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HUMAN FACTORS IN THE SPACE STATION DESIGN PROCESS

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ABSTRACT

Until now, human factors in the discipline that is concerned with the interactions between humans and other elements of a system have not been taken into account appropriately, which is why the level of performance on space stations, from the Mir to the current International Space Station, is reportedly low.

As underlined by the European Cooperation for Space Standardization, the integration of sound human factors into all project phases related to human space mission, starting from the very beginning, has become a primary necessity, in particular considering the approaching scenario of long duration/range missions. As a means for dealing with this need, this work proposes a new conceptual model, which focuses on incorporating human factors principles right from the preliminary design phase into all aspects of long-duration/range human mission projects in order to improve habitability. The new conceptual model -developed during five years of doctoral research at TU-Berlin- referred to herein as the Integrated Design Process (IDP), incorporates three key design principles: habitability factors, a user-centered approach, and a holistic methodology. The conceptual model was tested against existing models in four separate studies, specifically: a study on Moon Base design at the SSDW 2009; a study to investigate habitability on the Mars Desert Research Station; a study to design space equipment for system operations at the TU-Berlin; and a study to design a closed-loop habitat for long duration missions with the DLR. The results suggest that employing such a model during the design phase of a space mission will improve habitability and usability of the item under development, thus improving user performance, safety, and ultimately mission success. The implications of such a model extend beyond application in space and include other environments where individuals are expected to live and work in confined areas for extended periods of time, such as in research laboratories in Antarctica. It can also be applied in megacities as well as in retirement homes.

Keywords: Space, Habitability, Human-Machine Systems, Human Factors, Design Process, Concurrent Design

1. BACKGROUND

This paper is a revision of the PhD thesis Space Habitability (Schlacht, 2012)[i].

Habitability is defined by the NASA Operational Habitability Team as “the usability of the environment” (Blume, 2000)[ii], and internationally by different space agencies as “the quality of life in an environment” (AA.VV, 1999)[iii]. In space missions, human factors design aims to support habitability and overall system performance. In long duration missions, many human factors problems affect the habitability level. On the International Space Station, for example, these include issues such as small habitable volume without recreational space, crowdedness due to all kinds of equipment, lack of storage resulting in difficulties finding stuff, an absence of standardization regarding interfaces, lack of privacy, absence of variability, and many other factors. In the difficult conditions of space missions, the habitat needs to fully support human performance and well-being by reducing or avoiding potential psycho-physiological problems with sound and dedicated design.

Fig.1: Astronauts eating inside the ISS Zvezda Module (© NASA[iv])

2. CHALLENGES

Until now, human factors have not been taken into account appropriately and, as a consequence, the level of habitability on space stations, from the Mir to the current International Space Station, has been low. This situation is caused by two gaps. The first gap lies in the military approach that forms the basis of human space flight development. This approach does not consider the human side of the user, such as his or her sensory, affective, and cultural needs. The lack of application of these dimensions could become problematic in view of prolonged mission duration and the opening up of space missions to the general public as in space tourism. The second gap is found in the application of the same procedures for human and robotic missions, which even today do not include human factors from the preliminary and conceptual design phase. Indeed, the conceptual design of a system poses a significant challenge to the traditional design approach used for robotic or short duration missions (Osburg, 2002)[v].

In the interviews done by the author, 13 of the 14 astronauts interviewed suggested that habitability needs improvement, particularly in anticipation of long duration missions. As a result of the analysis of user interviews, mission debriefing reports, and space agency standards, it emerged that with increasing mission duration and distance from the Earth, the effect of the problems related to habitability and human factors grows so strongly that, if not adequately dealt with from the first phase of mission design, it will impact user performance and become a safety hazard for astronauts' lives. In particular, psychological and socio-cultural factors, which were identified as not being adequately considered in the current project methodology, are of increasing importance in the context of long duration/range missions. However, along with the psychological and socio-cultural factors, problems related to operational and physical factors were also identified as fundamental factors that have to be considered to ensure mission success and safety. In detail, stowage systems, living conditions, privacy, autonomy, and variability were identified as fundamental needs that have to be considered to ensure long duration/range mission success and safety.

As a consequence of denying human factors in the project, the current "man in a can" design (referring to the shape of the space station's habitat module) does not allow the performance, safety, and well-being of humans in space needed for the success of long distance/range missions. Only the application of sound human factors principles from the start of the design project will assure a level of habitability that will ensure mission success in long distance/range missions.

