An Intangible Risks’ Management Plan for Crewed Long-duration Missions Technical Report

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Abstract

Regarding the environmental challenges that arise from long-duration crewed missions to Mars and long-duration crewed missions in general with a particular focus on intangible risks, this report recognizes, accounts for, and assesses the threats of radiation, communication latency, and microgravity. Analyzing each risk’s potential threat on the human crew of a long-duration mission, this technical report utilizes research-based information to develop potential countermeasures for each invisible environmental risk with a diversity of measures that offer benefits for the specific parts of risks analyzed. Utilizing research feasibility and availability as the basis for analysis, the report also finds the severity of microgravity as a risk factor in such a mission is greater than that of communication and radiation respectively and that a need for research is required for this understudied risk in order for future long-duration mission success.

An Intangible Risks’ Management Plan for Crewed Long-duration Missions Technical Report

Humanity is currently entering a period of history that will radically change the reach of humanity to being multiplanetary, consequently allowing for an exponential explosion in technological development, resource availability, and scientific understanding so dramatic as to rival any other evolution in humanity as a species. With Mars being the next closest planet to Earth for human habitability, the risks and consequences associated with a first mission to Mars will be critical in defining the feasibility of true colonization and settlement of Mars. Even with the habitability being comparatively similar to Earth, Mars’ environmental characteristics and conditions make it a desolate and hostile destination beyond any natural environment on Earth for pioneering humans to explore and settle while actual travel to Mars only serving to further complicate matters with the sheer enormity of distances in the harsh and hostile vacuum of space serving to create an even more difficult environmental obstacle. Specifically, the three issues of radiation, communication, and microgravity all act invisibly over the inherently long-duration journey required for human missions to Mars, creating nuanced and situational issues that must be identified and managed for such serious missions.

Mars missions are endeavors for exploration and, even without human elements, must balance the natural risks that arise with the safety of the equipment to ensure scientific progress is made while financial costs are not incurred. However, the added element of humans on missions radically changes the paradigm as elements that previously were irrelevant become treacherous hazards to be avoided, lest an enormous human cost be incurred. Radiation is one such element, acting invisibly and inflicting irreparable damage to the humans on board that could result in serious problems for the safety of not just the crewmember, but also the mission itself. The distances between the Earth and Mars are astronomical and require unavoidable journey times beyond the safety of Earth’s powerful magnetic field, which blocks much of the radiation on Earth, and into interplanetary space where the extreme energies of the sun and other stars are made apparent by large releases of damaging ionizing radiation through solar flares, coronal mass ejections, and galactic cosmic radiation (Space Faring Radiation Challenge, n.d.). These stellar events all release energetic particles that tear through the DNA of cells, resulting in serious damage to crewmembers as such damage builds over the nearly year-long journeys to simply get to Mars. However, the issue of radiation persists for even the humans on Mars as Mars lacks a powerful magnetic field to repel radiation, with the radiation blocked by its own smaller field being negligible overall (Magnetic Shield System, n.d.). The presence of radiation throughout the entirety of the journey, including the interplanetary travel and surface stay, demands the identification of the degree of risk posed by the omnipresent hazard. Notably, the exact risks posed by radiation are not fully explored as current radiation knowledge relies on the incidents on Earth, which generally have high doses delivered in short time periods, and the lunar missions, which also lack the time scales necessary for accurate comparison between a potential Mars mission. Primarily, Earth-based research identifies the development of cancer, degenerative physical and cognitive efficacy, and tissue deterioration as effects of radiation on humans over time and deem development of these serious issues as likely over the course of an interplanetary mission (Chancellor et al., 2014). For astronauts that are routinely facing extreme physical and mental demands, development of any one of these issues could prove catastrophic as missions rely on the ability of the crew to perform in as extreme an environment as interplanetary space and Mars. Preventing such issues is thus a necessary and important step in managing the risk of radiation, which can be done through the same attentiveness to time, distance, and shielding used on Earth for radiation incidents (Protecting Yourself, n.d.). Firstly, astronauts will have planned for and been trained on minimizing their time in scenarios with higher amounts of radiation such as those beyond the shielding provided by potential bases or spacecraft. Distancing will be utilized on the surface of Mars as landing sites and bases for astronauts will be selected to be further from exposed landscapes in exchange for basins and ravines with natural distance and shielding being provided by the environment. Aside from using regolith and location as natural forms of shielding, astronauts will also be shielded during their interplanetary travels due to active electromagnetic shielding on the spacecraft, which has seen research from various space agencies and results in significantly less radiation exposure by blocking radiation through an electromagnetically activated magnetic field (Ambroglini et al., 2016). These electromagnetically driven shields will also allow for electronics to be protected from radiation and would allow for a greenhouse to be used for food production as a greenhouse would require exposure to the sun and its radiation to grow (Magnetic Shield System, n.d.). Astronauts will also be able to utilize an alternative means of combatting radiation for unavoidable Martian treks and for use on the spacecraft in order to replace the protection provided by regolith on the surface through the use of Vitamin C supplements, which are easily stored and have been shown to help with combatting the illnesses developed through radiation exposure cheaply (Sivher et al., 2021). Through these means, the risks of radiation will be effectively mitigated as the weaknesses of each method is countered by the strength of another. While radiation will always pose a challenge, the proper astronaut training and mission preparedness can minimize the downsides of the interplanetary travel and extraterrestrial conditions that would threaten the benefits of crewed Mars missions.

