MARS ANALOG SIMULATIONS

Heidi D. Beemer and Robert L. Haines, Jr.

Embry-Riddle Aeronautical University

Beemerh@my.erau.edu

ABSTRACT

Scientists and engineers alike explore how crew members interact with each other and their environment. The discoveries from this research directly impacts technology development and pushes the industry forward. Because human space exploration testing is so complex and expensive, earth based analog simulations are used to test human interactions as well as new technologies to help prepare for future space mission. This paper focuses on four of these analog simulations, each of which are dedicated to researching various topics for future Mars exploration. The four missions analyzed include the Mars Desert Research Station (MDRS), Flashline Mars Arctic Research Station (FMARS), Hawai'i Space Exploration Analog and Simulation (Hi-SEAS) and the National Aeronautics and Space Administration Extreme Environment Mission Operations (NEEMO). This paper concluded that despite only conducting missions for two weeks, MDRS and NEEMO are capable of developing protocols for long duration space exploration. The longer missions like FMARS and Hi-SEAS are useful for validating these protocols by conducting repeated measures over the duration of the mission. Earth-based analog Mars mission will continue to be used to determine what is possible for future Martian exploration.

Keywords: Mars, MDRS, FMARS, Hi-SEAS, NEEMO

Mars Analog Simulations

Simulations have been around in the field of aviation since planes first took to the sky. According to Moroney and Lilienthal (2009), simulated flight training became common during World War II, where aviators used a "blue box" that consisted of an enclosed cockpit for pilots to practice their flying skills and techniques (p. 5). They continued, stating simulations are now a popular workplace occurrence used by many operators to include pilots, drivers, navigators, nuclear power plant operators, physicians, maintainers, technicians, and others. According to Lee (2005), the need for realistic ground-based simulations continues to grow while the designs not only require appropriate hardware but also a better understanding of the human responses to what they experience during flight (p. viii). Simulations today are not only used to train employees, but also to develop, build and test increasingly intricate systems. Generally, employers utilize simulations for a common purpose, to test human factors of a particular field to determine how humans will interact with the equipment they are working with in the most realistic way possible (Vincenzi, 2009, p. 9).

The Federal Aviation Administration (FAA) clearly defines an airplane simulator as a "full-size replica of a specific type or make, model and series airplane cockpit in ground and flight operations, a visual system providing an out-of-the-cockpit view, and a force-cueing system" (Vincenzi , 2009, p. 8). These specifications are put in place to provide a realistic-as–possible training environment for pilots to train without having to use resources to fly actual airplanes. Today's simulations are not just used to support the pilot's experience of flight but also the pilot's performance of specific tasks (Lee, 2005).

In the aerospace industry, as a space capsule becomes more automated, it can be argued that less time needs to be spent training astronauts how to fly the spacecraft, and more time is invested learning how crewmembers interact with each other and the equipment while accomplishing specific tasks inside the capsule. With current technology, for example, crews of four to seven people would spend eight months inside a small area while traveling through space. They would then be expected to spend up to 500 days on the surface of Mars (Zubrin, 1999). Special simulations must be conducted with these crew members to train mission-specific skill sets, improve human interaction, and help identify problems with equipment and life support before ever leaving Earth (Rai & Kaur, 2012a).

PROBLEM

Humans traveling to Mars will be in isolation with a small team for up to eight months. They will then experience the seven minutes of terror: the time it took the spacecraft Curiosity to land on Mars in 2012 (Khan, 2013), only to live and work on the Martian surface for months to years before making the return trip home. Mars's atmosphere is 1% that of Earth's and the gravity is 38% less than Earth's (Zubrin, 2011). It is a harsh, unforgiving planet. However, it has water in the form of ice on and under the surface; it has the chemical building blocks for producing oxygen, rocket fuel, and other life essential compounds (Zubrin, 2011). With the right technology, humans will overcome these challenges and walk, work, and live on Mars. Analog simulations give engineers and scientists the opportunity to not only test the hardware that will be sent to Mars, but also understand the psychological traits crew members will have to possess to participate in this mission successfully. As of now, Earth-based, Mars analog research missions are the only way to test the technology and group dynamics to allow humans to survive this epic journey.

This paper investigates research conducted at four different Mars analog research sites. Both human factor-focused research and testing of new technology has been conducted at these four analog sites. Despite the fact that each simulation varies in magnitude of isolation, level of fidelity, and overall realistic characteristics, these missions as a whole continue to add to the understanding of how to accomplish future human exploration Mars missions. The problem investigated by this paper is whether there is a better way of collecting and distributing the findings of this research.

PURPOSE

The ultimate goal of Mars exploration analog missions is to develop protocols in which humans will follow when they actually attempt to go to Mars (Mars Society, n.d.-b). With this in mind, Mars analog missions primarily focus on three things: human and team dynamics of a crew consisting of four to seven astronauts, testing newly developed technology to be used on the journey, and exploring how humans will interact with this newly developed technology when they are

140,000,000 miles away from home (Zubrin, 2011). The purpose of this investigation is to determine the best ways of meeting these three objectives and determining if the current Mars analog missions are meeting these objectives.

EXAMPLES OF MARS ANALOG RESEARCH

Several organizations have dedicated resources to establishing simulations for future space exploration missions. Each of these analogs have unique characteristics that allow them to study different aspects of a Martian mission. None of these analogs contain all the factors humans would face on Mars, but by combining the lessons learned from each station, a better understanding can be had of what it will take to keep astronauts alive in such a harsh, unforgiving environment.

