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DESIGN FOR THE FUTURE: FLEXHAB PROJECT, THE FUTURE LUNAR EXPLORATION HABITAT; M.A.R.S.; AND EXOHAB.

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Abstract

In the future, humans will live in more hostile environments, for example as a result of increased desertification on Earth or following the establishment of habitat settlements in Space. To prepare for this contexts, the European Space Agency (ESA) is now looking into developing a Moon analogue mission facility where to test future technologies, architectures, design, services, etc. In order to increase the feasibility of such a project in the present time, one strategy may be to create a project habitat with restricted cost and volume that could be built using the current launch technology. This work presents different projects of a Moon simulation facility based on the utilization and restyling of the current ISS mockups such as the design of the Future Lunar Exploration habitat (FLEXhab) for the next Moon analogue facility at the ESA Astronaut Training Centre (EAC) in Germany, the EXOHAB project at ESA-ESTEC/ILEWG in the Netherlands, and the Modular Analogue Research Station project (M.A.R.S) in Poland.

Fig. 1. Interior of EXOHAB, ESA-ESTEC.

I. INTRODUCTION

Considering the next plan for a habitat simulation facility at EAC, there are three main aspects that need to be approached:

1. Space utilization in accordance with the Moon environment and launch constraints (cargo dimension and weight, radiation, difference in gravity, isolation)
2. Interactions of humans in lunar gravity
3. All human factors involved under such conditions: operational, physical, environmental, socio-cultural, and psychological (1).

In particular, such a project should be developed in order to:

- Create an instrument for training astronauts, develop test equipment and procedures, and carry out scientific research.

- Create a European center for simulating missions on the Moon
- Support outreach and public involvement without compromising the scientific quality of the mission simulation. The key elements of the project are multi-functionality and flexibility of the space layout and equipment utilization.

The project should consist of:

- Analysis of the users' & collaborators' needs (astronauts, scientists, trainers, visitors, sponsors, etc.)
- Definition of the goals of the facility (simulation of reduced gravity, isolation, etc.)
- Strategy for addressing the goals (suspended weight, isolation of the facility from external visitors during the simulation, etc.)
- 3D sketches of the project
- Description and visualization of examples of relevant utilization scenarios
- Considerations regarding the utilization and restyling of the current ISS mockups.

II. FEASIBILITY CONCEPT

In order to increase the feasibility of such a simulation facility project in the present time, one strategy may be to create a module with limited cost and volume that could be built using the current launch technology. Taking into account that the current ISS modules are optimized and tested for current space launch capabilities, a possibility for the habitat modules could be to build these on the basis of the ISS modules, allowing an ideal module cargo of 5 tons. For example, to build the simulation facility, one option could be to use the ISS module mock-ups that are used to train astronauts for ISS missions and convert them into a part of the simulation habitat.

This will allow having a module with the same dimensions as on the ISS (e.g. Coulmbus), so it will be able to be flown to the Moon using the current launch technology.

III. PROJECT OF APPLICATION

On the basis of a study on space simulation facility (2), in this paper, the project and elements of inspiration applicable to the next ESA EAC Moon facility and based on the presented feasibility concept are reported.

In particular, three projects are described:

1. EXOHAB based on one module
2. M.A.R.S. based on 4 Modules and a dome
3. FLEXHAB based on 2-3 Modules and a dome.

Finally, a lighting system to enhance the overall habitability of the module and dome is presented.

IV. EXOHAB

ExoHab is an operational simulation facility based at ESA-ESTEC in Noordwijk, The Netherlands.

The facility is based on a "concepts for a minimal Moon-Mars habitat, in focusing on the system aspects and coordinating every different part as part an evolving architecture (3, 4). The ExoHab Habitat and Laboratory concept constraints were validated during the EuroGeoMars campaign at the Utah desert research station (from 24 January to 28 February 2009)" (5, p. 1). ExoHab is intended in particular for support studies and field simulations with the specifics of human exploration, with a focus on astrobiology.

The ExoHab pilot concept project (supported by ILEWG, ESA & NASA), brings the case for a "scientific and exploration outpost allowing experiments, sample analysis in laboratory (relevant to the origin and evolution of planets and life, geophysical and geochemical studies, astrobiology and life sciences, observation sciences, technology demonstration, resource utilisation, human exploration and settlement)" (6, p.1).

