January 2014

Human Performance Profiles For Planetary Analog Extra-Vehicular Activities: 120 Day And 30 Day Analog Missions

Tiffany M. Swarmer

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HUMAN PERFORMANCE PROFILES FOR PLANETARY ANALOG EXTRA-VEHICULAR ACTIVITIES: 120 DAY AND 30 DAY ANALOG MISSIONS

By

Ms. Tiffany M. Swarmer
Bachelor of Science, Sonoma State University, 2010

A Thesis
Submitted to the Graduate Faculty
of the
University of North Dakota
in partial fulfillment of the requirements

for the degree of
Master of Science

Grand Forks, North Dakota
December
2014
This thesis, submitted by Tiffany M. Swarmer in partial fulfillment of the requirements for the Degree of Master of Science in Space Studies from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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Dean of the School of Graduate Studies

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Department: Space Studies

Degree: Master of Science

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Tiffany M. Swarmer
10/18/2014
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ACKNOWLEDGMENTS

Many thanks are needed for this study as support has come from numerous directions. My advisors have provided guidance and reflection throughout many stages of this project. My thanks goes out to the University of North Dakota’s (UND) Human Spaceflight Laboratory that allowed me to conduct my research with their Lunar/Mars Analog Habitat (LMAH). I would like to thank the Hawaii Space Exploration Analog and Simulation group for allowing me to conduct my research with their facility. A very big thanks goes out to both the HI-SEAS crew members and LMAH crew members for actively participating in this study. Lastly, one must point out that a project of this magnitude is virtually impossible without support and there are many here who have not been listed, thank you to all for supporting me during my research.
ABSTRACT

Understanding performance factors for future planetary missions is critical for ensuring safe and successful planetary extra-vehicular activities (EVAs). The goal of this study was to gain operational knowledge of analog EVAs and develop biometric profiles for specific EVA types. Data was collected for a 120 and 30 day analog planetary exploration simulation focusing on EVA type, pre and post EVA conditions, and performance ratings. From this five main types of EVAs were performed: maintenance, science, survey/exploratory, public relations, and emergency. Each EVA type has unique characteristics and performance ratings showing specific factors in chronological components, environmental conditions, and EVA systems that have an impact on performance. Pre and post biometrics were collected to heart rate, blood pressure, and SpO2. Additional data about issues and specific EVA difficulties provide some EVA trends illustrating how tasks and suit comfort can negatively affect performance ratings. Performance decreases were noted for 1st quarter and 3rd quarter EVAs, survey/exploratory type EVAs, and EVAs requiring increased fine and gross motor function. Stress during the simulation is typically higher before the EVA and decreases once the crew has returned to the habitat. Stress also decreases as the simulation nears the end with the 3rd and 4th quarters showing a decrease in stress levels. Operational components and studies have numerous variable and components that effect overall performance, by increasing the knowledge available we may be able to better prepare future crews for the extreme environments and exploration of another planet.
Astronauts put themselves into extreme high risk environments and undergo a variety of physiological and psychological changes. Up to this point manned space exploration is limited to the Earth’s orbit, but future plans focus on extending this exploration out of low Earth orbit (LEO) and eventually onto other planetary bodies. Advances in propulsion, life support, and vehicle design are providing technological means to extend human exploration times and distances. In order to decrease the risk of mission failure researchers and operational support will need to understand how the crew will respond within an isolated, confined, and extreme environment. Current studies in this area rely heavily on analogs and LEO research for data, but these often lack the expected level of risk associated with future space missions exiting Earth’s orbit (Connors, 1985).

During interplanetary operations crews will have limited access to supplies, communication, privacy, and social support. Being in this type of restrictive environment causes significant stress and can lead to greater crew cohesion or cause severe debilitating social reactions that may endanger the mission (Binsted et. al., 2010). Difficult conditions during long duration spaceflight increases emphasis on crew selection, human factors, and procedural development. Spaceflight missions are shorter in duration deemphasizing the needs for strict crew selection and human factors procedures. Current missions on the ISS last about four to six months, and a yearlong mission is currently scheduled to occur in the near future, but even with the increasing time in
LEO many questions remain concerning longer missions and interplanetary travel. Mars has long since been a fascination for explorers and remains high on the list for near future exploration.

**Martian Environment**

Mars is approximately one half the size of Earth, with an orbital time period of 687 days, and approximately a 24 hour and 40 minute day (Eckhart, 1996). The planetary environment of Mars is has increased radiation, an atmosphere comprised of mostly CO2, thermal ranges colder than Earth, dry climate, and severe periodic dust storms. This environment is hostile to human life and, like the space environment, requires humans to provide their own means for life support. Some of the Martian environmental characteristics provide benefits for manned exploration while characteristics, such a low atmospheric pressure, require complex and heavy technologies to mitigate.

**Gravity:**

The Martian gravity is approximately one third of Earth’s and astronauts reaching Mars are predicted to need up to two weeks to re-adapt to one third gravity (NASA, 2009) due to the time spent in microgravity while traveling to Mars. The precise effect of one third gravity on humans over a long duration is unknown and demonstrates a large gap in gravitational physiology knowledge. Many studies have been conducted in one g environments and zero-g environments, but the human reaction to gravities between one and zero is limited only to the short stays on the Lunar surface during the Apollo missions. A direct linear relationship is thought to exist between one and zero-g, implying that astronauts will have one-third of their gravitational physiology functioning while on the surface. The decreased gravity may be able to assist astronauts while on the planet and will enable them to move and use increased loads while working. The long
exposure to decreased gravitational conditions may have little to no deteriorative effect, but additional studies will be needed to confirm how 1/3 g acts on physiology.

**Radiation:**

The thinner Martian atmosphere allows for increased ionizing and non-ionizing radiation to reach the surface. However, due to the distance from the sun the amount of solar electromagnetic radiation that reaches the surface is 0.43 relative to that of Earth (Eckart, 1996). The ionizing radiation that reaches the surface comes from two sources: galactic cosmic rays (GCR) and the solar particle events. These sources are more influential on the Martian surface due to the lack of a planetary geomagnetic field, relying only on the thinner atmosphere to provide protection from ionizing radiation.

Protection from GCR is important, in particular protection from secondary particles which are created through interaction with shielding material, surface materials, and the atmosphere. The strength of radiation reaching the surface is highly dependent on many variables such as surface pressure, atmospheric temperature, water column density, season, and local time (Keating and Goncalves, 2012). Surface operations are partially protected from half of the GCR by the planet itself, but the doses reaching the surface may prove to be problematic and need further definition for a better understanding of the possible effects on performance and human health.

**Temperature and Atmosphere:**

Mars’ temperatures vary from 130K to 300K, with an average value of 215K and tend to be region specific (Eckhart, 1996). The soil can absorb solar energy throughout the day and may reach temperatures around 280K depending on the region and outside temperatures. Due to these lower temperatures and the overall decreased atmospheric pressure liquid water has not been
noted on the surface of Mars. These temperatures are too cold for human life to survive long and require crews to be thermally protected against the outside thermal variations.

The atmosphere on Mars is made up of mostly carbon dioxide and nitrogen with traces of argon, oxygen, carbon monoxide, and water vapor. The pressure is much lower than on Earth at 7 mb and requires crews to have a contained pressure vessel similar to a spacecraft. This pressure can vary with seasonal up to 25 percent as a result of condensation at the polar caps. The dryness and wind gusts found on Mars promote the introduction of dust particles into the atmosphere. Thermal variation and atmospheric heating increases the lifting of dust particles into the air causing regional and global dust storms. Major dust storms are believed to occur once every three to four years and do not appear to be predictable (Cantor et. al. 2001).

**Geomorphology:**

Mars is currently a hyper-arid cold desert with geomorphological evidence for possible hydrological activity. The surface composition varies between regions, but is made up of two unique hemispheres. The southern hemisphere is made up of highlands with large impact craters and the northern hemisphere is made up of lowlands thought to be the result of a large body of water early on in Mars’ history. Many geomorphological features and mineralogical evidence indicates episodic availability to liquid water on the Martian surface (Jaumann et. al., 2014). Liquid water would play a significant role in the geological cycle of the Martian planet and may indicate previously habitable conditions.

The Phoenix lander in 2008 was able to detect approximately 0.6% by weight of perchlorate salt in the soil. This has caused some debate as to the possibility for formation via water or through calcium and magnesium interactions with atmospheric HClO4 (Kounaves et. al., 2014 and Cull
et. al., 2014). Perchlorates are commonly found on Earth, but the levels on Mars may be concerning for a human crew and could be a potential source for health issues.

*Magnetism*

Mars magnetic dipole moment is thought to be around $10^{22}$ G/cm$^3$ (Eckart, 1994), although the most direct information about the Martian magnetism is from a class of Martian meteorites called SNCs. These indicate that at one time, approximately 180 million years ago, Mars had a weak dynamo similar to Earths approximately $1/10^{th}$ the Earth’s dipole moment (Schubert and Spohn, 1990). Magnetic fields can affect circadian rhythms and melatonin levels; however the lack of major magnetism on Mars would be expected to have little to no effect on sleep patterns.

*The Martian Day:*

The Martian day is close to Earth’s at 24 hours and 40 minutes, this will help explorers to maintain a familiar circadian rhythm and day night cycle similar to the cycles seen on Earth.

*Earth-Mars Communication*

At the farthest point away, $10.1 \times 10^7$ km, any crew on the Martian surface would need to be almost autonomous due to a 20 minute communication delay. This delay means that any communication to mission support would take 40 minutes to send and then receive a response. This type of delay increases the isolation of any manned mission and will require crews to increase their self-reliance in day-to-day operations and emergency scenarios.

Crews on the Martian surface will be some of the first to face autonomy and separation from a ground support team. This autonomous state is quite different than previous exploration missions
and increases the isolation factors for the crew. For example the Apollo missions were heavily monitored by mission control and followed strict timelines and planning during their lunar EVAs. Mission control was only delayed by 1.3 seconds when talking with Lunar crews and this allowed for real time reactions to the crew’s needs. The communication delay with a Mar’s crew will be quite different and will range based on how Earth and Mars a situated, but the longest communication delay is 20 minutes. Making real time instruction impossible in communication with earth based mission control.

Mars mission durations are defined as either opposition-class (short stay 30-90 days) or conjunction-class (long stays 500 days or more) and even with the shortest planetary stay of 30 days crews will have more flexibility and control over their schedules than the shorter lunar missions (NASA, 2009). Any changes to schedules or unforeseen events will be reported to mission control, but with the delayed communications crews will need to be able react to any urgent situation without ground support’s direction. The need for flexibility often requires support teams and crews to plan out multiple scenarios and allow room for unexpected adjustments (Bell et. al., 2011). With this in mind creating goals and tasks for crews to complete within various flexible timelines may increase performance and decrease stress through a combination of ground support and crew autonomy has shown that crews can complete tasks safely and successfully (Kanas et. al. 2011).

*Mars Mission Design Architecture 5.0*

The most recent plans for a Mars mission developed by NASA in 2009 and laid out in the Mars Mission Design Architecture 5.0 focus on a Mars mission that utilizes technology from 2025 and occurs around 2030. Two potential timelines are outlined and each is defined by the amount of
time spent on surface operations. These are a vital component to any manned mission; the opposition class mission has 30-90 day surface time and the conjunction class mission has a 500 day surface time (See Table 1 for mission times). Long interplanetary travel followed by confinement within isolated and hazardous environments makes it difficult to use previous spaceflight and lunar activities to predict human performance while on the Martian surface.

<table>
<thead>
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<th>Mission Type</th>
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<tr>
<td>Opposition Class</td>
<td>430-560 Days</td>
<td>30-90 Days</td>
<td>500-650 Days</td>
</tr>
<tr>
<td>Conjunction Class</td>
<td>360-420 Days</td>
<td>500 Days</td>
<td>900 Days</td>
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Table 1: Mission times for a manned Mars mission according to the NASA’s Human Exploration of Mars Design Reference Architecture 5.0.