The four outposts studied in this paper include the Mars Desert Research Station (MDRS) and Flashline Mars Arctic Research Station (FMARS), both operated by the Mars Society, as well as the Hawai'i Space Exploration Analog and Simulation (Hi-SEAS) and the National Aeronautics and Space Administration (NASA) Extreme Environment Mission Operations (NEEMO), both funded by NASA (n.d.). Each of these simulations provide a space for scientists and engineers to conduct research to prepare for the future exploration of Mars.

Mars Desert Research Station (MDRS)

Owned and operated by the Mars Society, MDRS is a prototype research center used by scientists to demonstrate humans' ability to live and work in a manner similar to astronauts living in a remote base on Mars (Rai & Kaur, 2012a). In a TechFragments article, Horton (2009) explained that the MDRS was the first of four planned analog stations in the Mars Society's Mars Analog Research Station (MARS) Program and is located in Hanksville, UT in the San Rafel Swell (see Figure 1). This location includes red-colored hills, soils, and sandstones due to the presence of iron oxides which are similar geology and qualities as the deserts of Mars (Chan, Komatsu, Ormö, Perry, & Beitler, 2004). According to the MDRS website (Mars Society, n.d.-c), the cylindrical habitat, first manned in 2001, has a diameter of eight meters and consists of two decks. Its design is made to represent a lander module as depicted in Figure 2. Downstairs one would find a geological, biological, and construction work space, two simulated airlocks, a toilet and shower, and an Extra Vehicular Activity (EVA) prep room. Upstairs there are six "staterooms" or crew quarters, an open kitchen, and a dining area that doubles as a work space (Rai & Kaur, 2012a). The hab also has a small observatory and for five field seasons it had green hab--a greenhouse structure for growing plants and conducting experiments. Unfortunately, the green hab was destroyed by a fire in the middle of the night on December 29, 2014 (Stoltz, 2015). The entire MDRS floor plan is found in Figure 3.

According to Rupert, the MDRS director, crews of six or seven members stay at the research station for two weeks, concluding with a one-night handover with the incoming crew (personal communication, November 29, 2014). Field seasons generally run from late winter to early spring, in order to avoid the harsh cold of winter and extreme hot conditions of summer for the safety of the volunteer crew members (Mars Society, n.d.-d). Crews consist of a crew commander, executive officer, health and safety officer, crew engineer, crew geologist, crew biologist, crew astronomer, crew journalist, crew scientist, and a green hab officer; each person can have multiple roles depending on the number of crewmembers (Mars Society, n.d.-a).

It is at the crew commander's discretion how long they remain in simulation during the two-week stay. However, once the crew doors are closed and the commander calls time of simulation, crew members must remain inside the hab and only go outside while wearing a simulation space suit. The crew must also rely only on the resources provided at the start of the simulation (S. Rupert, personal communication, November 29, 2014). Daily schedules are generally managed by the executive officer and include meal preparation, daily chores, EVAs, and experiments. Figure 4 displays several of these daily activities.

Research conducted at MDRS. There have been several human studies conducted at MDRS. For example, Sawyer, Hancock, Deaton, and Suedfeld (2012) investigated the psychological and human factors of finding the right team. They investigated a crew of six, English-speaking international members of various ethnicities. The study used several psychological assessments, Post Expeditionary Growth Scale, the Perceived Stress Questionnaire, and the Positive and Negative Affect Scale Extended or PANAS-X, all of which were administered at the beginning, mid-point and end of a two-week rotation (Sawyer et al., 2012, p. 5483). The results showed that the group grew closer as a result of the mission (Sawyer et al., 2012, p. 5483).

Rai and Kaur (2012b) discussed investigations into sleep disturbances of crew 100b in 2011. They hypothesized that mental and physical stress may affect taste during a two weeks MDRS rotation. Twelve crew members conducted sleep, work, and leisure activities followed by profile of mood state and saliva samples. The results of the experiments showed that mental and physical tasks resulted in a reduction of the duration of taste.

Geological experiments have also been conducted as a result of MDRS crew rotations. In 2009, the amino acid content of several soil samples, collected near the MDRS, was analyzed (Martins, Sephton, Foing, & Ehrenfreund, 2011). It was determined that the organic composition was strongly influenced by the mineral composition of the soil. The researchers realized that samples with high content of clay did not have detectable amino acids, which they determined to be considered for future life-detection missions to Mars (Martins et al., 2011).

Kereszturi (2011) conducted EVA research at MDRS by investigating time and distance restraints while conducting EVAs on foot and by vehicle. It was determined that the maximum amount of time for EVA was six hours, three for travel and three for work, before the crew members became overworked. He was able to characterize the types of formations that would require multiple EVAs and investigated the use of pressurized mobile transports to prolong explorers' EVA capabilities.

Human factors research published as a result of MDRS missions are generally conducted during two-week rotations with a sample size of six to seven depending on the size of the crew (Rai & Kaur, 2012a). Hard science experiments, such as geology, astrobiology, and chemistry experiments conducted at MDRS are conducted while in Martian simulation and the results are generally presented in a manner in which future scientists can learn from lessons learned found by the crew members. This research, therefore, fits the previously mentioned category of human and team dynamics of a crew consisting of four to seven astronauts, as well as making inferences about how science experiments could be duplicated in the future.