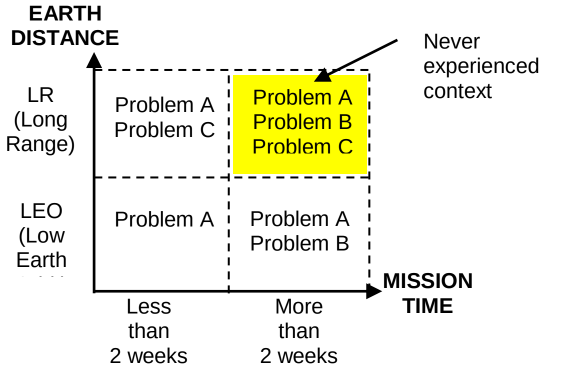

Fig.1: Examples of the snowball effect of habitability problems

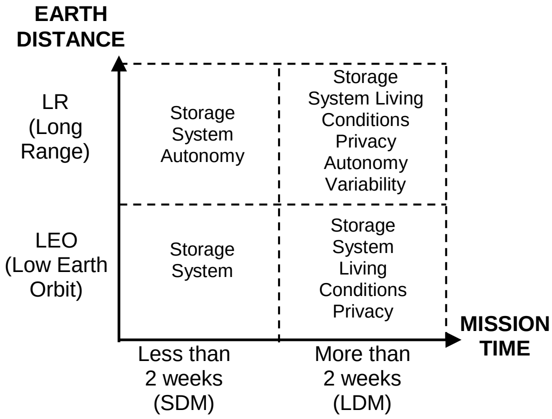

Fig.2: Examples of habitability problems

3. SOLUTION

In 2008, the European Cooperation for Space Standardization underlined the need for integrating human factors into all project phases from the beginning: "The customer's total cost of ownership will be dramatically reduced if HFE (Human Factors Engineering) practices are well integrated into all project phases, from the very beginning" (ECSS, 2008, p. 8)[vi]. This concept is of primary importance for reducing mission costs, but is also necessary for mission success and for the safety of the users; and it becomes fundamental in view of far distances and prolonged mission duration. At the European Space Agency, there currently exists no adequate process for integrating human factors from the preliminary phase of design projects for human missions; this has repercussions on the overall system habitability.

The highlight of this dissertation is the development of a new conceptual model that integrates the design of human factors from the preliminary phase of design process in order to enhance long duration mission habitability. This new conceptual model is labeled the Integrated Design Process (IDP) because it integrates operational, physical-environmental, psychological, and socio-cultural habitability factors starting from the conceptual phase of a long duration mission. The IDP effectively supports the quest for knowledge in space missions from multiple and qualitative perspectives, including, beyond the scientific perspective, the cultural gaining of knowledge. This helps the astronauts to not only acquire new knowledge, but also to express it. The IDP is based on a human-centered approach and a holistic methodology. To support the human side of the project, such as cultural and affective dimensions, the human-centered design focuses on three techniques: designing the experience of the user (user experience), designing together with the user (participatory design), and designing by identifying oneself with the user (empathetic design). The holistic methodology aims at supporting the user in relation to the system and is composed of the interrelation among three main qualitative-oriented methods: multidisciplinary team (integrating humanities), concurrent design, and human-machine-environment interactions. The application of the design model in respect to the current methodology increases habitability because it supports usability, livability and flexibility when it comes to designing innovative solutions.

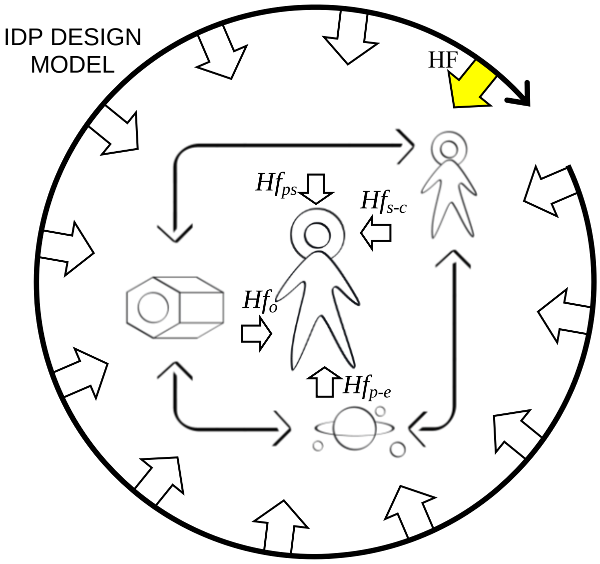

Fig.2: IDP integrates qualitative HF dimensions into the preliminary mission design to support the habitability factors (Hf) aimed at increasing quality of life in long duration missions

4. VERIFICATION

To verify the validity of this methodology, the IDP has been applied to the conceptual phase of studies related to long duration space missions. The case studies varied from the design of an individual element of the system, such as debriefing procedures, sensory stimulation, entertainment, and fitness equipment, to overall habitat design, such as the design of a Moon Base.