Specific expectations for scientific investigations include the ability for crew members to traverse great distances from the landing site, increased surface mobility, and subsurface access. The types of activities that will dictate surface operations are broad ranging from geological focus to astrophysics (Table 2). The current expectations for acclimatization to the Martian surface and the 1/3 gravity is around two weeks and depends heavily on the 0-g mitigations available during transit to and from Mars. With recent research into torpor states and the potential for use during Mars transit (Schaffuer, 2014) adds additional concerns about a crew’s condition upon arrival and how these will affect performance. Additional factors with the potential to affect EVA performance are the surface habitation module, medical facilities, planetary suit design, hatch design, safety concerns, EVA scheduling, sleep schedules, and
workload (NASA, 2007). Previous Apollo astronauts have all expressed concern over the schedule of EVAs and workload for any future planetary/lunar exploration.

**Table 2: Types of Activities that will Dictate Surface Operations**

- Understand the Martian Geological Systems
- Search for past/present life on Mars
- Understand Early Mar’s biogeochemical cycles and chemistry
- Understand Mar’s Climate history/weather systems
- Ancillary Sciences (heliophysics, astrophysics, etc.)

The DRA 5.0 mentions surface operations will always be done by a minimum of 2 crew members and a maximum of 4 to ensure safety and decrease workloads. Robotic partnerships with pressurized/unpressurized rovers and scouting robotics are expected to develop in the EVA procedures and may decrease workload and provide extended consumables to decrease suit weight and lengthen EVA times. Transitions between inside habitable volume and suits are a concern and have a direct effect on activities and performance. If the transitions are difficult crew will need to stop EVAs earlier than simplistic systems to ensure enough energy to safely doff the suit.
CHAPTER II

APOLLO EVAS

Currently the only planetary EVA experience occurred during the six Apollo missions to reach the lunar surface (NASA, 1975); accumulating 81 hours Lunar Extra Vehicular Activity (LEVA) time with just under 300 hours on the lunar surface. Apollo crews spent almost 20% of their total EVA time in the lunar rover moving between sites, about 16 hours. This data could be extended for future Martian operations with expectations of longer stays and exploration of terrain further from the habitat. The Lunar system used during the Apollo era would need several modifications before being adapted for use on Mars: 1) Adapted for 1/3 gravity, 2) Function in atmosphere instead of vacuum, 3) Minimize external contamination into the living space.

During a face-to-face summit meeting with Apollo astronauts in June of 2006 the astronauts provided feedback on the operations and lunar systems. The suits used during lunar operations proved to be one of the main sources for decreases in performance. The crew cited the gloves as particular problem with a lack of “flexibility, dexterity, and fit.” The repetitive gripping tasks caused some minor hand trauma and muscle fatigue, it was noted that during training the muscle fatigue occurred, but no hand trauma was noted. Suit mass for EVA performance was both a hindrance and benefit. The astronauts cautioned that suit mass was in some respects a benefit to operations in decreased gravity, but overall a decrease in suit mass by a factor of 2 would aid in operations while keeping enough mass to assist with the decrease in gravity.
The difficulty with general mobility of the Apollo suits lead to decreases in performance and increased energy expenditure. The suits lacked hip mobility and limited knee mobility for easy sampling and equipment use. The astronauts had to awkwardly bend at the knee and dip down to reach the ground. The neck joint lock the view forward and required the astronauts to move their entire body to look to the side. The center of gravity within the lunar suits was not noted as an issue which lies aft and slightly high. Helmet fogging was noted for future explorers with potentially catastrophic consequences. Donning and doffing the suits was difficult and after the initial EVA dust contamination of the single zipper mechanism occasionally made it difficult to close the suit. No major issues occurred during the Apollo Lunar missions, but repeated exposure to the lunar environment could produce difficulties over time. The ability to enter or exit the Lunar Module was difficult and caused an increase in energy expenditure due to the suits bulk and the small hatch size.

Apollo crews were highly concerned with the workloads that future lunar explorers may experience and stated that a two day on with a third day for maintenance would decrease the risk for overwork. This is in part due to the difficulty crews had sleeping in the lunar module cause decrements in performance believed to be based on disrupted circadian rhythms, increased noise within the Lunar Module, and psychological state (i.e. excitement over current circumstances).

During initial operation crews would feel a little “wobbly” in the 1/6th gravity; astronaut coordination increased throughout the first few operational hours on the lunar surface. This “wobbly” state was attributed to the different gravity and less of a vestibular system issue (NASA, 2007). Development of constraints for Lunar EVA (LEVA) operations such as limiting mobility on slopes greater than 20 degrees and making the mission focus project-oriented instead of a timeline focus would aid in EVA safety and increase the potential for higher levels of
performance. Additional concerns were raised about safety risks and identification methods for potential safety concerns. For example crews struggled to grip the lunar lander’s ladder with the suit gloves a consideration that could prove a safety risk (NASA, 1975). Perception and visual acuity on the lunar surface was altered during operations, however it is unclear if this due to environment alterations, physiological changes, or equipment. Concerns for maintaining spatial orientation could be mitigated through use of a lunar positioning device to ensure the crew can easily locate the lunar module.

Increasing system simplicity and reliability is preferred by Apollo astronauts over increase function. The ability to fix and maintain the suits and systems is an important component for planetary operations and will have increasing importance as crews become more autonomous.

Training was discussed as a vital component for lunar EVA success. The training provided to the Apollo crews was found adequate to prepare them for lunar surface operations. Training focused on parabolic flights, underwater simulations, and operational training in various lunar analog environments. Later in this document the author will discuss some of the differences between training and real application, although the differences during the short lunar operations were not found to have any effects on the performance.

An interesting consideration was mentioned by previous Apollo crew members that not just physical rest should be provided, but also time set aside for mental relaxation and down time (NASA, 2007). Indicating an understanding by the Apollo astronauts of the complex dynamics behind high stress situations and maintaining high performance capabilities. The Apollo astronauts strong wish to safe guard down time and relaxation for longer missions has gone a
long way in changing LEO operations and long duration spaceflight stays aboard the International Space Station (ISS).
CHAPTER III

LEO (ISS/SHUTTLE) EVA

The extravehicular mobility unit (EMU) is made up of three main components: the Primary Life Support System (PLSS), the space suit backpack, and the pressure garment. The suit provides breathable air, thermal regulation, protection from radiation, and protection from particle impacts (Jordan et. al., 2006). Figure 1 provides a breakdown of all the major EMU components.

The suit has 14 layers of protection between the astronaut and the external environment with a clear polycarbonate helmet assembly providing sun protection, lighting, and cameras. The suits can maintain a stable environment for 6.5 to 8 hours limiting the length of EVA operation duration. The modern EMU’s design was based off of the Apollo missions’ lunar EVA suit and later adapted in 1981 for the Space Shuttle and eventually for use on the ISS. Initially the EMU was designed for very limited capabilities allowing astronauts to complete the minimal operational requirements and has since been used for major LEO EVA operations (Jordan et.al., 2006 EMU spec). The EMU was originally designed to be used for brief stays in LEO after which it is returned to Earth with the crew for servicing. Improvements to increase lifetime for up to 180 days without Earth servicing required the development of suit components that could be resized and replaced as needed, alteration to increase EMU interface abilities with the ISS, basic equipment for maintenance and cleaning of the suits, and the develop a means for on-orbit evaluation of battery systems (Wilde et. al., 1997 EMU improve).
Developments for increasing suit life are beneficial for future planetary operations and ensure that suit procedures and equipment for long duration missions with little available support can maintain and repair their operational suits. Additional measured taken in preparing the EMU for use on the ISS such as the development of minor on-orbit alterations or interchangeable components to increase fit and comfort for astronauts of various sizes.

Continual improvements in glove design, mobility, and flexibility may also benefit future planetary EVAs. The EVA training created for long stays on the ISS cultivate basic skill development that can be utilized for multiple types of EVA (Gast and Moore, 2010).

Understanding performance and expected responses to planetary EVAs is difficult to extract from on-orbit data. Differences in the gravity, suits, and EVA type make effect performance and workload making comparison for operations more complex and subjective. Workload is
particularly difficult given the slight physiological changes, such as fluid shifts, that create variations in biological metrics. Given this lack of data analog platforms provide a way to gather an understanding of potential risks and difficulties for planetary EVAs.
CHAPTER IV
ANALOG STUDY PLATFORMS

Mission analogs and simulators are vital in understanding technical and human requirements for long duration planetary missions. These simulations are useful for engineers and scientists to gather data for future equipment designs, space missions, and aid in the development of higher fidelity training facilities. Although they cannot mimic all aspects and stressors of spaceflight and long duration isolation away from Earth they can create a gradual series of practice efforts and under partial operational conditions prior to a mission.

Analog sites exist all over the world; these sites are generally selected for their various similarities to space/planetary conditions. Sites in Antarctica, the Atacama Desert and Yungay area in South America, Kamchatka in Russia Central, Western Australia, Axel Heiberg Island (with McGill Artic Research Station), Devon Island, the Saline Perennial Springs in Canada, the black point lava flow and cinder lake in Arizona, and Mauna Loa volcano in Hawaii are a few of the geomorphological and isolated sites that provide correlations with known Martian and Lunar features (Preston et.al., 2012). For the purposes of this review I will focus on four specific analog sites that focus on human exploration analogs: Devon Island (FMARS), Mauna Loa (HI-SEAS), Florida (NEEMO), and Arizona (D-RATS).
Devon Island

Devon Island located in the Canadian high Arctic (Preston et. al., 2012) with a polar desert environment, sparse vegetation, no population, and extremely cold temperature is considered a good analog for both Lunar and Martian exploration. On the western side of the island is the Haughton Impact Structure; this structure provides an analog for impact structures with various geomorphological sites of interest. The crater has been used as a geological analog for Lunar and Martian operations and the isolation of Devon Island provides a realistic backdrop for studying human exploration activities and human factors in extreme and risky environments. The impact structure and surround area offers a wide variety of impact structures and terrain to test new technologies and operational procedures. The harsh environment provides a study site for astrobiological comparison studies and helps researcher examine terrain similar to Mars.

Devon Island houses two different facilities, the Haughton-Mars Project Research station (HMPRS) and the Flash-line Mars Arctic Research Station (F-MARS). HMPRS Allows for researchers to conduct exploratory traverses into the crater on foot and through the use of all-terrain vehicles. For HMPRS the field sessions are typically 6 weeks in length and due to the isolation strict safety protocols are put into place. F-MARS is run by the Mars Society and typically runs two week missions with the longest mission running for just under four months (Binsted et. al., 2010). The missions focus on technology, procedure, operational, and scientific development with the four month mission focusing on human factors research. The crews experience both psychological and environmental stresses associated with isolation within an extreme environment.
**NASA Extreme Environment Mission Operations (NEEMO)**

This 400 square foot laboratory/habitat is uniquely situated underwater off of the coast of Key Largo, Florida. The submerged habitat provides a unique analog environment that mimics the dangerous external environment of space requiring “aquanauts” to wear life support systems when outside of the habitat. Missions generally last 7-14 days and the environment mimics the isolations, cramped quarters, and increased risks seen in human spaceflight missions. Experiments focus on isolation, confinement, communications, telemedicine, and remote collaboration. Crewmembers also use weighted dive belts and tethering lines to simulate the challenges of performing tasks such as sample collection at multiple gravity levels and anchoring to an asteroid surface.

![Image 1: An analog researcher from NEEMO 16 mission performing a simulated EVA outside of the Aquarius habitat module. (NASA, 2012)](image)

The NEEMO simulations have been running since 2001 and completed their 16th mission in June of 2012. This mission had four analog researchers focused on studying operational and technical concepts for asteroid mission scenarios (NASA, 2012). The analog researchers utilize three main elements of this system, a life support buoy at the surface, a habitat module, and a base plate that secures the hab to the ocean floor. The unique underwater environment allows NASA to test
EVA procedures for microgravity conditions in a less controlled environment than the Neutral Buoyancy Lab in Houston. This environment also allows for testing microgravity operations in a more isolated and risk environment making for a high fidelity simulation.