Flashline Mars Arctic Research Station (FMARS)

The FMARS is located in the high arctic on Devon's Island, Nunavut, Canada as seen in Figure 5 (Binsted et al., 2010). This Arctic station is also owned by the Mars Society and is structure two of the MARS program. The facility was established in 2000 and crew rotations last four months during the Arctic summer. The research focus for these missions include long duration analog studies and conducting human factors and mission operations research in a realistic, Mars environment (Binsted et al., 2010, p.1). Crew roles are the same as at MDRS and the crew commanders have the same responsibilities during the simulation (S. Rupert, personal communication, November 29, 2014).

The interior of FMARS is similar to MDRS with a few subtle differences. As seen in Figure 6, FMARS is also designed with the lander concept. This two-story building is 26.3 feet in circumference and is slightly taller than its MDRS counterpart. The FMARS does not have an observatory or a green hab. Like MDRS, the station is not pressurized, but instead utilizes two simulated airlocks during simulation. A floorplan of this hab is shown in Figure 7.

The FMARS location provides a realistic analog site for Mars simulation missions. Its remote location allows for the investigation into potentially hazardous conditions that Martian crews would be expected to encounter (Binsted et al., 2010, p. 1). Its location is an hour by plane from the nearest town, which forces crews to develop and train for the appropriate countermeasures for dangerous situations more so than MDRS (S. Rupert, personal communication, November 29, 2014). The Arctic research station also integrates a 20-minute time delay to all outside communications which simulates communication between Earth and Mars and further adds physiological intensity to the mission (Bishop, Kobrick, Battler, & Binsted, 2009, p. 2).

Research conducted at FMARS. Binsted et al. (2010) conducted several human factors research projects at FMARS in 2007. The first of these studies was to investigate "countermeasures to stress and isolation related to long duration work in extreme environments" (Binsted et al., 2010, p. 5). They interpreted the success of telecommunication support sessions and the use of personalized exercise programs as coping mechanisms for stress in isolated environments.

Bishop et al. (2010) also published their work on stress and coping from the same seven-person crew at FMARS in 2007. They used psychological questionnaires and the Cohen's perceived stress inventory (PSS) before, during, and after the four-month rotation to determine the crew's ability to cope with stress (Bishop et al., 2010, p. 4). The results of this study showed that crew members dealt with high stress, especially near the midpoint of the rotation, and overall stress was shown to notably decline for six of the seven crew members toward the end of the rotation.

Another study that Binsted et al. (2010) conducted was an assessment of the station environmental habitability. In other words, how did the design and layout of the habitat affect the crewmembers during the mission (p. 6)? These data were collected using a combination of both the monthly use of Planetary Habitat Analogue Design Efficiency Survey and the Spaceflight Cognitive Assessment Tool for Windows (Binsted et al., 2010, p. 6).

The first FMARS crew in 2007 conducted a sleep study during their 37 days in Martian Sol simulation (24.65 hr solar day-night cycle) (Gríofa, Blue, Cohen, and O'Keeffe, 2011, p. 1). Participants used sleep diaries and subjective sleep monitoring pre- and postsleep by using a questionnaire. Crew members reported changes in difficulty sleeping, sleep quality, and mood upon waking during the Sol simulation (Gríofa et al., 2011, p. 2).

Bamsey et al. (2009) conducted a four-month water consumption study where they determined that each person utilized 82.07 L/day over the expedition with a standard deviation of 22.58 L/day. This included water for hygiene, cooking, conducting scientific experiments, and cleaning. By using data acquisition hardware and flow meters, the crew was able to calculate the average consumption of each crew member for the duration of their simulation.

Pletser, Lognonne, Diament, and Dehant (2009) conducted a geophysics experiment investigating seismology methods to detect subsurface water on the surface of Mars (p. 457). Several lessons learned were recorded in the study to include operational skills and equipment ergonomics. The study reached its goal of demonstrating the feasibility of conducting seismic experiments in extreme conditions (p. 465).

Hawai'i Space Exploration Analog and Simulation (Hi-SEAS)

Instead of using the lander concept used by the MARS program, the Hi-SEAS habitat is a 1,000 square foot isometric dome, based on the idea of using inflatable technology to house astronauts on Mars (Miles, Caraccio, & Hintze, 2014, p. 2; see figure 8). The Mars analog habitat is located on the slopes of Mauna Loa volcano on the Island of Hawai'i as seen in Figure 9 (Miles, Caraccio, & Hintze, 2014). The simulation is the result of a $1.2 million NASA contract to run four consecutive Mars analog missions, four months, four months, eight months, and a full year-long mission (Engler, 2014). The study has been led by the University of Hawai'i at Manoa and is supported by several other universities and organizations (Engler, 2014, para. 2).

The Hi-SEAS project is a continuous, two-and-a-half year task that began in 2013 (Engler, 2014). The first mission ran from April through August 2013. Mission 2 lasted 120 days from March 2014 through July 2014. The most recent mission was Hi-SEAS 3 that began in October 2014 and completed June 2015. The last, year-long mission is still in the planning phase. The mission start date has not yet been released. The research collected during the first missions will be compared to the final studies being conducted later this year. This project is still ongoing, therefore peer-reviewed research is not yet available. However, the research is vitally important to the collective of Mars research and is worth being noted in this paper.

Research conducted at Hi-SEAS. The primary research focus of the Hi-SEAS missions is to test food that would provide the needed nutrients for astronaut survival while still adding a variety of choices for the crew members to avoid food boredom (Green, 2013). The two types of food preparation strategies investigated were prepared meals that only require adding water versus cooking with shelf-stable ingredients (Green, 2013). The results of this study have not yet been published because the research is still ongoing with the current Hi-SEAS crew. The research is promising and should add value to the already existent base knowledge of space exploration food studies.