4.1 Study 1

The aim of the first study was to design a Moon Base habitat. The study was conducted by two teams of students in the context of a Space Station Design Workshop, which is performed every year at the University of Stuttgart. The results were compared with the results of the teams that applied the usual methodology. The comparison revealed that the IDP teams focused more on the human factors in the project and found highly innovative solutions by applying new technologies to increase habitability in long duration missions (Messerschmid, 2009)[vii].

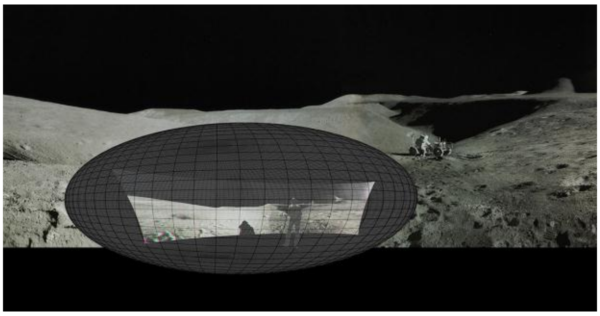

Fig.3: SSDW-IDP LunoX Moon Base camera obscura: Little holes in the wall of a dark module sealed with lenses will create the inverted projection of the external environment, with sky and EVA (SSDW 2009, Leonard Boeldieu, supervised by I.L. Schlacht).

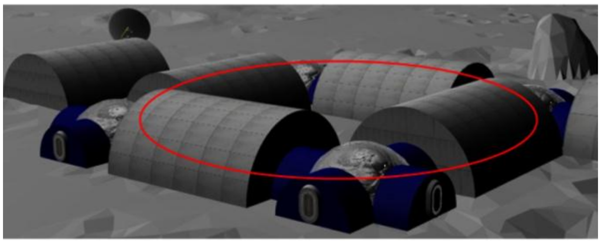

Fig.4: Moon Base Team Blue SSDWIDP 2009. This configuration, used also by the ancient Romans and by nomadic populations until today, creates a feeling of safety against a potentially harmful environment, supporting psychological well-being (SSDW 2009, Jan Grippenkoven, supervised by I.L. Schlacht).

4.2 Study 2

The aim of the second study was to perform research on human aspects in preparation for future extra-terrestrial planetary exploration. The study was conducted during ESA-ILEWG mission campaigns at the Mars Desert Research Station. Habitability debriefing procedures, creative activities, and innovative sensory equipment to counteract sensory monotony were prepared and tested. The results were compared with the previous year one. The comparison revealed that both studies dealt with problems related to the working conditions; however, the IDP study tackled problems related also to the working conditions, supporting personal expressions and creative approaches, which are needed for acquiring and communicating new knowledge, finding problem solutions in unknown scenarios, but also for psychological stability.

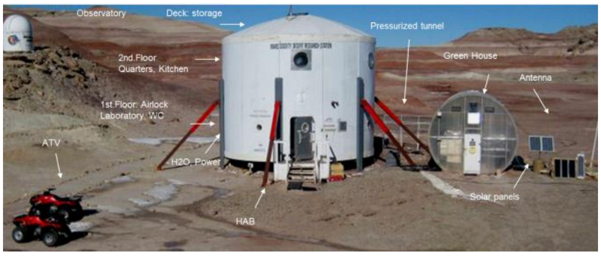

Fig.5: MDRS structure (computer manipulated photo based on photo by Mars Society)

Fig.6: Problems with geological instrument interaction at MDRS, 2010: The instrument monitor is not visible because of solar light and helmet; the interface is not usable with EVA gloves; the instrument's design should be dedicated to the particular human-machine-environment interaction of space. It is not convenient to adapt earth instruments for use in space exploration.

4.3 Study 3

The aim of the third study was to find solutions to habitability problems in long duration missions. The study was conducted with three classes of students of the Human-Machine System Chair at TU-Berlin. During the study, new disciplines specifically applied to the space context were created. New technology and equipment were developed that considered the challenges related to space habitability right from the start. The result revealed that the class attempted to find innovative design solutions and equipment dedicated to the difficult space scenario. This turned out to effectively support user needs from a multidisciplinary perspective.

Fig.7: "Apertura", the new window to space. Clare Lillian Johnston under the tutoring of I.S. Schlacht MMS Seminar WS 2010. TU-Berlin.

4.4 Study 4

The fourth study concerned the conceptual design of the first habitat design realized by the German Space Agency DLR for a closed-loop habitat facility for long duration space missions. In comparison to the standard procedures used for robotic missions, a more dynamic procedure was incorporated, which fully integrated user-centered design and a holistic methodology. This resulted not only in support for problems related to physical and operational factors, but also led to a new project solution related to psychological and socio-cultural human needs.