Desert Research and Technology Studies (D-RATS):

The D-RATS group focuses performing manned analog studies to test new hardware and operations. The testing facilities are mobile and are generally setup in Arizona’s Black Point Lava Flow (BPLF) near Flagstaff (Bell, et. al., 2013). These tests are generally run for two weeks and allow crews and study staff to focus on different mission concepts while testing in an environment more forgiving to mistakes. These tests have allowed many factors to be examined such as communication framework, ability to complete significant scientific objects, testing of new rover technologies, and testing the development of strategies for human and robotic planetary exploration missions.

The most recent 2010 D-RATS setup used a habitat called the Habitat Demonstration Unit (HDU), which has now been repurposed as the Human Exploration Research Analog (HERA) currently be utilized by NASA Human Research Program (HRP) and housed at Johnson Space Center (JSC). The setup had two pressurized rovers capable of carrying 2 person teams carrying out 7 day rover exploration missions (Eppler et. al., 2012). Additionally the study tested out a portable utility platform, pressurized excursion module mock up, and an unmanned cargo transport robot. Ground support was provided by a mission operations team using a remote Mission control center at the Black Point Lava Basecamp.
The geomorphology of the BPLF is a basaltic lava flow that has significance for both lunar and Martian planetary bodies. This site was used back in the days of Apollo to help train the astronauts on geological and scientific exploration techniques, test out new lunar technology, and operational planning in lunar like environments (Eppler et. al., 2013). Through testing at BPLF NASA was able to optimize lunar surface missions and increase the overall success of each mission.
CHAPTER V
ANALOG FACILITIES FOR THIS STUDY

*Hawaii Space Exploration and Analog Simulation*

The Hawaii Space Exploration Analog and Simulation (HI-SEAS) had its initial 120 day mission in 2013 following this success with another 120 day mission in 2014. The habitat sits on the slopes of Mauna Loa at approximately 8500 feet. It is a geodesic dome with approximately 1300 square feet and designed to support 6 crew members. The habitat has a galley, dining/meeting room, open space, two bathrooms (one with a shower facility), lab, 6 crew quarters, and a storage facility housing the main power components (C-Can).

The power is entirely off grid running on solar power with a diesel generator and hydrogen fuel cells as backup systems in the event of a power failure. Trash and waste are stored and removed periodically, about once every 90 days. Water is stored at the site in two 500 gallon water tanks and replenished about every 16 days. Gray water is removed at about the same interval. The composting toilets manage the black water and only grey water is produced and stored by the occupants. The habitat is a double membrane layer that aids in retaining heat, supplemental heat is provided by a propane tank. Crew maintained a 40
minute communication delay with ground support to simulate the communication during a Mars mission.

The external environment is similar to the Tharsis region on Mars and provides a higher fidelity site for EVA operations. The terrain has two types of lava, a’a’ and pa’ hoe’hoe, with numerous volcanic features including but not limited to: pit craters, lava tubes, skylights, and cinder cones (See Images 4-8). The volcanic terrain provides a realistic environment to test EVA performance, protocol, and equipment. Crews were required to carefully plan EVA activities and monitor EVA participants to ensure safe EVA operations. The terrain and geology around the site are challenging and create a high risk high stress environment simulating conditions similar to those for planetary exploration. The isolation and autonomy simulated at this site allow EVA operations to evolve and provides the ability to research how increased autonomy will affect EVA performance and crews.

Two types of analog planetary suits are used at the HI-SEAS facility, the University of Maryland’s MX-C and a modified Hazmat developed by the facility. The MX-C is made of both adjustable and non-adjustable components and can fit a variety of people from 5’4” to 5’10” between weights of 115 pounds to 170 pounds. As mentioned before, the suits’ weight is distributed over an internal backpack harness system that allows the user to adjust shoulder and waist straps to the most comfortable fit for distributing the full weight of the suit over the shoulders and waist. The suit is padded in the arms, legs, and lower torso to simulate
pressurization. When fully loaded with the LCG tank and battery the suit weighs approximately 50 pounds with most of the weight being low in the backpack section causing the center of gravity to shift towards the head of the suit. The backpack harness system distributes weight evenly, allowing the user to maneuver the suit on the extreme terrain surrounding the habitat. The modified Hazmat is altered from an original hazmat suit and has limited mobility and vision. The suit has two internal ventilation fans that provide air circulation and CO2 removal. The suit has internal straps that can be adjusted to slightly modify the fit of the suit. The hazmat suit weighs approximately 10 pounds and due to the decreased weight is most commonly used for more strenuous or higher risk EVAs.
The University of North Dakota’s Lunar/Mars Analog Habitat (LMAH) has had two analog simulations; the first was a 10 day simulation and the most recent was a 30 day simulation. This habitat is an inflatable, interconnected system that allows the user to move directly from the habitable volume into the rover and suits through the use of a rover tunnel and suitport system. The habitat is approximately 400 square feet and designed to support a crew of four for up to 30 days (Swarmer et. al, 2014). The analog simulations have been systems research focused with some additional research into habitability and human factors.
The external environment is flat and controlled with heavy monitoring from ground support during any EVA operations. Crews must plan and execute EVAs with minimal ground support, but due to the systems limited testing the crews are monitored heavily to ensure safety. The crew still performs all tasks and activities with minimal support, but communication and difficulties faced are handled by both crew and ground support.

LMAH used a pressurized analog planetary suit the NDX-2AT, designed and developed based on the University of North Dakota’s NDX-2 Lunar Suit. The NDX-2AT was designed to be compatible with a suitport system developed on the rover. This system allows for easy donning and doffing of the suits and decreases the risk for external contamination. The rover increase the distance crews can explore the surroundings and is believed to decrease the overall workload.
Images 12 (Left) and 13(Right): The image on the left shows the proto-type NDX lunar planetary suit. The image on the right shows the NDX-2AT, analog suit designed for use with the LMAH facility.
CHAPTER VI

TRAINING VS. REAL

Training and analog environments aid in training crews and operators for real world application. Training has been deemed by Apollo, Shuttle, and ISS astronauts (Gast and Moore, 2010) as sufficient; however, many of the problems faced by astronauts during EVA are more severe in nature during real operations. For example the astronauts talk about hand fatigue and muscle soreness while training in the neutral buoyancy lab (NBL) due to the suit gloves, however on orbit astronauts can have mild to moderate injuries to their hands due to the gloves not typically seen during earth based training (Bishu and Klute, 1995 and NASA, 2007). The controlled environment of training prepares astronauts to follow specific protocols and procedures, but does not necessarily simulate the precise conditions leaving some unknowns for real operations. This is something to consider when using analogs and simulations to gather data for the development of future procedures and equipment.

Increasing the realism of analogs allows users to gain better training and understanding of the requirements in real operations. This may aid in developing future training programs and in gathering knowledge on how operational issues develop. An analog cannot simulate all conditions, as many variables are not well understood, but developing a physiological pattern to follow provides users with a realistic understanding of how these stresses and physiological changes affect their performance.
CHAPTER VII

STATEMENT OF PROBLEM

Prediction of every factor and environmental issue for future planetary EVAs is extremely difficult. Analogs provide a platform to field test technology, procedure, and determine limitations within stressful and occasionally extreme environments to allow researchers and engineers to ensure developing is steadily improving. One of the difficulties is the current lack of data available on planetary EVAs; data such as performance, workload, difficulties, and how the human’s performance changes over long duration missions in these environments.

Generating a baseline of information and data from various analog simulations allows researchers to determine the stage of development currently obtained and use this information to compare future studies. Due to the variability of EVA activities and environment there are many dynamics that can affect EVA performance. The lack of operational data in workload, biometrics, stress, and performance make it difficult to determine if current procedures and technology will be successful in a planetary environment.
CHAPTER VIII

HYPOTHESIS

With current analog facilities and technology EVA performance will vary based on EVA type, general health and mood, mission chronology (when during the mission and time of day), and sleep patterns. Stress level before the EVA will generally be higher than afterwards, however, it is expected that this will vary depending on the type of EVA.

It is predicted that workload will vary based on the crew members’ previous fitness level, expected workload from highest to lowest: Exploratory, Emergency, Maintenance, Scientific, and Public Relations. Predicted stress levels from highest to lowest: Emergency, Scientific, Exploratory, Maintenance, and Public Relations. Overall EVA performance is predicted to decrease throughout the analog simulation and will depend heavily on EVA type.
CHAPTER IX
METHODOLOGICAL APPROACHES

This study focuses on understanding pre and post EVA metrics in hopes of determining patterns and developing performance profiles for the various EVA types. Data collection for this study uses the two previously mentioned analog facilities (HI-SEAS and LMAH) with data collected during a 120 day Mars simulation and a 30 day planetary simulation. Due to the differences in the two facilities data collection was similar but had to be adjusted for each facilities capability. The HI-SEAS provided a more realistic site, but had less availability to dynamic and variable simulation. LMAH is a more controlled environment making it less realistic of a Mars mission, but has the ability to control more variables and collect a larger amount of data.

**HI-SEAS**

HI-SEAS data was collected pre and post EVAs; pre vitals were collected about 10 minutes before donning the suits and post vitals collected immediately upon doffing the suits. Out of sixty two EVAs performed the crew collected viable biometric data for twenty nine EVAs and

Image 14: Collection of pre-EVA vitals at the HI-SEAS analog habitat.
logistical organizational data for fifty eight. The few EVAs mission logistical data was not accurately collected due to the urgent nature of the EVA making data collection secondary.

As seen in table 3, the crew collected pre and post vitals: pulse, blood pressure, and SpO2 as an indicator of current their current physiological state. Pre EVA reports outlining the objectives and EVA plan were collected. Post EVA reports were generated stating any EVA issues and a review of the EVAs operations. These reports provide data on the EVA type, length, objectives completed, crew numbers, suits used, and helps to extrapolate a performance rating.

Vital collection (Image 14) was done with an automated blood pressure cuff (also showing pulse rate) and a SpO2 monitor. The cuff would be placed on the left arm above the elbow lining up the reference markers to ensure the same orientation every time before turning the system on and automatically inflating for collection of blood pressure and pulse. Occasionally the cuff would display an error and the reading would need to be retaken after the cuff deflated. The SpO2 monitor was placed on the right hand’s index finger so the inflated cuff did not interfere with the reading.

<table>
<thead>
<tr>
<th>HI-SEAS Data Metrics Collected</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA Type</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Number of planned Objectives</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pulse</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SpO2</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Number completed Objective</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Eva length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Issues</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Number of Crew on EVA</td>
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<td>X</td>
</tr>
</tbody>
</table>

Table 3: HI-SEAS data metrics to be collected pre and post EVA.
Crews would complete a template EVA Operations planning form prior to any EVAs and would complete a template EVA log upon return to collect the logistical and administrative EVA details (Templates for EVA operations planning and EVA log can be found in the appendix).

LMAH

LMAH data was collected pre and post EVA; pre vitals were taken 15 minutes prior to the scheduled EVA start time and post vitals were taken immediately upon doffing the NDX-2AT suit in the rover. The crew filled out the same EVA request and EVA log template used at the HI-SEAS. For the LMAH simulation the crew also needed to fill out pre and post EVA surveys not collected during the HI-SEAS simulation. Data was collected for all 19 EVAs performed, but due to training and external interactions about 12 total EVAs can be used for analysis.