While radiation poses and issue that has been well-documented and experienced on Earth, Mars astronauts will also face unique and unprecedented challenges with communications. As with the increased radiation exposure caused by the lengthy trips between Earth and Mars, the vast distances of interplanetary space results in obstacles with communications as messages from Earth to Mars for the Curiosity mission have anywhere from 4 to 24 minutes of delay (Ormstom, n.d.). This delay also cannot be improved by any significant margin since the delay is a result of the fundamental limit on the speed of light, which current understanding of physics declares as an impassable barrier. Therefore, any crewmembers on a mission to Mars will be unable to gain the collective decision-making power of operations teams on the Earth within 20-minutes. However, beyond just the decision-making process being hindered, the delay in communications caused by a Mars mission also has rippling side-effects on making other tools common in low-Earth orbit inaccessible to the astronauts. For example, without the ability to have negligible latency, real-time conversations will become impossible and accordingly affect the ability of astronauts to access the psychological tools and benefits of therapy and conversation with friends on Earth. The lack of therapy will be especially detrimental, since long-duration space travel has already been flagged by psychological researchers as being more conducive to the development of depression and conflicts between the crew (American Psychological Association, n.d.). Furthermore, research of long-distance space exploration mission simulations were analyzed by researchers and resulted in findings of decreased social time and managerial reporting alongside the presence of at least one conflict in over 1,000 simulations within 90 days (Bell et al., 2019). Since Mars missions will be multi-year long endeavors, the relatively short time for conflicts to rise and the various behavioral changes of crews, which made the likelihood of psychological issues greater, present a great risk to a crewed mission and require alleviation by planning and training (Basner et al., 2014). One opportunity to lessen the stresses created by a long-duration space mission is computer programs, which can replicate the role of clinicians and provide a real-time opportunity for astronauts to mitigate interpersonal conflicts through psychiatric support (American Psychological Association, n.d.). These opportunities could also use recent advances in artificial intelligence to create counteract the sense of isolation that astronauts report feeling (Mars, 2018). Beyond issues in just the psychological status of astronauts on Mars come the risks of scientific progress being hindered by communication difficulties between the astronauts on Mars and ground crew on earth. Without the ability to directly communicate with experts about the scientific tasks taken on by Martian astronauts, miscommunication resulting in improper scientific analysis and progress from being made is a likely opportunity for communication impairment. In order to mitigate this risk, which would devalue the dangerous missions and thus make other risks more egregious, methods of communication can be used such as uninterrupted narration of reasoning by astronauts for the use of Earth-based control and up-close photography of material for visual representation on-top of a live video to allow for the best scientific collection to be done, as found by a research study (Stevens et al., 2019). Through the use of these methods, scientists will be able to guide astronauts on Mars with only minor delays and glean potential areas for further exploration through audio description and video analysis. Utilizing video technology, however, has another challenge as data is limited by the frequency of radio transmitters currently orbiting Mars. Through the use of optical data transmission devices such as lasers, researchers estimate that data rates would substantially increase and allow for the communication links necessary for cohesion between the crew and Earth, while also enabling better data rates on Earth over time (Next-gen Communication, 2021). While many of the issues with communication only arise during the surface stay on Mars, since the spacecraft will be relatively close during the transfer between the planets, the problems of communication necessarily must be overcome as they pose comparatively hidden dangers that affect mission efficiency and have the beneficial side effects of advancing many technologies that could be used on earth such as telemedicine and increase data rates through laser technology.

