Designing for Mars:
Mitigating Habitability Factors to Support Crew Performance

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This presentation provides an overview of the habitability factors that affect the design of space habitats for long-duration spaceflight missions. Components of habitability that affect human adaptation to an isolated and confined environment are discussed. These elements are presented as part of a larger group of environmental factors, aesthetics, and habitat architecture. Design recommendations are provided to support practicing human factors specialists, architects, and engineers in creating an environment that promotes productivity and supports crew performance. A comparison to a current Mars analog environment is included to illustrate the findings and recommendations for future habitat designs. Current research efforts implementing these recommendations are discussed.

INTRODUCTION

An interdisciplinary approach between human factors, architecture, and engineering is needed for designing future habitats for interplanetary missions. Simplicity and usability are key components to ensuring that residing in an isolated and confined environment (ICE) such as a space habitat are successful. Harrison (2010) has stated that in order for future spacefarers to live and work comfortably in space there must be a user-centered design effort undertaken by these disciplines.

Habitats that will house humans on Mars will be research stations that are built and packaged on Earth. Since the length of such a mission can extend up to 3 years, the architecture of the habitat will follow a functional role in providing an Earth-like interior with the additional life support systems to live and work in an extreme environment; analogue environments are commonly used to simulate these conditions. Behavioral research has suggested that habitat design issues for long-duration spaceflight can affect crew psychological states and behavior; therefore, these issues are even more important today as the private and government sectors of space exploration progress towards these types of missions.

Mars-analogue research stations provide a test bed to assess human performance in an isolated and confined environment. The reliability of these simulation environments are essential to sustaining the level of fidelity needed for a real Mars mission.

FACTORS EFFECTING HABITAT DESIGN

Kanas and Manzey (2008) have listed and briefly address some important habitability issues for long-duration space flights such as environmental factors (e.g. noise and temperature), architecture, living/working quarters design, hygiene and health facilities, facility management, and extravehicular activities (EVAs). However, this list is not all-inclusive as other studies have proposed additional elements to habitability. Mohanty, Jorgensen, and Nystrom (2006a) outlined design issues that can influence crew psychology and behavior, such as the habitat architecture, which can be considered an expansion and addition to items listed by Kanas and Manzey (2008). When compiled, the aforementioned findings, along with additional support for habitat aesthetics and improving the quality of life of future space crews (e.g. Kring, 2001; Stuster, 1996; Schlacht et al., 2010; Bannova & Jorgensen, 2006), highlight the need for additional research.

This presentation summarizes these findings by grouping them into three categories: environmental factors, habitat aesthetics, and architecture. Design recommendations will be provided for each category

ENVIRONMENT

Environmental factors that can affect habitability are illumination, temperature, sound, odor, and ventilation. These sample elements may appear to be less critical but can progress to affecting crew performance (Reed & Coutler, 2000; Kanas & Manzey, 2008; Mohanty, Jorgensen, & Nystrom, 2006a).

These factors surfaced during a recent human factors research mission to the Mars Society's Mars Desert Research Station (MDRS) (Iwig, et al., 2013). The MDRS is situated in an isolated location in the Utah desert. During the 2-week mission, participants completed questionnaires rating their perception of the habitat environment at the start, middle and end of the study. Environmental factors had a significant impact on habitability. Figure 1 displays the results for each participant; higher scores indicated positive ratings for the habitat environment. While scores did rise for the latter half of the mission, they did not recover to the original assessments. For example, crew member reports included negative responses about the disproportionate amount of artificial and natural light at the MDRS.

Recently, Caballero-Arce, Vigil-de Insausti, and Benlloch-Marco (2012) conducted an investigation to determine the significance of proper lighting (temperature and color) in a space habitat. The authors emphasized the importance of environmental psychology and habitat design as a joint venture. Since artificial light can have a negative effect on a person's circadian rhythms, a balance must be found where crews can have access to an ample amount of natural and artificial light.

The desert landscape of Mars provides an environment where proper ventilation systems will be needed to mitigate the accumulation of dust inside the habitat when crews are returning from an EVA. Suitable systems can also help dissipate odors with a continuous airflow. Insufficient ventilation can create a source of psychological and physiological stress. Also, a heating and cooling system must be operationally sufficient to maintain a nominal temperature range within the habitat despite the extreme temperature changes than can occur seasonally in the Martian atmosphere. Sounds created by such systems should be kept to a minimum acceptable level and located in areas that do not interfere with daily operations. While Reed and Coutler (2000) have stated that the environmental factors critical for survival are habitat atmosphere, radiation protection, and temperature, it is still imperative to recognize that the other factors listed here can be a detriment to performance, especially for a long-duration mission. Figure 2 is a preliminary sketch that implements a balance between natural and artificial light. A large window located in a central common area allows ample natural light, while softer, artificial light is located overhead. Analog research stations can adhere to these basic principles while providing an interior environment that is aesthetically pleasing.