Vital collection was done with an automated blood pressure cuff (also showing pulse rate) and a SpO2 monitor. The cuff would be placed on the left arm above the elbow lining up the reference markers to ensure the same orientation every time before turning the system on and automatically inflating for collection of blood pressure and pulse. Occasionally the cuff would display an error and the reading would need to be retaken after the cuff deflated. The SpO2 monitor was placed on the right hand’s index finger so the inflated cuff did not interfere with the reading. Crews would complete a template EVA Operations planning form and pre Eva survey prior to any EVAs and would complete a template EVA log and post EVA survey upon EVA completion (Templates for EVA operations planning and EVA log can be found in the appendix). The pre survey focused on general health, mood, hours of sleep, and exercise prior to the EVA. The post survey asked about mood, general health, EVA ease, EVA exertion, and EVA comfort. General health was rated on a scale from 1-10: with 1 indicating a feeling of deathly ill, 5 indicating an average feeling and 10 indicates feeling better than normal. Mood was denoted in
general terms such as happy, frustrated, tired etc. Exercise data was collected regarding duration and intensity of any exercise over the past 24 hours. The crew recorded the amount of water consumed in the past 24 hours.

<table>
<thead>
<tr>
<th>LMAH Data Collected</th>
<th>Pre</th>
<th>Post</th>
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<tbody>
<tr>
<td>EVA Type</td>
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<td>X</td>
</tr>
<tr>
<td>Number of planned Objectives</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pulse</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SpO2</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Number completed Objective</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Eva length</td>
<td></td>
<td>X</td>
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<tr>
<td>Issues</td>
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<td>X</td>
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<tr>
<td>Number of Crew on EVA</td>
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<tr>
<td>General Mood</td>
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<tr>
<td>General Health (1-10)</td>
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<tr>
<td>Hours of Sleep (past 24hrs)</td>
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<tr>
<td>Exercise Data (time and level)</td>
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<td></td>
</tr>
<tr>
<td>Water Consumed (past 24 hrs)</td>
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<td></td>
</tr>
<tr>
<td>Rated Level of Exertion (1-10)</td>
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<td>X</td>
</tr>
<tr>
<td>Rated Level of Ease (1-10)</td>
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<td>X</td>
</tr>
<tr>
<td>Rated Level of Comfort (1-10)</td>
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<td>X</td>
</tr>
</tbody>
</table>

Table 4: LMAH data metrics to be collected pre and post EVA.

Exertion, ease, and comfort were all rated on a scale from 1-10 with 1 indicating a level equal to performing the tasks without a suit and 10 indicating 100% exertion, for ease 10 indicates not being able to use the suit for the intended function, and for comfort 10 indicates that subject was unable to complete the task due to the suits comfort level. During the EVAs crew members will wear a heart rate monitor to indicate workload during EVAs.

In addition to the data collected during the study the crew members were required to complete some baseline tasks to provide biometrics for comparison to the biometric data collected during the analog. This comparison should provide some information to the physiological/stress state of
the participants prior to and during the EVA. The baseline testing consisted of three exercises, a 100 yard walk with no weight, 5 pounds, and 10 pounds, setting up a tripod, and performing sample collection. The exercises are performed once without the suits and once inside the suits. The baseline data was collected 4 days after the end of the simulation to give the crew time to rest and due to the operations during the 30 days the crew is familiar with the suits properties and capabilities. During the baseline testing crew members would take vitals pre and post, surveys pre and post, as well as wearing the heart rate monitors.

**Performance Rating Development:**

Performance was rated by the crew members based on the number of completed objectives and EVA issues. For example if there was four objectives planned but only two were completed the EVA would have a 50% performance rating. If on this same EVA the crew experiences communications trouble and additional 2-3% would be removed for each issue based on the severity. Performance was rated uniformly at both analog sites and created a basis for comparison of the two sites and any future similar research.
CHAPTER X
RESULTS AND ANALYSIS

General EVA Dynamics

General EVA dynamics and data varied between the two sites and is due in part to the different nature of each analog site. The HI-SEAS environment required more autonomy and increased planning before moving forward into unknown terrain. LMAH was in a controlled environment with minimal non-simulated safety concerns and minimal crew autonomy. LMAH’s controlled environment allows the focus to be on how the suits affect performance for each EVA type. The HI-SEAS was able to provide more trends and insight into operational factors and dynamics for EVA performance.

Each site had five basic types of EVAs: maintenance, public relations, emergency, survey, and science. For both sites data was collected for maintenance, public relations, survey, and science EVAs. Maintenance EVAs are generally conducted nearby the habitat and tasks range from inspection of the habitat systems, to minor repairs, and monitoring consumables such as water. Equipment and tools for these EVAs are specific to EVA task and range from imagery equipment to basic repair tools. Public relations EVAs are conducted near the habitat and require crew members to create images and videos for personal and public use. Imagery equipment and
personal items (such as flags or notes) make up the most common equipment taken on EVAs. Survey EVAs explore and examine new terrain for safety concerns, sites of scientific interest, and collection of initial site data. These EVAs take crew away from the habitat and occasionally out of communication. Science EVAs are performed both nearby and far away from the habitat depending on the EVA objectives and are planned after a survey EVA has been performed. During these EVAs new procedures and equipment can be tested, as well as, analysis for sites of geological interest and collection of samples. Emergency EVAs although rare occur due to a habitat or EVA systems failure and lead to rapid crew response. The equipment needed for these EVAs varies based on the situation, but due to the need for a rapid response no data was collected for this EVA type during either simulation.

For the individual sites EVA procedures and protocols are different due to the environmental and autonomous factors of each analog site. Even with the differences in the sites the EVAs shared similarities with the types of tasks, system limitations (mostly due to suits) and general objective requirements differing in the methods to complete each task. The HI-SEAS performed tasks with increased operational focus limiting their behaviors and EVA tasks due to safety concerns,
isolation, and the higher risk environment. LMAH was very controlled environment and the crew could see study staff continuously throughout their EVA decreasing the isolation and autonomy due to these interactions. The LMAH data was able to focus more on how the suits affect physiology and performance rather than focusing on how autonomous EVA operations affect physiology and performance.

**HI-SEAS EVA Data**

The HI-SEAS crew performed 62 EVAs totaling 3,755 minutes over a 120 day Mars analog simulation. The crew performed all five types of EVAs, collecting data for maintenance, public relations, survey, and science missing only the data from the emergency/urgent EVAs. EVAs were performed over a variety of times ranging from before sunrise to late night EVAs. The tasks/objectives of the EVAs ranged based on the assignment or goal.

As seen in graph 1 scientific EVAs make up the highest percentage of EVAs performed, comprising forty eight percent of the total EVAs performed. Maintenance EVAs are the least performed, comprising seven percent of the total EVAs completed. However, it is unclear how this will change with increasing mission or simulation duration. The average performance ratings (graph 2) show a decrease in performance of survey EVAs, completing only eighty six percent of the tasks and objectives. The other three EVA types had performance ratings in the ninety percentage range with public relations EVAs having the just over a ninety seven percent performance rating. The drop in performance for survey EVAs is not unexpected as these EVAs take crews into areas not previously explored exposing them to unknown terrain, hazards, and often removing them from communications with the habitat.
Breaking the EVA frequency into quarter’s (Graph 3) displays shows a drop in the number of EVAs performed in the second and third quarter. Maintenance EVAs occurred during the first and second quarter during the initial setup and basic organization of the habitat and its systems. General upkeep maintenance was not required very often due to the short duration of the simulation. Science EVAs maintained a steady presence all four quarters with a slight increase towards the end of the simulation. Survey EVAs also had an increase toward the end of the simulation, a trend that is interesting as it would be expected that fewer new locations would be examined. This increase may in part be due to the crew adapting to the environment and better comprehension of the EVA systems’ capabilities.
Average EVA performance (Graph 4) was lowest in the first quarter as the crew adjusted to the new environment and EVA systems. Another noted decrease in performance can be seen in the third quarter and fit with previous data showing a decrease in performance and motivation over long duration missions in the third quarter (Bechtel, 1991). Science EVAs had a performance decrease in the first quarter, but as the crew adjusted to the procedures these EVAs became repetitive and the performance ratings increased showing no third quarter decrease. Survey EVAs have the greatest performance variability and show a decrease in both first and third quarters. The PR EVAs’ performance remains constant with a slight dip towards the end; these EVAs display the highest level of performance, most likely due to the crews familiarity with the systems and the terrain.

Average crew number ranged for EVA type (Graph 6): maintenance EVAs had two crew members on average while the other three types had three average crew members. Survey and Science EVAs in particular normally had either two or three crew members. Average EVA length (Graph 7) was sixty two minutes, with survey EVAs taking the longest. The shortest EVA
was a maintenance EVA and took approximately twelve minutes, while the longest EVA took one hundred and sixty eight minutes.

Graph 3: Number of EVAs performed broken down into type and mission quarter over the 120 day mission.

Graph 4: The average occurrence of EVA issues by issues type.
Graph 5(top), 6 and 7 (bottom): Top shows the percentage performance rating per quarter and by EVA type. Bottom left show the average number of crew members per EVA type. Bottom right shows the average EVA length per EVA type.
**LMAH EVA Data:**

The LMAH simulation lasted thirty days and the crew completed nineteen EVAs a total of 1240 minutes. The crew performed four types of EVA: maintenance, public relations, survey, and science. No emergency EVAs were simulated during the thirty days. The tasks and objectives of the EVAs were the same for each week. The crew needed to perform a habitat inspection, survey a potential sampling site, sample a site of scientific interest, and complete tasks for personal and public media imagery. The EVA tasks were assigned weekly and EVA sites of scientific interest were simulated with hazards denoted by orange tape and samples of scientific interest places throughout the EVA site. Crews were instructed to perform a survey EVA first then return to the habitat to review potential hazards and located sites for future sampling. Due to the controlled environment the EVA field had little to no natural hazards and decreased the amount of stress on the crews.

![Graph 8: The percentage each EVA type occurred during the 30 day analog study at LMAH.](image-url)
During the LMAH simulation the highest frequency of EVAs performed (Graph 8) were maintenance EVAs, this is in part due to the shorter simulation. Maintenance EVAs seem to be prevalent early on during site setup and the early adjustment to the new environment. The other three types of EVA had the same frequency of occurrence, but differed in slightly over the different quarters of the mission. Science and public relations EVAs occurred with the same frequency and the lowest frequency of EVAs performed were science based.

Performance remained high during the simulation with science EVAs having the largest decrease in performance. Maintenance EVAs also saw a decrease in performance; this could be partially due to the proximity of the crew members to the habitat during these EVA operations. The close proximity may have made the crew more comfortable and a little more relaxed with the EVA systems knowing that help and the internal environment were only minutes away.

**Graph 9: Average performance rating (in percent) for each EVA type during the LMAH analog.**
EVAs during the LMAH simulation ranged from twenty five minutes to one hundred and twenty minutes and varied based on tasks or goals set by the crew. The overall average time was approximately seventy minutes. The longest EVAs seemed to be the survey EVAs, similar to results from the HI-SEAS and in part due to the unknown environment and requirement for crews to exercise more caution and time to accurately collect data about the EVA site. Maintenance EVAs took the shortest amount of time in part due to the proximity of the habitat and in part due to the familiarity attained by the crew over time. The longer duration for PR EVAs is different than the results from the HI-SEAS and it is unknown as to the origin of this difference. This could be crew specific as PR EVAs are more optional than other EVA types and can be a source of entertainment.

![Graph 10: LMAH EVA length by EVA type in minutes.](image)

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EVA frequency was lowest in the 1st and 4th quarters with an increase during the middle of the mission. This could in part be due to the availability of EVA times, these had to be planned out and approved ahead of time to ensure ground support was nearby and did not always allow the crew to perform EVAs as they would on a more autonomous mission. The first quarter was dominated by setting up the site and collecting some initial public relations material. The second quarter was focused on scientific EVAs and maintenance. The third quarter saw an increase in PR EVAs this could in part indicate a decrease in work focus, as mentioned before, it is a common third quarter issue. The fourth quarter was focused on exiting the habitat and most likely lead to the decrease in EVA number.

Performance during the thirty day is very difficult to rate by quarters due to the shorten simulation time and limited number of EVAs that are performed. This makes trending EVA patterns more difficult. The performance over the thirty days seems to increase as the mission continues with the greatest performance decrease in the early quarters, one and two (Graph 12).