NASA Extreme Environment Mission Operations (NEEMO)

According to Bell, Baskin, and Todd (2011), NEEMO missions have been conducted at the National Oceanic and Atmospheric Administration (NOAA) Aquarius Underwater Laboratory located 5.6 km from Key Largo, Florida as seen in Figure 10. Currently, this facility is operated by the Florida International University for the NOAA (Chappel, Abercromby, &

Gernhardt, 2013). This laboratory is located 62 feet below sea level in the Conch Reef (Bell et al,, 2011, p. 1). Crews consist of six NASA-trained astronauts called "aquanauts" and the mission duration varies from seven to ten days. Aquanauts conduct research during EVAs and other scientific missions inside and outside the habitat (Bell et al., 2011, p. 1). Fifteen NEEMO missions have been conducted by NASA since 2001 (Bell et al., 2011).

According to Thirsk, Williams, and Ancari (2006), the Aquarius is 13 meters long and has a diameter of 3 meters (p. 2). The research vessel has two sections which include the entry lock and the main lock. The entry lock has experimental bench space, a restroom, and houses the life support systems. The main lock is the living quarters with a kitchen and bunk room (Thirsk et al., 2006, p. 2). The Aquarius floor plan is seen in Figure 11.

The NEEMO site is the only analog simulation that is completely pressurized. It utilizes a wet porch that remains open to the ocean and water is kept out of the habitat by equivalent air pressure. The Aquarius is also unique because it is an ambient pressure habitat. This means that the atmospheric pressure inside the habitat is equal to the water pressure outside. This allows aquanauts to stay indefinitely without the risk of decompression sickness until a 17-hour decompression before they return to the surface. This underwater world allows aquanauts to train in a Mars-like environment in which the hostility of what is outside is an actual continuous threat. During NEEMO missions, its inhabitants must continuously monitor life support systems inside the habitat and outside during EVAs, as well as monitor their food, water, and essential supply consumptions. Many of the dangerous realities of human exploration are present during NEEMO missions (Thirsk et al., 2007).

<u>Research conducted at NEEMO</u>. Kanas et al. (2010) conducted research from data gathered from two NEEMO missions, 12 and 13. The purpose of this research was to interpret

the effects of the autonomy of the crews, meaning they investigated the differences between missions that rely heavily on communication with a mission control versus a more independent mission where crew members must rely on each other to solve problems as they arrive. The latter is more of what would be expected on Mars considering the 40-minute delay in communication (Kanas et al., 2010, p. 733). The results from this portion of their autonomy study showed that crew members favored the periods of autonomy because they were able to work together better with guidance from the commander and also demonstrated a decrease in fatigue (Kanas et al., 2010, p. 733). The paper also concluded that higher autonomy allows crews to be more creative and more likely to become closer together in their work environment (Kanas et al., 2010, p. 734).

Besides human factor research, NEEMO missions are designed to be used as a test bed to validate concepts, technologies, and procedures in adverse environments (Thirsk et al., 2007, p, 513). The NEEMO's s7th mission was focused on tests of surgical telementoring and telerobotic surgery technologies as a means of giving astronauts immediate care from remote locations (p. 513). The result of the investigation was that all six crew members were able to complete the five telerobotic surgery techniques with little to no surgical experience with the help of telementoring assistance (p. 516).

CONCLUSION

Mars simulations have been used to study human factors, test new technologies, and investigate human interactions with these technologies at analog sites all over the world. Some sites are more remote than others and simulate different aspects of the Martian environment. Through this investigation, it is clear there are many important factors that are not present in these simulations. Sawyer et al. (2012) concluded in their paper that, "the present testing environment has severe restrictions of transfer validity of information accumulated" (p. 5482).

These simulation environments range from a few weeks to months, which is a very small fraction of how long a real trip to Mars would take. The simulations lack many of the dangers of space exploration such as gravity, radiation effects, and total isolation, and the simulation can always be stopped if crewmembers become injured or do not wish to continue participation (Sawyer et al., 2012, p. 5482).

Although these simulations do not meet all of the criteria for a future Martian exploration mission, they are still useful to space organizations to help develop the selection criteria, protocols, and infrastructure that will one day be used to send people to Mars. These simulations are just the beginning and barely scratch the surface of the knowledge that is needed to successfully get men and women on Mars.

RECOMMENDATIONS

Developing Protocols

With further investigation, it is clear that although each of these analog sites have the overall goal of adding to the body of knowledge for future Martian exploration, each mission is contributing in a different way. The MDRS conducts hundreds of individual experiments during each field season. Most of these experiments focus on conducting field tests under simulation conditions and the end result is that MDRS crews have helped to develop the protocols and standards that future astronauts will follow while working and living on Mars.

Once the protocols are developed, there becomes a need to further validate the effectiveness of these standards under more realistic, isolated conditions with different crews. Because FMARS and Hi-SEAS missions are both conducted over longer periods, crews are capable of conducting repeated measures and longitudinal studies using the same sample. The results of these studies are statistically stronger when the same sample is tested before, during, and after a significant event and the results of these studies can be applied to future Mars missions.