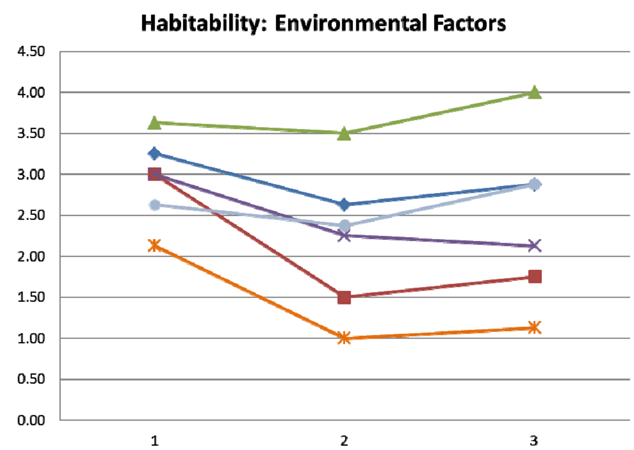

Figure 1. Environmental ratings per participant.

AESTHETICS

Schlacht et al. (2010), Kring (2001), and Stuster (1996) have detailed the need for aesthetics when designing for long-duration missions. Creating an Earth-like interior supplies the necessary sensory stimulation and supplements crew morale (Kring, 2001). For a mission to Mars, the simple activity of observing landscapes similar in appearance to those found on Earth should not be overlooked. For example, in Clearwater and Coss (1991), the authors reported on the psychological benefits and value of adding windows to the proposed International Space Station (ISS). Schlacht et al. (2010) suggested that for spacecraft design the individual needs, as well as those of the crew, should be considered from a holistic perspective; factors such as aesthetics are a contributor to an astronaut's quality of life and performance. This is especially important considering the other psychological effects that occur and corresponding countermeasures that are needed in ICEs.

From a historical perspective, Stuster (1996) discusses the positive impact of decorating private space with personal affects during long-duration expedition missions. It is proposed that future designs allow the flexibility to personalize the design of private quarters with input and feedback from the space crews that will be using them.

Other areas that can improve the aesthetics are materials used in the construction process. An environmentally-friendly material such as bamboo is a type of building material that can be used in many different applications. Bamboo, which is lightweight and visually appealing, can be used as flooring and support structure for crew quarters. A sustainable material such as bamboo can be grown in a greenhouse on Mars and be used for future architectural features.

Figure 2 is an elementary step in practicing on how to integrate aesthetics. The surrounding wall is no longer a familiar white but a dark pearl finish allowing for some light reflection. The individual workstation located on the left is made out of bamboo and the interactive display on the right can be used as a work station to view art or images from Earth. The floor is also constructed from bamboo and trimmed with polished aluminum to complete an aesthetically pleasing interior for a habitat.

Figure 2. Interior perspective of a space habitat.

ARCHITECTURE

Mohanty, Mount, and Nystrom (2006b) have investigated Mars-simulations' fidelity by examining the architectural, functional, organizational, and environmental similarities as well as collecting data from the participants on 'mission realistic' experiences. Studies such as these are critical to habitat design; their results are precursors to future habitat development.

It is a design challenge to construct a structure to house a small amount of individuals who must live and conduct various forms of research in a limited amount of space. A habitat is a continuous inspection on the architecture, an issue that not all simulations provide to raise awareness about the structure and support systems that protect crews from the harsh environment. The volume for designing a habitat is determined by mission length, size of crew, and mission objectives (Stilwell, Boutros, & Connolly, 2000). One of the design challenges is integrating multipurpose areas where the separation of public and personal space can exist. Another challenge is the strategic placement of certain locations such as the galley and hygiene areas that will not affect the crew and supporting programs (e.g. research workstations). Current simulations have a limited amount of operational architecture requirements and further research (e.g. functional task analysis and usability testing) is needed for proper analysis in creating a better architecture for the next space habitat.

Figure 2 is an example of a proposed layout; three common areas of a habitat are shown. These areas include an individual work station, a window outlook area, and an interactive display which multiple crew members can use. The perspective created can allow up to three to five crew members to view or work without interrupting one another. The separation exists by having a neutral area in-between two work areas. While providing natural sunlight, the window also creates a natural transition from one workspace to another.

DISCUSSION

An overview of habitability factors is presented with the focus on creating a positive environment for long duration space crews. Three areas of interest (environment, habitat aesthetics, and architecture) were identified as contributing factors to a positive experience for a long duration mission to Mars. Recommendations were suggested for future design. The optimal way to test and evaluate these factors is by analyzing the fidelity of Mars-analogue environments.

For example, the habitability ratings obtained by one of the authors at the MDRS Mars habitat analog location revealed several concerns in terms of layout and workstation design. Findings from this simulation, as well as our own review of literature related to design in ICEs, were incorporated into several design concepts for a crew module or habitat for planetary operations.

Our next step is to begin testing some of these recommendations in a test bed called the Mobile Extreme Environment Research Station, or MEERS. MEERS is a university-funded mobile habitat design facility that will provide a platform for conducting human performance and habitat design research. This project is an interdisciplinary effort amongst diverse departments across the university including human factors, engineering, computer science and the humanities. The goal of MEERS is to contribute to the expanding field of space habitability and architecture by simulating conditions expected to be found ICEs. Fundamental areas such as workstations, crew quarters and hygiene areas will be constructed with the flexibility of reconfiguration as optimal layouts are discovered. Solutions proposed in this paper will follow an iterative design process; feedback and expertise provided from participating departments will be integrated through each design phase. Initial areas for design review include evaluating new and existing environmental and life support systems, food preparation and storage, water storage and distribution, and crew quarters design.

It is generally accepted that crew performance can be influenced by a habitat's design. MEERS seeks to ameliorate current habitat design issues using a user-centered approach and recommendations discussed in this proposal.

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