Graph 11: LMAH EVA frequency by type and quarter.
The LMAH system only allows for two people to perform an EVA at one time and limiting the number of crew that can perform an EVA. All EVAs except for maintenance EVAs had two crew members. Maintenance EVAs are comprised of half single person EVAs and half two person EVAs. The number of crew members required for maintenance EVAs was dependent on the type of maintenance EVA. For example, if the crew were required to setup a new system, such as simulated solar paneling or wind protection they would need two crew members, but to inspect the habitat for any issues only one crew member was needed to complete this task.

Graph 12: LMAH EVA performance by EVA type for each quarter of the simulation.
**HI-SEAS Biometric Data**

As discussed earlier vitals were taken pre and post EVAs and could indicate the level of stress prior to an EVA and the workload post EVA. Heart rate, blood pressure, and SpO2 provided the majority of the biometric data. Graph 13 displays the general trends for pre and post vitals for all 29 EVAs with biometric data. As expected, heart rate and diastolic blood pressure both increase post EVA. Percentage O2 in the blood decreases post EVA, in part due to the increased workload and in part due to the suit design which increases the presence of CO2 circulation in the blood stream due to an increased presence within the suit. The systolic blood pressure shows a slight average decrease in the post blood pressure numbers, a factor that will be further examined in the analysis section.

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**HI-SEAS Average Vitals for All EVA Types**

Graph 13: Average vitals for the 120 day simulation.
The average heart rate varied based on EVA type, but all EVA types indicated an increase in heart rate post EVA (Graph 14). SpO2 levels showed a decrease post EVA for all EVAs except maintenance EVAs (Graph 15). Systolic blood pressure decreased post EVA for all EVAs except Science EVAs which had a slight post systolic increase (Graph 16). Diastolic blood pressure increased for all EVA types except for Survey EVAs which had a decrease in diastolic blood pressure (Graph 17).

Graph 14-17: Top graphs (14 and 15) display heart rate pre and post EVA in beats per minute and SpO2 in percentage. Bottom graphs (16 and 17) display systolic and diastolic blood pressure (mmHg) pre and post EVA. All graphs show the average rating per EVA type for the entire 120 day simulation.
Heart rate values per quarter (Graphs 18), indicate a general post EVA increase in all quarters except for the second quarter. The second quarter values remain equal pre and post EVA; this could be due to the crew physiologically adjusting to the 8500 feet altitude and/or becoming comfortable with EVA systems. The peripheral capillary oxygen saturation (SpO2) levels decrease post EVA for each quarter; however the most interesting quarter is the fourth quarter that has an average drop of three percent (Graph 19). The next closest drop is one and a half percent, the fourth quarters drop is nearly double the next largest drop. The reasons thought to be behind this drop will be further discussed in the HI-SEAS analysis section.

![HI-SEAS Heart Rate Pre/Post EVA by Quarter](image)

**Graph 18: Average heart Rate values by quarter.**

![HI-SEAS SpO2 Pre/Post EVA by Quarter](image)

**Graph 19: Average SpO2 values by quarter.**
Systolic blood pressure (Graph 20) remained fairly even through the first and second quarters. The third quarter displayed an increase in post systolic blood pressure. The fourth quarter systolic blood pressure decreased post EVA. This drop indicates a deviation from expected patterns and will be examined further in the HI-SEAS analysis section. Diastolic blood pressure (Graph 21) in the first and second quarters does not indicate any significant changes. The third quarter shows a higher diastolic pressure post EVA. The fourth quarter displays a different change illustrating a decrease in post diastolic blood pressure.

Graph 20: Average systolic BP values by quarter.

Graph 21: Average diastolic BP values by quarter.
**LMAH Biometric Data**

Vitals are the biometric component of the data collected from the thirty day LMAH mission. The crew collected heart rate, blood pressure, and SpO2.

Graphs 22-25: Top Left (22) Average heart rate (BPM) pre and post EVA by type. Top right (23) Average SpO2 by percent per EVA type. Bottom left (24) average systolic BP mmHg by EVA. Bottom right (25) average diastolic BP mmHg by EVA.
The heart rate data (Graph 22) by type shows an increase in post heart rate after every type of EVA. The higher increase in maintenance heart rate could be due to the shorten mission and increased maintenance EVAs needed to setup systems. Physiological differences in crew could also be playing a factor. SpO2 (Graph 23) decrease post EVA for all EVA types accept for Science EVAs. Systolic blood pressure (Graph 24) by EVA type shows an increase post EVA for all EVA types except for public relations EVAs which has a slight decrease. Diastolic blood pressure (Graph 25) increased post EVA for all EVA types.

Over the four quarters of the mission the post EVA heart rate (Graph 26) faster than the pre, but as the simulation continued the pre and post heart rate difference decreased with the average post heart rate declining. By the fourth quarter the average difference between pre and post heart rate was 3 beats per minute. The average heart rate change for the thirty day mission was approximately 20 beats per minute. Additionally, over the course of the four quarters heart rate pre EVA decreases, most likely due to the crew becoming familiarized with the EVA systems.

Graph 26: Average heart rate in beats per minute (bpm) pre/post EVA over the four quarters of the simulation and the average heart rate for the 30 days.
The SpO2 data (Graph 27) shows a slight decrease in percent O2 saturation in the blood for all quarters except the second quarter. The second quarter shows an increase in percent O2 saturation of approximately 0.5%. This could be due to several factors and will be discussed further in the analysis section.

Average systolic blood pressure (Graph 28) increases post EVA for the first three quarters, but shows a slight, almost negligible, decrease post EVA for the fourth quarter. Average diastolic blood pressure (Graph 29) shows an average increase post EVA for all quarters.
**LMAH General Mood, Sleep Patterns, Personal Health Ratings, and Exercise Data**

The crew describes their general mood pre EVA as positive or good with a 9% response of tired. Post EVA the crew describes their general mood as great or good with a 3% response of tired. Sleep patterns were fairly steady with an average sleep time of 7 hours for days with a scheduled EVAs. The crew rated their own health pre and post EVA, the lowest rating was a 6 and the highest was a 10, indicating they felt better than normal the entire simulation. Average pre and post health was mixed depending on the individual. Two data sets were collected for general health, but these data sets conflict with one another. The sets show one crew member who felt better post EVA and one who felt worse post EVA (Graph 30). Although with average health rating at 8.5 both crew members report that they felt better than normal before and after every EVA. Exercise data was collected, but does not provide any distinctive insight into patterns between exercise and performance.
Perceived Workload, Ease, and Comfort

The crew’s perceived workload, ease, and comfort (Graph 31) varied based on EVA type. All were rated on a scale 1-10 with 1 equaling performance without a suit and 10 equaling total expenditure and inability to complete the task due to exertion, inability, or being too uncomfortable. The crew expressed the greatest workloads from survey EVAs and the least from PR EVAs. The EVAs with the least ease is maintenance EVAs with the highest level of ease found with both survey and PR EVAs. The EVAs tended to be uncomfortable with the maintenance EVAs having the least amount of comfort and the PR EVAs having the highest comfort rating. Activities during maintenance EVAs, such as setting up solar paneling or correcting simulated damage to the habitat could explain the increase to workload, and decreases in ease and comfort. These EVAs require the crew to occasional maneuver in unnatural motions and requires increased fine motor function. While PR EVAs are more relaxing and reflect this in the lower workload rating and increased ease and comfort ratings.

Graph 30: Average health rating pre/post EVA. Rating is done on a scale from 1-10, 10 being the best rating and 1 being the worst rating.

**LMAH Perceived Workload, Ease, and Comfort**

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Baseline testing lasted between 5-10 minutes per run; each run had participants walk 100 yards with no weight, 5 pounds, and 10 pounds. Next participants had to setup a tripod and then collect a soil sample. The baseline testing took place four days after the simulation ended so that the crew was well adjusted to the EVA systems. As seen in graph 32 the baseline vitals do not follow the same patterns seen during the simulation which could indicate that the simulation caused physiological changes that led to the patterns seen during the 30 days. The systolic blood pressure out of the suit drops post baseline testing, but when in the suit the systolic pressure increases post testing. The same is true for average heart rate which decreases slightly post baseline activity, while suited testing shows a slight increase in heart rate post testing. As expected the suits cause an increase in workload and that is implied in the baseline data.

**LMAH Baseline**

Graph 31: Average workload, ease, and comfort rating by EVA type. A 1 rating equals performance without a suit and 10 equal the worst and most negative rating normally leading to a result of objective/EVA failure.
Graph 32: Average vitals during baseline testing pre and post baseline activity. (PP=Pre HR, PoP=Post HR, PBP=Pre Systolic BP, PoBP=Post Systolic BP, PDBP=Pre Diastolic BP, PoDBP= Post Diastolic BP, PO2=Pre SpO2, and PoO2=Post SpO2).
CHAPTER XI

DISCUSSION

Developing models from the above data is a complex task due to the high number of variables involved with each EVA. To complete profiles for each EVA type common specific variables need to be singled out. Each individual has different physiological responses based on genetics, health, and fitness levels, but general trends can be seen by averaging the biometric data. This data has the potential to aid in the development of EVA profiles for planetary operations and for this study a focus on EVA type and temporal factors will be used to create a general EVA profile for each site and EVA type.

Humans can adapt to various environments and their bodies attempt to maintain a steady physiological state known as homeostasis (Marieb, 2007). Temporary variations in biologic metrics indicate a state of physiological or mental stress to the individual as the body alters its basic internal regulation to maintain a set point, homeostasis. Prior to EVAs the body prepares for increased levels of physical and mental stress in some cases altering certain biological functions such as blood pressure and heart rate. This is a sympathetic nervous system response and is autonomously regulated within the body aiding homeostatic regulation and stimulating the flight or fight response as needed (Brodal, 2004).

In high risk dynamic environments many factors beyond physical condition can play a role in overall performance. Factors such as equipment, training, and even environmental conditions can alter performance in negative and positive ways. With this in mind focusing on how humans
respond to the stressful stimuli of analog EVAs may help in future prediction for performance and training development. In this study the goal was to focus the data collection on operational factors such as EVA type, length, and temporal variations. In addition each site allowed for a focus on a slightly different EVA factors with the HI-SEAS providing an operational focus and LMAH providing an increased focusing on how the planetary analog suits affected operational performance. Rating performance was difficult, but each site was able to rate based on the same scale.

EVA types varies between the two sites, the HI-SEAS analog facility provides insight into autonomous crew function within an isolated and extreme environment. This provides indications for operational EVA composition and displays how future crews may potentially organize EVA types and schedules. Each EVA type has its own unique components and both LMAH and HI-SEAS shared similarities for maintenance and public relations EVAs. However, the environmental and organizational differences made science and survey EVAs dissimilar for each individual site. The following discussion sections will review and compare data for the HI-SEAS, LMAH, and then compare the two sites data briefly. From this general biometric EVA profiles for each EVA type will be developed.

**HI-SEAS Discussion**

The 120 day HI-SEAS simulation had four main EVA types as previously discussed. These EVAs had distinctive frequency pattern with science and survey EVA types making up 76% of

![Image 18: The dedicated ventilation tube for the helmet.](image)
the total EVAs performed. Dedicated maintenance EVAs occurred during the first half of the simulation and had a high performance rating of 93% success. These EVAs are generally shorter in length averaging twenty two minutes. Like all EVA types maintenance EVAs saw an increase in heart rate post EVA of approximately five beats per minute indicating a possible increased workload. This increase could be due to the suit specifically, or due to the crew’s acclimation to the higher altitude and new environment. The systolic blood pressure during maintenance EVAs increased on average by 2 mmHg with the diastolic blood pressure producing a slight negligible increase of 0.34 mmHg. The systolic increase pre EVA is a trend for most of the EVAs and indicating a higher level of stress prior to an EVA with stress levels decreasing post EVA. Percent O2 (SpO2) within the blood stream shows an increase post EVA, this does not occur in any other EVA type. Numerous factors from individual fitness, decreased time within the suits, and decreased distance traversed could all play an aspect in the O2 increase. This factor is interesting considering that all other EVA types show a decrease in percent O2 post EVA and another possibility for the increased O2 exists. This increase could be due to the suit type most commonly used for maintenance EVAs. The MX-Cs were more commonly used during maintenance EVAs due to their increased fine and gross motor manipulation capabilities. The MX-Cs, unlike the modified hazmat suits, have a dedicate ventilation fan pushing air directly into the helmet portion of the suit thus increasing the flow of fresh air and removing carbon dioxide (Image 18).