However, while communication remains a surface-based problem only primarily occurring while the astronauts are on Mars, the issue of microgravity is one that will be present throughout all missions in space. For the crewed mission to Mars, the issue of microgravity will especially be important as Mars has only one third of the gravity of Earth which, while having the potential to counter the effects of zero gravity faced during the interplanetary voyage, will also pose an issue for astronauts due to the sudden transition they will face from zero gravity to Martian gravity. Specifically, research has found that one of the most impacted areas of microgravity on long duration missions will be the loss and deterioration of the musculoskeletal system, with bone mineral density decreasing along with muscle function and being potentially lengthy and unpredictably variable to reverse, resulting in diseases such as osteoporosis (Safe Passage, n.d.). With the astronauts having to transition from the zero-gravity environment of space to the Martian gravity environment rapidly during a time of great physical exertion due to the initial setting up of the base, the likelihood of a substantial medical emergency such as a fracture is paired with the potential for unsafe or improper initialization of the base. Along with these issues affecting the musculoskeletal system are issues affecting the ocular system as spontaneously discovered by astronaut John Phillips, whose vision became impaired after spending time on the International Space Station (Love, 2016). This issue, known as spaceflight-associated neuro-ocular syndrome (SANS), is the result of a redistribution of fluid in the body which, due to the microgravity environment, is brought from its general location in the legs to the head, resulting in stresses on the ocular system as pressure from the fluid strains the eye and, in the long-term, could lead to permanent blindness (Patel et al., 2020). With such significant issues to astronauts’ immediate health, the risks posed by microgravity require medical attention an alleviation as mission critical functions would be impossible with physically weakened or visually impaired astronauts. However, since microgravity is present through the interplanetary voyage, the effects and research into the risk have been established and studied for years aboard the International Space Station (ISS). The muscle atrophy that results from the microgravity environment of space can be allayed with exercise, which requires the use of elastic workout tools due to astronauts’ inability to use weight in a microgravity environment (May, 2015). While exercise also benefits bone strength and prevents some bone density issues, the mineral loss plays a large role in the weakened bones and must also be neutralized. These mineral changes can be diminished through the ingestion of vitamin supplements and calcium rich foods, along with other pharmaceutical agents that have been developed due to the ability to study microgravity on the ISS (Iwamoto et al., n.d.). Research into SANS has also found potential in having astronauts sleep with their heads tilted down, although the effects are not fully eliminated (Ong et al., 2021). However, one opportunity that would allow for the issue of microgravity to be side-stepped for the interplanetary voyage entirely is the spinning spacecraft. By utilizing the centripetal force of rotating bodies, an artificial gravity can be produced that would allow for astronauts to avoid the effects caused by microgravity (Dunbar, n.d.). However, due to the Coriolis effect, astronauts would be unable to accurately perform delicate tasks and maneuvers as the relatively small size of a spacecraft would cause human brains to miscalculate locations of objects (Allain, 2022). Due to the costs associated with spinning an entire ship, a centrifugal section could be implemented for astronauts to sleep in, allowing for tasks to be performed without requiring the full mobility of the ship. Through the implementation of these methods in a long-duration mission, the perilous issues of microgravity on the human body can be mitigated and avoided. With the risks associated with astronaut safety, the opportunities to counter the health issues of spaceflight are comparatively manageable, especially with the consideration of the human factor and public interest of any long-duration space mission.