Many of the studies previously conducted concluded that the results of their observations or experiments were, "more suggestive than definitive. . .because] they lack sufficient power to provide normal standards of evidence for significance testing" (Sawyer et al., 2012, p. 5484). Besides conducting these measures over a longer period of time with the same crews, it is recommended that the studies be replicated by each new crew throughout the entire field season. The MDRS, FMARS, and even NEEMO should be conducting similar experiments in the same way that Hi-SEAS is conducting their food study. These organizations should be mandating that each new crew has to conduct simple human factors experiments in the form of surveys or assessments in order to increase the sample size of these experiments, ultimately validating the data that have already been collected.

Technology Advancement

As technology continues to improve, so will the hardware that astronauts will use on Mars. Analog Mars environments are used today as a test bed for technology that may one day be used on Mars. This will continue to be the case until an organization is tasked with developing the infrastructure for an actual Mars mission. When that day comes, analog simulations will be used to test the life support systems, space suits, and communication systems that will be used during this mission. Field tests will be conducted with astronauts to ensure the functionality of the equipment and determine to ease of use for the astronauts who will be relying on these technologies to keep them alive.

Mars is a harsh, unforgiving place. The mission of exploring it comes with unanswered questions about the crew dynamics and human interactions, as well as demands for new technologies that will keep astronauts attempting this journey safe. Earth-based Mars analog missions are the best way to test both of these key links under one roof. There is still a lot to be learned from low fidelity analog simulations. They continue to produce tangible results to important questions about how to keep humans alive on Mars. As simulations become more realistic and new technology becomes available to cheaply simulate real living conditions on Mars, these simulations will transition from being used for researching protocols and lessons learned into actual training platforms for the future Martian explorer.

REFERENCES

Alexander, A. (2015). About Aquarius. Retrieved from www.uncw.edu/aquarius/about/about

Bamsey, M., Berinstain, A., Auclair, S., Battler, M., Binsted, K., Bywaters, . . . McKay, C. (2009). Four-month moon and Mars crew water utilization study conducted at the Flashline Mars Arctic Research Station, Devon Island, Nunavut. *Advances in Space Research, 43*, 1256-1274. doi:10.1016/j.asr.2009.01.009

Bell, M. S., Baskin, P. J., & Todd, W. L. (2011, March). NEEMO - NASA's extreme environment mission operations: On to a NEO. Paper presented at the 42nd Lunar and Planetary Science Conference, The Woodlands, TX.

Binsted, K., Kobrick, R. L., Griofa, M. Ó., Bishop, S., & Lapierre, J. (2010). Human factors research as part of a Mars exploration analogue mission on Devon Island. *Planetary and Space Science, 58*, 994-1006. doi:10.1016/j.pss.2010.03.001

Bishop, S. L., Kobrick, R., Battler, M., & Binsted, K. (2010). FMARS 2007: Stress and coping in an arctic Mars simulation. *Acta Astronautica, 66*, 1353-1367. doi:10.1016/j.actaastro .2009.11.008

Caraccio, A. J., Hintze, P. E., & Miles, J. D. (2014). *Human factor investigation of waste processing system during the Hi-SEAS 4-month Mars analog mission in support of NASA's logistic reduction and repurposing project: Trash to gas.* Paper presented at the 65th International Astronautical Congress, Toronto, Canada.

Chan, M. A., Komatsu, G., Ormö, J., Parry, W. T., & Beitler, B. (2004). A possible terrestrial analogue for haematite concretions on Mars. *Nature, 429*(6993), 731-734. doi:10.1038 /nature02600

Engler, S. (2014). *HISEAS research overview*. Retrieved from http://hi-seas.org/?p=1644

Green, K. (2013). Hi-SEAS Food Study [Video]. Retrieved from http://hi-seas.org/?p=803

Gríofa, M. O., Blue, R. S., Cohen, K. D., & O'Keeffe, D. T. (2011). Sleep stability and cognitive function in an arctic Martian analogue. *Aviation, Space, and Environmental Medicine, 82*, 434-441. doi:10.3357/ASEM.2570.2011

Horton, M. (2009, January 8). Mars desert research station simulates Mars like base. *TechFragments*. Retrieved from http://www.techfragments.com/218/mars-desert-research-station-simulates-mars-like-base/

Kanas, N., Saylor, S., Harris, M., Neylan, T., Boyd, J., Weiss, D. S., & Marmar, C. (2010). High versus low crewmember autonomy in space simulation environments. *Acta Astronautica, 67*, 731-738. doi:10.1016/j.actaastro.2010.05.009

Khan, A. (2013, August 4). A year after Curiosity's landing, reliving 'Seven Minutes of Terror.' The LA Times. Retrieved from http://www.latimes.com/science/sciencenow/la-sci-sn-curiosity-anniversary-year-mars-landing-seven-7-minutes-terror-20130804-story.html

Kereszturi, A. (2011). Geologic field work on Mars: Distance and time issues during surface exploration. *Acta Astronautica, 68*, 1686-1701. doi:10.1016/j.actaastro.2010.11.008

Lee, A. T. (2005). *Flight simulation: Virtual environments in aviation*. Burlington, VT: Ashgate.