The increase in SpO2 within the blood should be examined further to better understand the potential of utilizing this component within the MX-C suit’s design to increase biometrics and potentially increase performance. Maintenance EVAs required more equipment and were generally attempting to fix failed components external to the living space. Normally this type of
activity should have more issues and difficulties due to the complex nature of these EVAs. However, maintenance EVAs had a performance rating of 93%, this higher success rate is most likely due to multiple components such as EVA length and overall workload, but another potential factor increasing performance is the better circulation and increased SpO2. To fully confirm this additional studies focused on SpO2 and performance within analog environments should be examined. Previous studies have shown that people with higher SpO2s or hyperoxic air have faster reaction times and generally perform at a higher level than people with lower SpO2 (Chung, 2009). Another study performed shows that hypoxic conditions and moderate exercise had little effects on cognitive function and reaction time (Ando, 2013). The conflicting results for performance with slightly decreased SpO2 make it unclear if this played a factor in performance during maintenance EVAs or if it was due to physiological differences between crew members.

Scientific EVAs make up the bulk of EVAs performed during the HI-SEAS simulations with the last three quarters of the mission having the highest frequency (Graph 3). Science EVAs generally last approximately seventy minutes and can occur close by and far from the habitat depending on the objectives. The average heart rate increase post EVA for science EVAs is 1.5 beats per minute and does not denote a high workload, most likely the increase is due to the workload increase caused by the suit and not an increase due to the EVA’s tasks. Systolic and diastolic blood pressure both increased post science EVA, with the low heart rate increase this blood pressure increase could be due to increased mental stress. The average increase in systolic blood pressure is almost negligible at just over 1.5 mmHg. Science EVAs were generally task specific and required very specific protocols be followed while completing data collection. These additional requirements could cause more mental anxiety and stress related to the tasks. Science
EVAs had approximately a 92 percent performance rating, higher than survey style EVAs, but a lower rating than maintenance or public relations EVAs. SpO2 data displayed an average decrease of approximately 1.6 percent. This decrease in blood oxygen saturation is much smaller than the average for survey or public relations EVAs and this may indicate a smaller workload for these types of EVAs. This decrease in SpO2 is small, but may have contributed to the decrease in performance for science EVAs, as discussed previously decreases in SpO2 have been linked to lower performance levels, especially during exercise (Ando, 2013).

Survey EVAs make up approximately twenty five percent of the total EVAs performed and were most commonly performed in the 4th quarter. This increase can be attributed to the crew’s familiarity with the EVA systems, operations, and local environment. During the previous three months the crew gained operational knowledge of their environment which made planning and executing survey EVAs less time consuming enabling an increase in frequency and performance. Survey EVAs were the longest with an average time of one hundred and two minutes and always took place away from the habitat. During these EVAs crew would explore previously unexamined terrain looking for safety concerns and areas of scientific interest. Planning stages began early on and required crews to detail out EVA plans, routes, and emergency response measures. While on EVA crew members had increased vigilance looking for potential safety concerns and monitoring crewmates to ensure their safety.

Interestingly, survey EVAs share some similarity with pilots who fly combat missions. Planning begin before combat missions, the crews participating attend a pre-mission brief the evening before, a last mission brief the morning of the mission, perform the mission, and then hold an end of mission debrief. The one difference between combat pilots and crew on a survey EVA is the increased stress pilots experience during landing signifying the end of the mission. By
comparison once the EVA crew has completed the survey of the area returning to base is not considered to be a stressful event. Heart rate increase and variability in combat pilots is believed to be correlated with an increase of catecholamines, the body’s primary reaction to stress (Otsuka, 2006) and in the pilots case indicating the bodies attempt to increase focus and mental work during landing (Dussault et. al., 2009). This corresponds with the increased blood pressure seen at the beginning of survey EVAs as crew prepares for an EVA requiring more intense focus and mental work. The increased heart rate post EVA may correspond with the workload more physical stress than mental.

Heart rate increased by an average of 8.8 beats per minute from pre to post EVA, indicating a higher cardiovascular workload, possible due to the increased time in the field. Systolic blood pressure on average decreased by 4 mmHg and diastolic blood pressure also decreases only for survey type EVAs decreasing on average by 2mmHg from pre to post EVA. This is interesting when compared to science EVAs which had an increase, but seems to have had less physical work indicating a mental stress component unique to survey EVAs.

The stress leading up to survey EVAs is higher than stress leading up to science EVAs, but once crew returns home from a survey EVA a sense of relaxation occurs that is not seen in the science EVAs. This may in part be due to the nature of both EVAs; survey EVAs take many hours of planning and prep work and individuals must be on alert while performing a survey EVA due to unforeseen hazards and risks within the new terrain. Science EVAs occur in areas already explored during previous EVAs providing some familiarity with the environment. The science EVAs require crews to follow strict procedures and protocols for data collection. Additionally, before a science EVAs success and performance can be determined crews must return to the habitat and analyze the data to ensure data accuracy and proper techniques throughout the EVA.
Science EVAs tend to be done for other researchers and with a group of astronaut like individuals completing these and collecting data successfully is a very important goal to the crew. Whereas survey EVAs require a different type of focus and have more broad based objective and repetitive tasks focused on identifying specific safety concerns or points of scientific interest. Survey EVAs are performed in a more risky environment causing a change in the EVA focus and altering the behavior patterns of the crew remaining at the habitat. All crew members make sure to prepare and focus on the task of surveying a new area safely and ensuring physical and mental preparations for any potential emergency response. Once survey EVAs are complete and the crew has returned to the habitat there is little additional work and the crew has instant feedback on success of the EVA. The differences between physical and mental demands for science and survey EVAs could be the main reason behind the different blood pressure profiles.

As expected and in correlation with the other EVA types the percent O2 saturation of the blood post survey EVA decreases. This average decrease between pre and post EVA is 2.25 percent, a decrease greater than science EVAs, but less than public relations EVAs. The SpO2 rating falling between the science and public relations EVAs is interesting. Public relations EVAs have a higher difference between pre and post SpO2 than either science or survey EVA types. This could be due to an increase in physical work or due to the increased time on EVA.

Public relations EVAs make up 17 percent of the EVAs and were most commonly executed during the 1st and 4th quarters. The higher frequency of public relations EVAs appears to correspond with the external interest in the program; occurring at the start of the simulation and just before the simulation ended and the crew exited the habitat. These EVAs had the highest performance rating at 97.5 percent and were commonly performed within 200 meters of the
habitat. The EVAs average length was around fifty four minutes, most of this time was spent setting up and taking down the components used for media creation. Heart rate may indicate an increased workload, with an average change of 9.5 beats per minute difference between the pre to post EVA data. Similar to other EVA types the preparation prior to the EVA seems to be more stressful than after the EVA is completed.

Systolic blood pressure shows a slight decrease of 3.5mmHg; the decrease infers that the public relations EVAs provide relaxation for the crew. Science and public relations EVAs have similar average EVA times with a difference of approximately 15 minutes, but objectives for each EVA type are generally accomplished in different locations. The differences between these two EVA types illustrates that other components beyond just EVA length dictate performance, stress, and workload for each EVA type. For example, the increased systolic pressure in the science EVA may indicate that these EVAs are more stressful than public relations EVAs. Both science and public relations EVAs have an increase in post diastolic blood pressure. With public relations EVAs Diastolic pressure displaying the highest increase out of any EVA type with 4.2 mmHg difference from pre to post. Both science and public relations EVAs have only a few factors in common that may indicate potential factors behind the similarities in diastolic blood pressure. Factors such as EVA length, familiarity with EVA objectives, similar crew numbers, and the requirement for post EVA analysis. One or several of these factors could be the cause behind the diastolic blood pressure similarities. Collection of additional metrics such as cortisol or dehydroepiandrostendion (DHEA) would provide a better understanding of the physiological and mental stress of each crew member (Groemer, 2010) and provide insight into pre and post stress patterns and biometrics for all EVA types. The percent O2 saturation for public relations EVAs indicates a slightly increased cardiac workload with a difference of 3.25 percent from pre to post EVA.
This change in percent O2 saturation is interesting considering these EVAs are performed near the habitat and last for about 50 minutes, indicating another factor not examined may be affecting these EVAs to increase the workload while decreasing stress. The difference between blood pressure and SpO2 levels one indicates a decrease in stress levels while the other seems to indicate an increase in workload. Exercise has shown many positive mental health benefits and can even supplement or act as treatment for patients with anxiety disorders (Jayakody, 2014). A similar effect may be occurring during public relation EVAs and would explain why workload seems to increase while stress decreases.

Pre and Post EVA vitals during the 120 day study were not consistent throughout the simulation indicating temporal factors played a role in performance, stress, and workload for EVA operations. The second and third quarter, especially the third quarter, display a decrease in total EVAs performed over that quarter. The equal number of science EVAs were completed during the 2nd and 4th quarters, but all other EVA types decreased in frequency (Graph 3). Heart rate was elevated for all quarters except the 2nd quarter. This difference could be due to crews’ natural adjustment to the higher altitude and familiarization with the EVA systems. This trend did not continue with the 3rd and 4th quarter, but average heart rate pre and post is decreased in comparison with the 1st quarter supporting the idea that the first quarter was more stressful due to the unfamiliarity and increased environmental stress (higher elevation).

Systolic blood pressure, the blood pressure as the heart pushes blood into the arteries, was typically higher pre EVA indicating an increase in the bodies stress response in preparation of activity. Diastolic blood pressure, the pressure within your blood vessels as the heart relaxes, was typically lower pre EVA and increased post EVA (Marieb, 2007). In the 4th quarter for both systolic and diastolic blood pressure display a drop between pre and post EVA numbers. This
only occurs in the 4\textsuperscript{th} quarter and this drop in blood pressure post EVA implies that by the end of the simulation the crew was experiencing positive effects from EVAs. It is unclear if this is due to increased familiarity with EVA system or a general positive reaction to the near completion of the simulation. During the final month the crew appears to return back to the habitat less stressed than when they left. The reasons behind this are unclear and need further investigation to fully understand the factors behind the decreased stress.

SpO2 over all four quarters on average decreased post EVA; with the greatest difference in SpO2 occurring during the 4\textsuperscript{th} quarter. This difference may be due to increased use of the modified hazmat suit due to difficulties with the MX-C in the 4\textsuperscript{th} quarter. The modified hazmat suit did not have dedicated helmet ventilation like the MX-C and was used almost exclusively due to some damage on that occurred on the MX-Cs.

Performance over the course of the HI-SEAS simulation varied based on both EVA type and when in the simulation the EVA occurred. The average performance rating over the four quarters of the simulation had an interesting pattern with distinct performance decreases in the 1\textsuperscript{st} and 3\textsuperscript{rd} quarters. The 1\textsuperscript{st} quarter decrease was most likely due to a settling in period, during which the crew physiologically, mentally, and organizationally adjusted to their new environment. In the 2\textsuperscript{nd} quarter all EVA types and the average EVA performance increased by 8 percent. The 3\textsuperscript{rd} quarter displayed a common trend seen previously in operational setting called the third quarter syndrome (Bechtel, 1991). A sharp decline in survey EVAs lead to a decrease in the overall EVA performance average. In addition the third quarter had the least number of EVAs performed with a total of 10 EVAs. The other EVA types experience the same or slightly increased levels of performance. Survey style EVAs are the most unique within the EVA composition due to their exposure to higher risk environments and the unknown factors that align with the exploration of
unknown territory. The focus required for these EVAs is another unique component and is most likely the reason for the decreased performance values. Focus and motivation in the third quarter commonly drop during aerospace operations, the full reasoning is not understood, but it appears that this trend occurred for the HI-SEAS crew and especially indicated by a decrease in survey EVAs. The 4th quarter saw an increase in EVA number and performance, however, science and public relation EVAs both decreased slightly with a large increase, of 17 percent, in the performance of survey EVAs.