While the dangers of radiation, communication, and microgravity are patently real and pose a genuine risk to the astronauts, they act intangibly on spacefarers for any long-duration mission beyond Earth and must face optimized solutions built on researched scientific discoveries. Yet, the dangers posed by each are not necessarily equal and weighting the risks in any future management plan requires a proper assessment of the threats these invisible risks pose. Though radiation has some of the most damaging effects on humans, with the development of cancers, degenerative cognitive illnesses, and cardiovascular diseases, the risks of radiation are well-understood on Earth and relatively easy to test compared to the effects of microgravity or communication latency (Patel et al., 2020). For example, in one study, scientists were able to find that cancer rates and other radiation related illnesses had not statistically increased in the astronauts by analyzing the historic events of the moon landing and Russian space race and using data of the astronauts’ causes of death. Furthermore, the ability to counter radiation is an area of active research and mature knowledge, with the main need being a transition of radiation defenses to those cost-effective for use in space. Moreover, the issue of radiation on Mars for long-term colonies and habitation can be solved with the use of regolith since research estimates substantial benefits in using a regolith covering for lower radiation doses (Llamas et al., 2020). Communication provides a relatively greater challenge as the physics-based origin of the issue makes an impassable barrier that requires only workarounds instead of direct solutions to the latency problem. Still, communication issues between well-trained astronauts are generally rare and the ability to study the effects on isolation and communication delays on Earth is fairly simple and has been done through many studies, which show that psychological effects can be avoided through training measures and pharmaceutical drugs in necessary cases (Headspace, n.d.). For these reasons, radiation and communication respectively pose the least danger in comparison with the issue of microgravity. While microgravity studies are possible to do for astronauts on the ISS, long-term studies have not, and cannot, be done with a large enough sample size due to the nature of long-term studies and the need to rotate the small crew on the ISS due to the severity of microgravity problems themselves. Furthermore, issues such as SANS require medical procedures that would be impossible in microgravity in order to gain the necessary information for study into the syndrome, while being niche enough due to the issue occurring only on spaceflights to be understudied (Patel et al., 2020). Finally, the primary solution for microgravity, the spinning spacecraft, has a number of flaws and will notably be unable to sidestep the unavoidable lower gravity on Mars, increasing the chances of serious injuries that would likely prove fatal depending on the severity (Allain, 2022). The focus on research for long-duration space missions should therefore be more on the effects of microgravity than the effects of communication latency or radiation as an abundance of needs are not yet met with potential solutions or even potential research.

Arriving on Mars will be one of the most monumental achievements in human history, requiring the efforts of scientists and researchers from around the world to investigate and solve the primary challenges facing those first astronauts. With the intangibility of radiation, communication latency, and microgravity comes a greater need for attention and planning as the risks poses by these hazards are powerfully physical. While microgravity hosts the greatest danger for any risk management, research into all three threats must be analyzed to form effective solutions that allow for human habitation on Mars to become permanent and accessible. While the obstacles posed by the threats are great, the ingenuity of humanity has precedent for conquering even the most difficult problems as the tenacity of astronauts is bolstered by strong planning and knowledge from the research of a plethora of scientists who serve to help colonize Mars for humanity.

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**Appendix A**

Outreach Page

The astronauts that will first set foot on Mars will become the first human on another planet, a monumental achievement that will define human ingenuity and ability for the rest of human history. Yet, these brave crewmembers will not be done with their journey after just a few days as their predecessors on the moon were. Instead, they will be on Mars for months as part of a multi-year long journey that will have barely just started.

During this multi-year long journey, as you, the public, watch with spellbound wonder, the astronauts will be subjugated to invisible risks that they must continuously fight off with the preparation of hundreds and thousands of the brightest scientists’ and researchers’ work. The first of the three dangers faced by these astronauts will be radiation, which will bombard them as the sun relentlessly works with extrasolar rays of radiation to damage the cells of these heroes. However, with the use of magnetic and regolith shields prior to and during the surface segment of the mission respectively, radiation will be unable to hurt the astronauts. The second of the dangers will be isolation and communication since, like an antique ship sailing the open ocean, they will be too far for even light to travel instantly and must deal with dangers with only the guidance and training of the smartest and most inventive people in humanity as backup. Sending your positivity to the astronauts will allow you to do your part in keeping their spirits soaring amongst the stars. Finally, the astronauts will battle the microgravity of space. However, with the rotating ship that will wow imaginations, astronauts will only need the power of plenty of vitamins and nutrients to keep themselves strong and healthy.

The work of an astronaut is inherently risky, as they must pioneer in what was the heavens for our ancestors, becoming a star that guides us from the choppy sea of space to new worlds.