Mars Society. (n.d.-a). *Crew roles.* Retrieved from http://mdrs.marssociety.org/crew-roles

Mars Society. (n.d.-b). Goals of MDRS. Retrieved from http://mdrs.marssociety.org/home /goals-of-mdrs

Mars Society. (n.d.-c). *Mars desert research station*. Retrieved from http://mdrs.marssociety.org /home

Mars Society. (n.d.-d). *Previous field seasons.* Retrieved from https://sites.google.com/a /marssociety.org/mdrs2012/home/previous-field-seasons

Martins, Z., Sephton, M. A., Foing, B. H., & Ehrenfreund, P. (2011). Extraction of amino acids from soils close to the Mars desert research station (MDRS), Utah. *International Journal of Astrobiology, 10*, 231-238. doi:10.1017/S1473550410000431

National Aeronautics and Space Administration. (n.d.). *Journey to Mars.* Retrieved from http://www.nasa.gov/topics/journeytomars/index.html

Pletser, V., Lognonne, P., Diament, M., & Dehant, V. (2009). Subsurface water detection on Mars by astronauts using a seismic refraction method: Tests during a manned Mars mission simulation. *Acta Astronautica, 64*, 457-466. doi:10.1016/j.actaastro.2008.07.005

Rai, B., & Kaur, J. (2012a). Human factor studies on a Mars analogue during crew 100b international lunar exploration working group EuroMoonMars crew: Proposed new approaches for future human space and interplanetary missions. *North American Journal of Medical Sciences, 4*, 548-557.

Rai, B., & Kaur, J. (2012b). Mental and physical workload, salivary stress biomarkers and taste perception: Mars desert research station expedition. *North American Journal of Medical Sciences, 4*, 577-581.

Sawyer, B. D., Hancock, P. A., Deaton, J., & Suedfeld, P. (2012). Finding the team for mars: A psychological and human factors analysis of a Mars desert research station crew. *Work, 41 Suppl 1,* 5481-5484.

Thirsk, R., Williams, D., & Anvari, M. (2007). NEEMO 7 undersea mission. *Acta Astronautica, 60*, 512-517. doi:10.1016/j.actaastro.2006.09.015

Moroney, W. F., & Lilienthal, M. G. (2009). Human factors in simulation and training. In D. A. Vincenzi, J. A. Wise, M. Mouloua, & P. A. Hancock (Eds.), *Human factors in simulation and training* (pp. 3-38). Boca Raton, FL: CRC Press.

Zubrin, R. (1999). *Entering space creating a spacefaring civilization*. New York, NY: Penguin Putnam.

Zubrin, R. (with Wagner, R). (2011). *The case for Mars: The plan to settle the red planet and why we must* (Rev. and updated.). New York, NY: Free Press.

Appendix

Figure 1. Map of Utah. MDRS is located near the west border of Utah in the San Rafel Swell near Hanksville, Utah. Retrieved from Google Images.

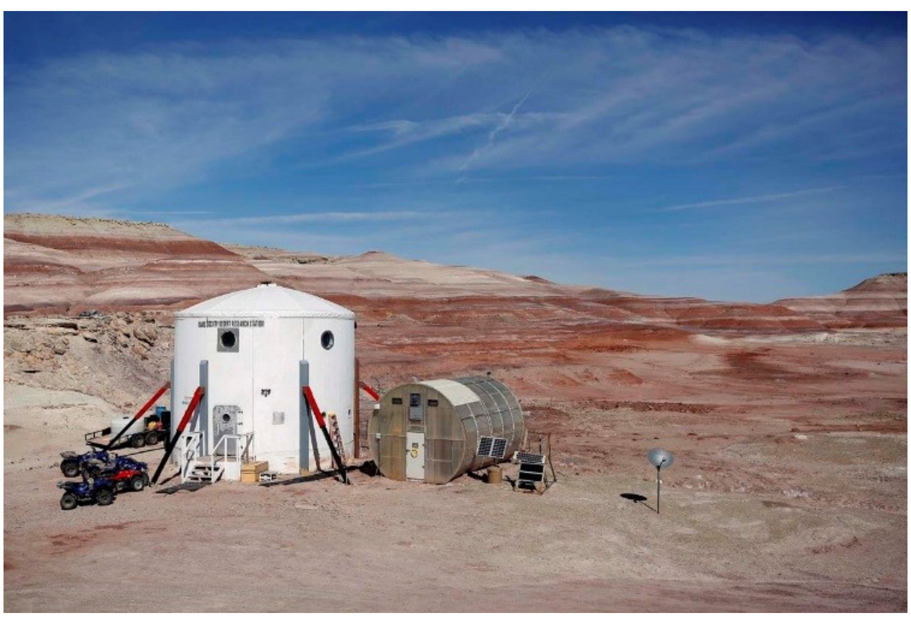

Figure 2. Exterior view of MDRS. Also seen is the green hab and Mars surface exploration vehicles. Photo taken by crew member of Mission 99. M. Fagin, 2011.