From this it can be seen that performance of all EVAs is typically lower in the first quarter while the crew adjust to their new environment. For a crew exploring Mars a similar reaction may occur in the 1st quarter even with extended training for surface operations before the mission. The 3rd quarter decrease is specific to survey EVAs and may be similar for a Martian crew, although with travel time to the planet followed by surface operations with travel back to Earth after these operations it is unclear if the same temporal cycle will hold true or if the mission will be divided by the environmental changes and each new environment treated as an individual mission.

**LMAH Discussion**

The 30 day simulation utilized an EVA system designed to support two manned operations. The EVA systems have an electric rover and suitport to designed to decrease the pre EVA stress (both physiological and mental) by making preparation easier and suit donning and doffing more efficient. During the 30 day simulation a total of 19 EVAs were performed, eight maintenance, three science, four survey, and four public relations EVAs. All of the EVAs were well supported
by ground crew, a factor that the simulation crew stated increased their level of anxiety during EVA tasks and removed them from the simulation mind set. This could have one of two effects on the data, the increased anxiety could be considered similar to the stress that occurs within an extreme environment or this stress could alter the data in a non-operational manner. With this variation in the data it is difficult to use this system to examine the operational factors for EVA performance; however, the more controlled environment of LMAH provides a way to examine a few of the analog suit effects on overall performance. The small sample size makes significant conclusion less likely but can display minor trends and focus future research directions.

Maintenance EVAs are performed in all four quarters of the simulation and made up 42 percent of the total EVAs completed. These EVAs had a performance rating of 90.5 percent, a slight decrease from the overall EVA average. The average maintenance EVA length was approximately 52 minutes and kept the crew within close proximity to the habitat. The average heart rate difference between pre and post EVA is an increase of 35 beats per minute. A factor that could indicate increased workload or increased mental stress when performing tasks. Maintenance EVAs had three different task, habitat inspection with minor repairs, setup of simulated solar paneling, and the setup of a fence/windscreen. Maintenance setup tasks versus maintenance inspections (Graph 33) have similar trends, but based on the pre and post vitals of the different EVA types the setup style has increased stress and workloads. The exertion, ease, and comfort rating for the maintenance EVAs indicate that in the LMAH system maintenance EVAs cause the most exertion, are the most difficult, and are the least comfortable. Indicating that the decrease in performance for these EVAs is most likely related to the difficulties in maneuvering and utilizing the NDX-2ATs.
Scientific EVAs make up 16 percent of the EVA composition and on average took sixty nine minutes to complete. These EVAs have an average success rating of 79.3 percent, the lowest rating out of any of the EVAs. These EVAs required the crew to perform extensive geologic sampling and on site analysis of these samples. This required the crew to maneuver the suits completing fine and gross motor functions to complete the objectives. The difficulty in completing these tasks is most likely due to the effort required to overcome the analog suits limitations.

Science EVAs occur after a survey of the site has been completed to mark safety hazards and points of scientific interest. Both maintenance and science EVAs have the lowest performance.
ratings for this simulation (Graph 9), as well as, having the highest (worst) average ratings for ease, and comfort (Graph 31). The ratings indicate that the suited individual’s comfort and ease of function plays a role in determining EVA performance and objective completion. Basic vitals during these EVAs show an average increase in heart rate, systolic BP, diastolic BP, and an increase in SpO2. The increase in SpO2 seems out of place given the general SpO2 decrease in all other EVA types. The increase is 0.65 percent due to this small increase it is most likely due to physiological difference crew members rather than associated with any factors related to the site or EVA systems. Systolic and diastolic blood pressure both increase post EVA and possibly indicate that these EVAs caused more stress during and post EVA, most likely associated with both physical and mental stress. The comfort of the suits also could of played a role in increasing stress levels during these EVAs.

Survey EVAs make up 21 percent of the total EVAs completed and on average took 80 minutes to complete. These EVAs similar to the HI-SEAS were generally the longest; the sites had simulated hazards, but no real hazards present and could be one of the factors for the higher performance ratings of 100 percent. Crews were displayed an average increase in heart rate, systolic BP, and diastolic BP with a decrease in SpO2. These biometric increases were much less than the increases seen in any other type of EVA. One reason for this maybe the survey EVA setup which decrease the workload and stress for one of the EVA crew members. The setup has one crew member in the rover monitoring the suited crew member and writing down this crew member’s observations.

Survey EVAs have better ratings for exertion, ease, and comfort than maintenance or science EVAs and are rated as having increased exertion with decreased ease and comfort when compared to public relations EVAs. This may in part be due to the specific tasks required during
each EVA type. Survey EVAs require less fine and gross motor skills than maintenance or science EVAs focus more on walking around the EVA site and making visual observations. The Public relations EVAs are rated as being the most comfortable, with the least workload, and most ease. This may in part be due to the less direction and specific task assignment common to public relations EVAs. Crew members were able to develop and design the specific procedures to complete public relations tasks and were more familiar with the systems used, such as a camera.

Public Relations make up 21 percent of the total EVAs completed and general took 77 minutes to complete. These EVAs have a high performance rating of 100 percent and the crew general used these to collect images and on two occasions meet scheduled visitors to the site. Two of the four public relations EVAs had crew members interacting (talking, taking photos, and answering questions) with the visitors to the habitat. These EVAs occurred on day 17 and again on day 20, the interactive EVAs have some differences from the non-interactive PR EVAs (Graph 34). Heart rate increased for both types of public relation EVAs with a post EVA heart rate increase of 16 beats per minute for interactive and an average increase of 7.5 beats per minute for non-interactive. The systolic blood pressure increases only for PR EVAs with interaction, these have an average increase of 1.5 mmHg and could be considered due to the workload in the suits and not the interactions. The non-interactive EVAs show an average decrease, 4mmHg, in systolic blood pressure, indicating that the crew is returning to the habitat more relaxed and less excited. This indicates that the interaction plays a factor on the crew’s stress levels and alters their physiological response. The same pattern is seen with diastolic blood pressure with the interactive public relations EVAs showing an average increase 22.5mmHg, and non-interactive shows an average decrease of 4.6mmHg. SpO2 reading decrease for both types of public relations EVAs: the interactive shows an average decrease of 2.5 percent and non-interactive
showing a decrease of 0.3 percent. Non-interactive EVAs appear to cause either more stress or more excitement during the EVA and leave the crew with elevate biometrics not similar to typical public relations EVAs. Taking a closer look at the difference in interactive verses non-interactive public relations EVAs through individual analysis for the two public relations EVAs shows the same trends seen in the group analysis (Graph 35). This removes any group bias and shows that these trends indicate a real change in physiological response to the two different public relations EVAs. The effects of the different EVAs are difficult to quantify and it appears for the LMAH simulation that this had no effect on overall EVA performance for public relations EVAs.

Graph 34: Biometrics pre and post public relations EVAs for interactive vs. non-interactive EVAs.
EVA performance over the course of the simulation shows an average increase with no discernable change in the 3rd or 4th quarters. This can be explained by the crew becoming familiar with the EVA systems and operations, leading to a direct increase over time in performance.

Average heart rate pre and post EVA decrease post EVA by the 3rd quarter and could indicate a decrease in workload. This also appears to correlate with the performance rating that increased in the 3rd and 4th quarters. The difference in systolic blood pressure post EVA shows a distinct drop in the third quarter when compared to the 1st and 2nd quarters. The 4th quarter systolic blood
pressure, like the HI-SEAS data, shows a decrease post EVA and may indicate a decreased stress level upon returning to the habitat. Diastolic blood pressure increases every quarter, but in the 3\textsuperscript{rd} quarter the crew displays a decrease average starting diastolic blood pressure. The 4\textsuperscript{th} quarter shows a smaller change in diastolic blood pressure between pre and post. This change in vitals in the 4\textsuperscript{th} quarter corresponds to the change seen during the HI-SEAS simulation and could be due to the proximity to the simulations end or a familiarization with the EVA components.

\textit{EVA Profiles}

Developing accurate profiles for each EVA type will take additional data and more analog simulations in operational environments. Based on the data from the HI-SEAS mission some general EVA trends can be selected and utilized to create a rough EVA profile by EVA type and timing. These profiles may allow for future prediction of performance, limitations, or requirements when developing planetary EVA equipment and procedures. By taking the difference between each individuals pre and post EVA metrics and adding then averaging these metrics together and taking the average error on either side of this number provides a specific range of vitals and logistics for each EVA type. Each profile shows the range in which each biometric should change from pre to post EVA based on EVA type.

\textit{Midpoint equation:}

Equation 1.1 \( \frac{(A_2-A_1)+(B_2-B_1)+(n_2-n_1,...)}{\text{number of data sets}} = \text{Average Change} \)

\textit{Low/Highpoint Equation:}

Equation 1.2 \( \text{Average Change} \div \text{Number of Data Sets} = \text{Set variation} \)
Equation 1.3 \hspace{1cm} \text{Midpoint} \pm \text{Set variation} = \text{Low}/\text{Highpoints}

The biometric profiles display the range of change expected for each biometric. The larger the color grouping is the higher the variability between pre and post EVA biometrics. Each biometric profile represents the unique blueprint for each EVA type.
Maintenance EVAs (Graph 36) have greater variability in heart rate and systolic blood pressure pre and post EVA. These EVAs have a positive change in heart rate and SpO2 with a negative change in systolic and diastolic blood pressure.

Graph 37: Biometric profile for science type EVAs, from individual data sets collected during the HI-SEAS 120 day simulation.
Science EVAs (Graph37) have their greatest variability in diastolic blood pressure between pre and post EVA. They have positive change for heart rate, systolic blood pressure, and diastolic blood pressure; the SpO2 value decreases.
Survey EVAs (Graph 38) have their greatest variability in heart rate, with a notable amount of variability in systolic blood pressure. These EVAs have a positive change in heart rate and a negative change in systolic blood pressure, diastolic blood pressure, and SpO2.

Public relations EVAs (Graph 39) have their greatest variability in heart rate and a notable amount of variation in diastolic blood pressure. These EVAs have a positive change in heart rate and diastolic blood pressure with a negative change in systolic blood pressure and SpO2.

<table>
<thead>
<tr>
<th>Heart Rate Changes BPM</th>
<th>Systolic Changes mmHg</th>
<th>Diastolic Changes mmHg</th>
<th>SpO2 Changes Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>9.17</td>
<td>-3.93</td>
<td>4.21</td>
</tr>
<tr>
<td>Mid</td>
<td>11</td>
<td>-3.5</td>
<td>4.75</td>
</tr>
<tr>
<td>High</td>
<td>12.83</td>
<td>-3.06</td>
<td>5.29</td>
</tr>
</tbody>
</table>

Graph 39: Biometric profile for public relations type EVAs, from individual data sets collected during the HI-SEAS 120 day simulation.
CHAPTER XII
CONCLUSIONS

Human exploration of Mars becomes progressively possible as new technologies and knowledge become available. As human presence expands away from LEO it will be important to ensure astronaut safety by understanding how this move into extreme and isolating environments will affect performance. Collecting data from Earth based analogs provides a starting point for technology, procedural, and logistical developments. In this study the author was able to focus on field operational factors of analog planetary EVAs for specific EVA types.

