear that it should have been. Setting a law rather than just a precedent will be important for the next century of human space exploration. It has been only 64 years since the first satellite was launched and already satellite debris is an issue. Articles 4 and 7 of *the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies* address non-contamination and that "Due regard shall be paid to the interests of present and future generations" however, these articles lack specific regulations as well as specific consequences and again do not address non-state actors.[13] To avoid a similar debris problem developing on the Moon, a regulation that all materials brought to the Lunar surface must be disposed of properly and cannot be abandoned as waste would be beneficial.

Relevant Space Law

Both t*he Antarctic Treaty* and the United Nations *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space* have clauses which make the claiming of land by any nation illegal. Antarctica sets a clear precedent that a research station, even a permanent one, is not a claim of land by a nation. Article IV, subsection 2 of *the Antarctic Treaty* says, "No acts or activities taking place while the present Treaty is in force shall constitute a basis for asserting, supporting or denying a claim to territorial sovereignty in Antarctica. No new claim, or enlargement of an existing claim, to territorial sovereignty shall be asserted while the present Treaty is in force."[14] This statement differs slightly from *the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space* which states in Article II "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other

[13] Agreement governing the Activities of States on the Moon and Other Celestial Bodies, 1979
[14] The Antarctic Treaty, 1959

means."[15] The ideas conveyed in *the Antarctic Treaty* suggest that nations will be acting on Antarctic territory in a way that, if they were not signees of the treaty, could be interpreted as claiming sovereignty over an area. The outer space treaty is worded in a way to keep nations from acting in a way that could be interpreted as claiming sovereignty of the Moon.

The United Nations *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, which was signed 16 years later, takes an approach more similar to *the Antarctic Treaty*. In Article 11, subsection 3 it says, "The placement of personnel, space vehicles, equipment, facilities, stations and installations on or below the surface of the Moon, including structures connected with its surface or subsurface, shall not create a right of ownership over the surface or the subsurface of the Moon or any areas thereof."[16] This phrasing clearly implies that these activities are expected by the signees and they do not equate to claims of sovereignty even though they could be interpreted as such without the agreement in place. The Antarctic Treaty shows that these understandings of permanent stations not being equivalent to claims of land are practical. These rules regarding the Moon have just been theoretical and Antarctica offers substantial proof that these treaties can be relied on for decades to quell competition and the urge by any nation to claim the land they want to use for research.

Important Changes to Space Law

This new type of human space exploration will be just that, new. Current space law is outdated to such advancements, the language in the United Nations treated that designate international agreements could be improved to better fit this new mission type. One clear issue with these laws is their lack of clarity towards non-governmental actors. The Artemis missions

[15] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 1963
[16] Agreement governing the Activities of States on the Moon and Other Celestial Bodies, 1979

will rely on private contractors, so any lunar surface base likely would as well. These contracts will encourage private companies to develop the ability to travel to the Moon and they may have incentive to go on private business outside of their contracted involvement with NASA and partner agencies. These treaties are from a time before the possibility of private actors building crew vehicles was plausible and thus they do not account for that reality. While it could be argued that the regulations in these agreements apply to non-governmental organizations in the same way they apply to governmental agencies, the fact that it would need to be argued is troublesome. The gap in coverage of these treaties is obvious and could lead to an act first and debate legality later mindset due to their lack of specificity which could seriously damage scientific interests on the Moon and set a similar precedent for elsewhere in the solar system. Amendments to these treaties which include specific language applying the regulations included to any actor on the Moon, not just government agencies should be seriously considered to avoid exploitation and contamination of sites of scientific interest. Another glaring issue with the language not including non-state actors in provisions for the safety of astronauts. Commercial development in the ability to land on the surface could lead to private researchers paying for transport or even space tourism one day. While Article 10 of *the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies* says that "they shall regard any person on the Moon as an astronaut", there are still gaps in the language of other sections and of other treaties.[17] Such as Article V of *the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* which says, "In carrying on activities in outer space and on celestial bodies, the astronauts of one State Party shall render all possible assistance to the astronauts of other States Parties" specifically

[17] Agreement governing the Activities of States on the Moon and Other Celestial Bodies, 1979

excluding astronauts which are not representatives of a State.[18] which clearly constricts astronauts to state representatives not private citizens.

Some of the research stations on Antarctica have been abandoned.[19] Seeing how out of control the space debris problem has become in Earth's orbit, an agreement against abandoning waste on the Lunar surface should be considered. No such provisions were included in agreements on satellites and orbits because it was not considered common enough to be a concern, however looking back now it is clear that it should have been. Setting a law rather than just a precedent will be important for the next century of human space exploration. It has been only 64 years since the first satellite was launched and already satellite debris is an issue. Articles 4 and 7 of *the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies* address non-contamination and that "Due regard shall be paid to the interests of present and future generations" however, these articles lack specific regulations as well as specific consequences and again do not address non-state actors. To avoid a similar debris problem developing on the Moon, a regulation that all materials brought to the Lunar surface must be disposed of properly and cannot be abandoned as waste would be beneficial.

Conclusion

A human mission to mars will be the most ambitious mission ever attempted, to truly be ready, NASA must focus on preparing now. The Artemis missions are a chance to push human spaceflight abilities forward to a new standard. These missions should not be wasted by repeating old missions practices. The short surface visit model will only offer limited scientific opportunity, it is not sustainable, and it does not prepare for any conceivable Mars mission. The

[18] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 1963
[19] Fieger & Wilson, 2021

most logical Mars mission archetypes revolve around extended surface stays, those missions should be more closely mirrored by lunar missions. As spaceflight trends towards human exploration again, a more permanent foray into the Universe is necessary to advance science.

Improving human space exploration capabilities requires making changes. We are entering a new era of human space exploration, if we want it to be sustainable and efficient, it must be different than it was before. Repeating the same mission structure of visiting target locations from an orbiting craft will only get us so far. NASA has already demonstrated success in orbiting stations and short stay surface visits. It is time to focus on a new aspect of human space exploration we have less demonstrated success in. For a more robust human space program there needs to be an ambitious answer, and there must be updates in space law to best accommodate these new endeavors.

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