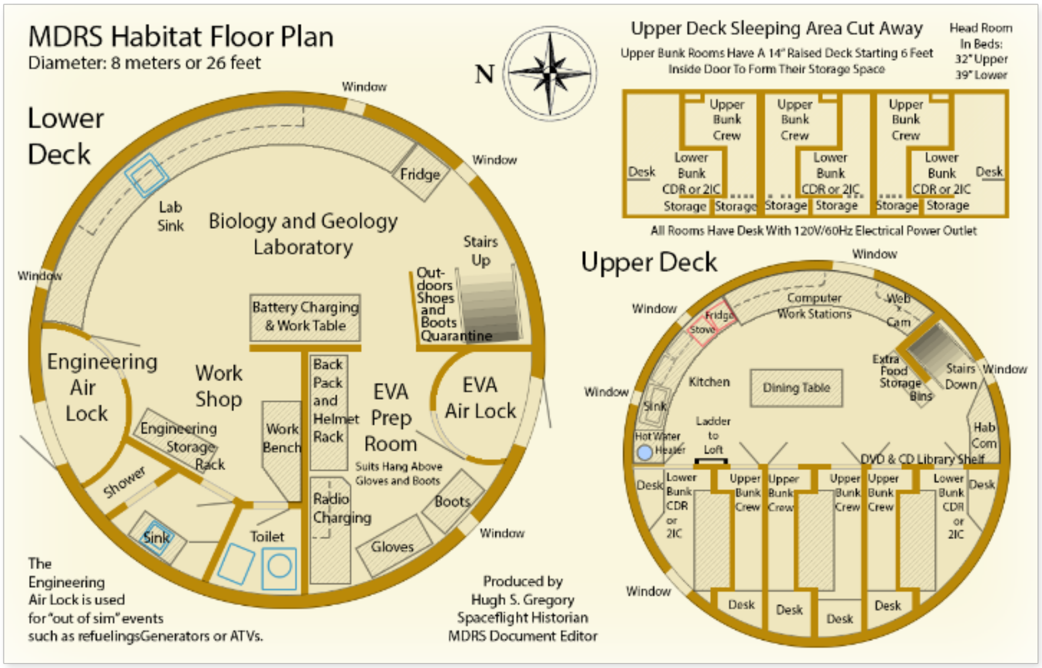

Figure 3. MDRS floor plan adapted from the Mars Society website. H. Gregory (2005). Retrieved from http://mdrs.marssociety.org/home/mars-hab-layout

Figure 4. Day to day life of a MDRS crewmember. Crew 144 lives and works at the MDRS, November 2014. Y. Murakami, 2014.

Figure 5. Location of Flashline Mars Arctic Research Station. Retrieved from Google Images.

Figure 6. Flashline Mars Arctic Research Station. The hab is designed as a lander. M. Stoltz (n.d.). Retrieved from http://fmars.marssociety.org/

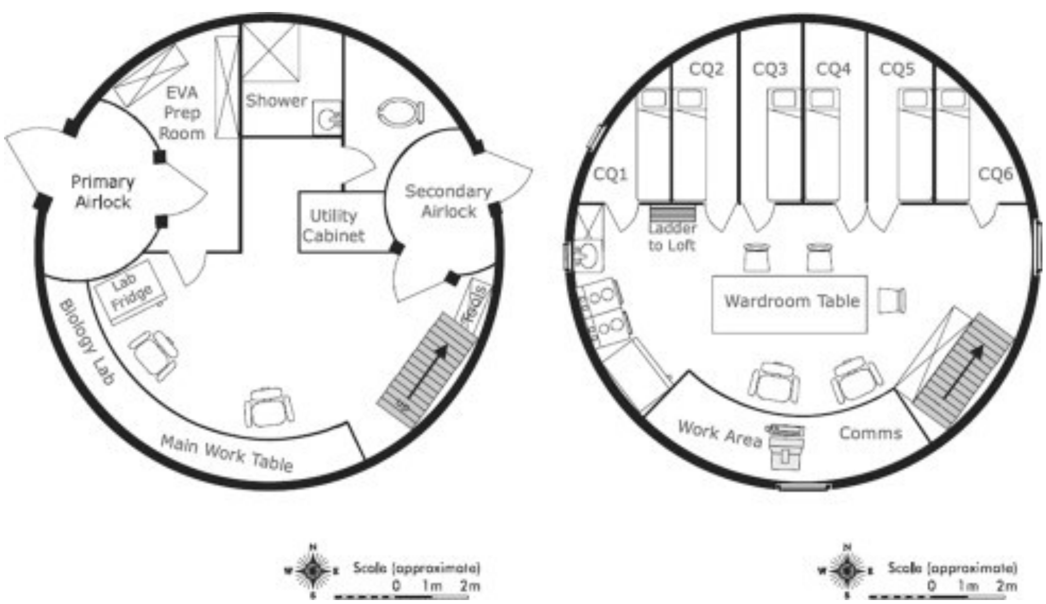

Figure 7. Flashline Mars Arctic Research Station floor plan. Binsted et al., 2010.