The results verify that in all research phases and when considered as a whole, the IDP sustains not only functional but also sensory, cultural, and emotional needs in the habitat system. Before, space projects were based only on operational and physical needs. The IDP methodology also supports psychological and socio-cultural factors. In comparison to the classical quantitative design process used by space agencies, this process also supports the qualitative dimension of habitability and the social and "cultural significance of human space exploration" (Arts Catalyst, 2005)[viii]. Finally, in comparison with projects carried out without the IDP methodology, the results show high value scores, following an evaluation system based on usability, livability, flexibility (Häuplik-Meusburger, 2011)[ix], and innovation values.

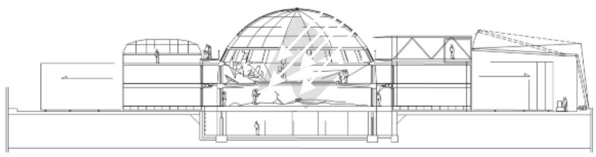

Fig.8: FLaSH habitat section, drawn by Ondrej Doule and elaborated by Irene Schlacht (DLR FLaSH study in 2011)

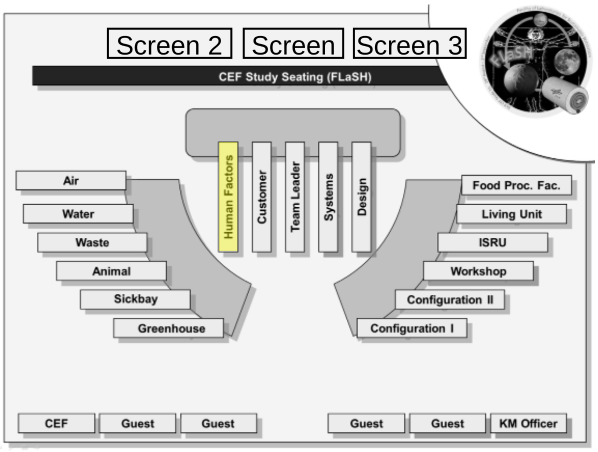

Fig.9: Concurrent Engineering Experts Configuration

5. CONCLUSION

Space missions are performed to make the human dream of getting to know the universe at large come true. This research aims to realize the optimum level of habitability and performance for astronauts in order to allow them to reach and communicate new heights and reveal the unknown so as to benefit all of humankind. The currrent design process for human space missions does not properly integrate the basic principle of quality of life into the astronauts' environment. However, this is necessary to achieve not only new knowledge, but also to ensure the safety of the astronauts. Considering the need to integrate this principle from the start of the mission design, the Integrated Design Process is the concept of a design model that aims to fulfill this need. This concept model has been used in different projects and experiments, in particular considering the context of long duration and long range missions. The results increase the sustainability and quality of habitability solutions for human space missions in order to support astronaut performance and safety.

6. Future Research Directions

Living and working in extra-terrestrial habitats means being potentially vulnerable to very harsh environmental, social, and psychological conditions. Different from machines, "human requirements are not secured constants; instead they are a product of our society and the experience made in it by individuals within a certain time and specific environment". For this reason the human needs are the result of the unpredictability of the constant interaction between humans and the space environment. "So far this mutable constant was neglected in manned mission strategies" (Häuplik-Meusburger, 2005 p. 1)[x]. However, experience shows that the factor time, and thus unpredictability, must be taken into account in the first draft and onwards from there. For this reason it is essential to apply in the project all the dynamics that are currently part of the design and architecture process. Only mutual cooperation between people with a technical or engineering background and people with expertise in the design of human factors will allow achieving a sustainable and competitive system to support human life in space.

If one of the main goals of human space exploration is the furthering of knowledge, creating the best and safest habitability conditions to facilitate such a quest for knowledge must be at the forefront of space research. As demonstrated in this research, this can be supported by integrating the discipline of human factors into the design of long duration space missions through the application of the Integrated Design Process. This methodology increases habitability in the most extreme, life-threatening conditions in which humans are able to live.

Further development of the model from the conceptual stage to actual application has been considered as a post-doctoral proposition for the Concurrent Design Facility at the European Space Agency, as part of a cooperation request regarding the further development of the first DLR CDF project for human long duration missions.

Moreover, further applications of the IDP methodology may also include different contexts, such as improving habitability in retirement homes, prisons, research facilities in extreme environments such as Antarctica or underwater facilities, as well as other contexts much closer related to the acquisition of experience in extreme environments, such as in the newly emerging field of space tourism. The rapid growth of the world's population and the proliferation of megacities also increase the need for sustainable human-machine-environment systems, making the IDP not only applicable in extreme environments but also in our daily lives.

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