In an analog setting EVAs are divided into five main groups, maintenance, science, survey, public relations, and emergency operations. Maintenance EVAs are shorter in length, occur in a higher frequency early on, and are performed near the habitat. These EVAs can be divided into two types: systems setup/repair and monitoring. Each maintenance type requires increase fine motor control and may display an increase in stress pre-EVA. Science EVAs are longer, occur regularly after the 1st quarter, and can be performed near or far from the habitat depending on the specific EVA objectives. These EVAs have increased mental focus and require crew members to follow specific instructions to complete tasks. Post EVA metrics indicate increased stress upon EVA completion and this may be due to the post EVA processing of data. Survey EVAs take the most time, have lower performance ratings, and occur away from the habitat. Due to the exploration of unknown terrain these EVA require increase preparations and while the crew is exploring new terrain requires hyper-focus to maintain safe operations. Once out of the new
terrain crew members relax and show a general decrease in stress post EVA. The public relations EVAs occur near the habitat, are shorter in duration, and crews use media systems already familiar to them. A slight trend towards increased stress post EVA may be due to the mental focus of completing a specific task and the post EVA processing of material. These various EVA types have unique characteristics and biometric profiles that display similar trends between two different planetary analog facilities.

Current training programs focus on the development of specific or broad skills, but are not tailored to specific EVA types. This is part due to the microgravity and vacuum environment of LEO which leads to similar EVAs. As seen in the analog studies planetary EVA activities may have distinct operational and biometric patterns that could be used to develop training programs specific to EVA type.

EVA type and chronological dynamics appear to play a factor in EVA performance. The HI-SEAS and LMAH analogs have a decrease in performance in the 1st quarter that can be attributed to the crew’s acclimation of the new environment and EVA systems. The HI-SEAS simulation experienced an additional drop in performance that occurs in the 3rd quarter. This drop is similar to a pattern, the third quarter syndrome, seen in some previous environments associated with high stress, extreme conditions, and isolation.

After the initial acclimation period most EVA types illustrated a decrease in biometrics post EVA. The biometrics increase indicate a pre-EVA state with more stress than the EVA or post EVA period. This did not hold true for all EVA types; science and PR EVAs have minor trends of increased stress post EVA. As mentioned earlier these increases could be due to the requirement for post processing of EVA data and media. Biometrics in the 4th quarter of both
Simulations decrease post EVA, a unique trend within the timeline. This increase could be due to the excitement and happiness present near end of the simulation. The 4th quarter did not seem to display any negative effects from this change in biometrics and a performance increase was noted. Examination of specific factors leading to performance increases in the 4th and 2nd quarters may provide reasons for these increases that can be applied to an entire mission to provide a mission wide performance increase.

Analog suits have a negative effect on the biometrics and performance ratings, increasing workload, while decrease comfort and output. During the LMAH simulation an EVAs with decreased comfort ratings have a correlation with EVAs displaying a lower performance rating. In the HI-SEAS simulation it is possible that a decrease in air circulation within one type suit led to a greater negative change in SpO2 data between pre and posts EVA data sets. Additionally, EVA tasks needing more fine and gross motor function over observational tasking had reduced performance rating. This reduction can be attributed to the decreased range of motion and motor control that occurs within the analog suits. This was particularly true for the LMAH facility since only one suit type is available. At the HI-SEAS crew members had two analog suit type with complimentary attributes and limitations allowing users to select the suit that would be most beneficial in accurately completing the objective. Bringing up an interesting thought of how multiple suit types or replaceable suit components would alter performance and if this could be a potential way to increase performance.

When conducting operational analog EVA studies it is important to ensure that subjects meet the basic qualification, or are “astronaut like.” Individuals with less fitness or increased stress reactions tend to have a different physiological and mental response to environments with increased stress and isolation. When performing data collection for operational metrics the
higher the realism of the simulation the stronger the data set. Safety always takes precedence over simulation, but measures should be taken to increase realism when focusing on operational data to ensure that accurate correlations can be obtained. The LMAH facilities EVA systems have a suitport component that decreases overall stress and preparation time, however, the early state of development led to increased ground support and crew interaction. The crew stated that this interaction removed them from simulation and increased anxiety, giving them a “watched” feeling. This most likely altered their biometric and logistical data making it difficult to correlate operational factors beyond how the suits affected performance.

The development of profiles for specific EVA types can aid in the development of training methods, procedures, and equipment. It shows areas that have a higher potential for failure and indicates some reasoning for these failures. Autonomous EVA function is likely to be a component of future planetary EVAs and understanding the physiological and logistical dynamics may be achieved through the use of analog facilities and the understanding of how autonomous crews in extreme environments react to typical EVA tasks.
CHAPTER XIII
FUTURE RESEARCH DIRECTIONS

This study provides some insights into trends and patterns for analog planetary EVAs, but has raised more questions such as: what factors in an EVA cause specific reactions and what factors are reliable to performance? This data can be built upon to continue gathering an understanding of pre and post EVA biometrics in operational settings. By understanding these patterns increased realism can be introduced to the training environments; increasing the monitoring of trainees to ensure realism on a biological level.

Mimicking the patterns developed in real world operations and analogs could prepare future explorers for planetary operations. Additional consideration for the journey to the planet will need to be researched to best understand how this will affect the EVAs early on. As seen in this study the crews will most likely adapt to their environment by the second quarter of operation, but the journey may have unforeseen impacts on the crew.

Additional studies conducted in varying extremes and isolation will aid in teasing out some of the underlying factors associated with performance metrics and biometrics during EVAs. Places such as the Arctic, NEEMO, and Antarctica could provide increased realism and stress to better understand the many factors associated with planetary EVAs.
APPENDIX

Appendix A
Common Acronyms

Acronyms:

BP - Blood Pressure
BPM - Beats per Minute
EVA - Extra-vehicular Activity
HI-SEAS - Hawaii Space Exploration Analog and Simulation
HR - Heart rate
ISS - International Space Station
LEO - Low Earth Orbit
LEVA - Lunar Extra-vehicular Activity
LMAH - Lunar/Martian Analog Habitat
MX-C - Maryland Experimental C
NASA - National Aeronautics and Space Administration
NDX-2 - North Dakota Experimental 2
NDX-2AT - North Dakota Experimental 2 Analog Trainer
UND - University of North Dakota
Appendix B
Data Collection Protocols Provided to the LMAH Crew

EVA Performance Data Collection Protocol:

This study is focused on determining and creating a base profile for how stress affects crew members’ EVA performance over the duration of an analog mission. You will be collection data Pre and Post EVAs by the following methods

- Vitals
- Salivary Collection for cortisol analysis
- Pre/Post Surveys
- Collection of EVA Requests and Logs

**Vitals**

- Heart Rate
- Blood Pressure
- SpO2

Vitals should be collected:

- 10-20 minutes before entering the Rover.
- Immediately upon returning to the Rover and doffing the suit.

**Blood Pressure Cuff (Heart rate/Blood pressure)**

- Blood pressure and heart rate will be collected through the automatic blood pressure cuff.
- Place the cuff on the left arm 3-4 inches above the elbow crease.
  - The cuff should be snug but not tight.
- Press the start button
  - The cuff should inflate
  - The cuff can become mildly uncomfortable
  - Occasionally (1/3 of the time) the cuff shows an E indicating an error and the cuff needs to be allowed to completely deflate before re-attempting to inflate the cuff.
• Document the Blood Pressure reading (i.e. 120/80).
• Document the heart rate.

**Cortisol**

• 2mL of passive drool Saliva

Saliva should be collected

• 10-20 minutes before entering the Rover.
• Immediately upon returning to the Rover and doffing the suit.

**NOTE:** Do not eat, drink, or brush your teeth with 15 minutes of salivary collection any contaminants will ruin the sample.

Saliva collection:

• Label the Saliva collection 2mL tube with EVA number and Subject number.
• Saliva is collected using a passive drool method.
• Place the salivary collection aid into the 2mL collection tube.
• Do not force spit, but allow saliva to passively fill the tube by “drooling” into the collection tube.
• Place the sample into the sample collection box and store in the freezer.

**Survey:**

• Pre EVA Survey
• Post EVA Survey

Surveys should be filled out:

• Pre-surveys completed no more than an hour before the EVA
• Post-survey completed no more than 30 minutes after the EVA

**PRE-SURVEY Questions:**

1) Hour of sleep in the past 24 hours?
- List any sleep from the past 24 hours prior to completing this survey (i.e. if you are fill out the survey at 9:00AM Tuesday count only the hours of sleep that occurred between Monday 9:00AM to Tuesday 9:00AM, in this case do not include any sleep before Monday 9:00AM)
- Include any naps or brief sleeps.

2) General Mood?
- Provide your mood at this exact moment.
- Use general terms (in example but not limited to Happy, frustrated, tired, depressed)

3) General Health Rating (1-10):
- The scale indicates 1 as feeling deathly ill, 5 indicates feeling average, 10 indicates feeling better than normal. (i.e. if you have a minor headache you would rate this as a 4)

4) Have you exercised in the past 24 hours (if so provide duration and intensity)?
- List any exercise from the past 24 hours prior to completing this survey.

5) How much water over the past 24 hour?
- If possible list any water, tea, coffee, Gatorade, any liquid consumed in the past 24 hours.
- If the exact number is difficult to track or calculate please estimate or provide a rough idea of liquid consumption.

6) What and when was your last meal?
- List time of last meal.
- List meal and about how much of the meal was eaten.
7) EVA Type?
   o List type of EVA is a Maintenance, Science, Survey, or PR EVA.
   o If the EVA is a combination select the EVA type based on the most prominent activity. (i.e. if you plan to survey a new EVA site and clean the solar panels list the EVA as whichever activity is the main objective).

8) Planned Objectives:
   o List all Objectives of this EVA
   o Objectives should be listed in order of importance.

POST-SURVEY Questions:

1) EVA LENGTH
   o Time from undocking from the habitat to returning to the rover from the NDX-2AT.

2) # OF OBJECTIVES COMPLETED
   o List as a ration with number of objectives complete on top and total number of objectives on the bottom (i.e. 3/4 for 3 out of 4 objective complete).

3) # OF ISSUES
   o List total number of issues the occurred on EVA include communication, deviation from plan, suit issues, equipment difficulties, etc.

4) ISSUES:  EQUIPMENT________OPERATIONAL________ SUIT__________
   OTHER___________
   DESCRIPTION:_____________________________________________________________________
   ________________________________
   o List a breakdown of the issues into the appropriate category.
   o If unsure list as other and give a brief description.

5) Rate EVA success on a scale of 0-100%
Rating should be done based on the following:

- If you have 4 objectives each objective equals a total of 25% towards EVA success, 2 Objectives would make each equal to 50% of total EVA success.
- Any issues occurring, such as loss of communication, broken tools, should each count as -2%.

6) Rate Level of Perceived Exertion/Workload (1-10)

- Rating Level of exertion from the time of undocking with the suitport until re-docking with the suit port.
- Scale goes from 1 being no noticeable exertion, 5 is 50% of total exertion, 10 is 100% total exertion and completely unable to move or function.

7) Rate Level of Ease (1-10)

- Rating the ease of use of the NDX-2AT and suitports while performing EVAs.
- Scale goes from 1 being equal to the ease of use when not wearing the suit, to 10 being unable to use the suit for the intended purpose.

8) Rate Level of Comfort (1-10)

- Rating level of comfort from the time of undocking with the suitport until re-docking with the suit port.
- Scale goes from 1 indicating comfort similar to performing these activities out of the suit to 10 being unable to perform the activities due to the suits comfort level.

9) General Mood?

- Provide your mood at this exact moment.
- Use general terms (in example but not limited to Happy, frustrated, tired, depressed)

10) General Health Rating (1-10)

- The scale indicates 1 as feeling deathly ill, 5 indicates feeling average, 10 indicates feeling better than normal. (i.e. if you have a minor headache you would rate this as a 4)
REFERENCES


Cull, S., Kennedy, E., & Clark, A. Aqueous and non-aqueous soil processes on the northern plains of mars: Insights from the distribution of perchlorate salts at the phoenix landing site and in earth analog environments. Planetary and Space Science, (0)


Gri, M O Gríofa, Marc Blue, Rebecca Cohen, Kenneth O’Keeffe, Derek. (2011). Sleep stability and cognitive function in an arctic martian analogue. Aviation, Space, and Environmental Medicine, 82(4), 434-441.