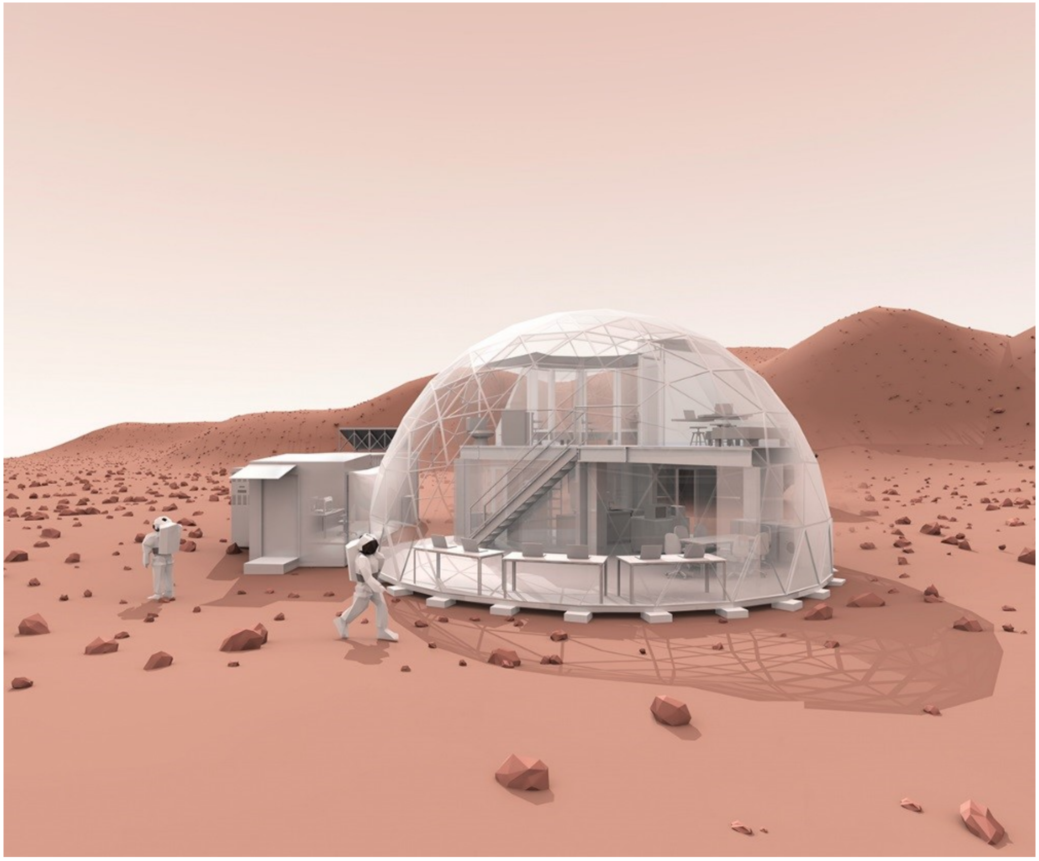

Figure 8. Hi-SEAS isometric dome. This inflatable dome houses six crew members for varying duration Mars analog missions. Retrieved from Google Images.

Figure 9. Location of Hi-SEAS. Retrieved from Google Images.

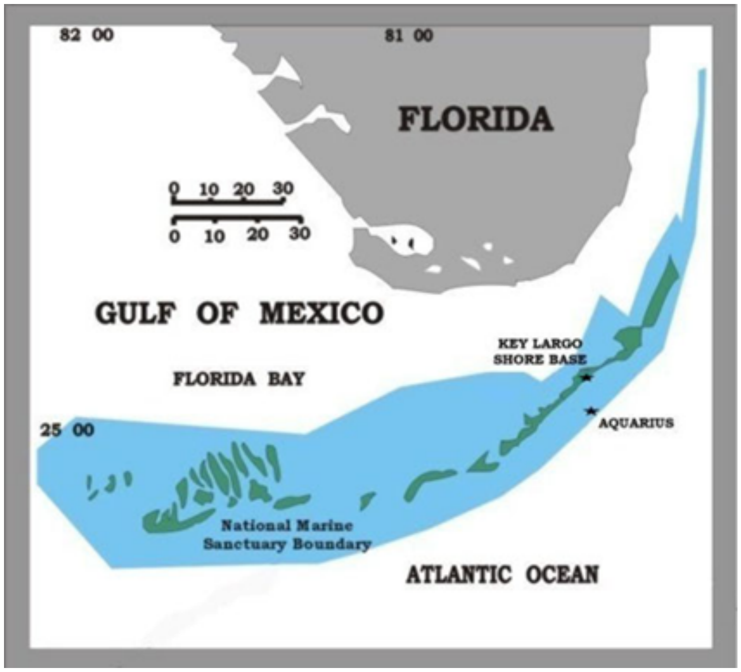

Figure 10. Location of the Aquarius Underwater Laboratory. NEEMO missions are conducted at the Aquarius Underwater Laboratory off the southern coast of Florida. Retrieved from http://ecoforecast .coral.noaa.gov/

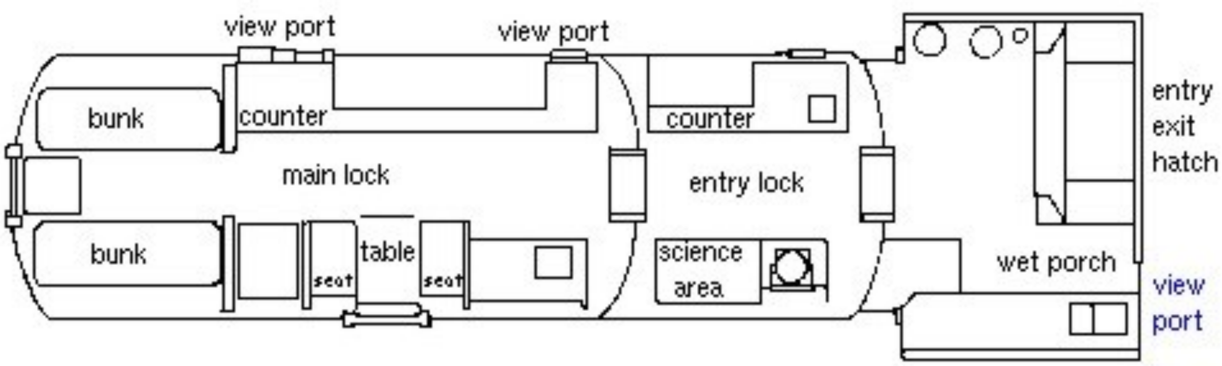

Figure 11. Floor plan of the Aquarius Underwater Laboratory by A. Alexander (2015). Retrieved from http://www.uncw.edu/aquarius/about/about.htm