Fig. 2, 3. Interior of EXOHAB

"In this modular concept, we consider various infrastructure elements:
- core habitat,
- Extra Vehicular activity (EVA),
- crew mobility,
- energy supply,
- recycling module,
- communication,
- green house and food production
- operations.

Many of these elements have already been studied in space agencies' architecture proposals, with the technological possibilities of industrial partners (landers, orbiter, rovers, habitats …). A deeper reflection will address the core habitat and the laboratory equipment, proposing scientific and exploration experiments. Each element will be added in a range considering their priority to life support in duration (7). Considering surface operations, protocols will be specified in the use of certain elements" (8, p.1).

V. M.A.R.S.

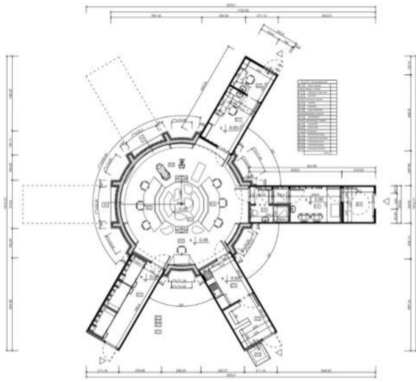

Fig. 4, 5. M.A.R.S. Project top view © European Space Foundation 2016, Image © Jan Popowski 2016.

The Modular Analogue Research Station (M.A.R.S.) is a Polish project of a station for simulating Moon and Mars missions that has been built in August 2016. "The aim of this project is "to develop the first in Poland scientific habitat to investigate human-robotic relations during long-term planetary missions". In particular, MARS will "apply novel tele-medicine solutions, novel architecture design and novel methods of planning and working to simulate not only "the beginning of life" in the habitat but also "a need to develop", which will be reflected in future analog missions" (9).

The project foresees the support of new technologies, with its main objectives being:

- "professional platform to perform analog planetary missions
- wide range of opportunities for development of space technologies
- incubator for innovative science" (10)"(11).

Fig. 6. M.A.R.S. Habitat © European Space Foundation 2016, Image © Mariusz Slonina 8.2016.

The planned living surface is 108 m^2. This could also include CELSS and food production tests in a later stage. With the greenhouse and the recycling compartment, the total surface is 138 m^2.

The feasibility concept proposed here has been fully supported. In particular, the use of standard containers not only allows testing the space close to one of the Columbus modules, but also envisioning Earth applications using the same concept of feasibility with modules that are standard and easily movable and settled anywhere in the world.

Fig.7. M.A.R.S. Astronauts 2016, Poland, © Mariusz Slonina 8.2016 (12).

In August 2016, six astronauts, selected using a sound process, performed the first mission simulation.

Among the activities successfully performed by the astronauts was the collection of Moon regolith simulant samples during EVA operations and the use of the telerobotic arm of the Moon Rover. Spectrometry was performed to search for minerals.

During EVAs, the astronauts tested communications with the Lunar Rover, the Rover's ability to cope with difficult terrain, and Rover operations, esp. the collection of soil samples.

VI. FLEXHAB

FLEXhab is the name for the Future Lunar Exploration habitat based at EAC. Its architectural concept is currently being designed as part of a SpaceShip EAC initiative at EAC. The FLEXhab concept is designed to be connected to LUNA, the inflatable Lunar surface dome currently under construction at the ESA/DLR campus (Figure 1).

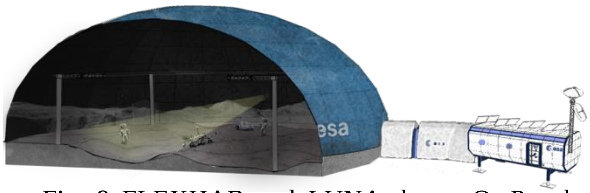

Fig. 8 FLEXHAB and LUNA dome. O. Punch, 2016

FLEXhab's design brief and requirements were created from a set of input interviews with EAC subject matter experts and past analogue/space flight participants. The primary function of FLEXhab is to provide an analogue habitat to meet the needs of EAC in the development of operations and training for future exploration missions beyond the International Space Station, in particular for potential human and telerobotic Lunar surface missions.

Architecturally, FLEXhab's design objective is to enable EAC to carry out analogue simulations in a flexible, reconfigurable, low-cost, and timely manner that is tailored to the needs of EAC and its partners for any potential Lunar mission scenario. As of August 2016, no human Lunar mission has been announced; therefore, FLEXhab's internal architectural design is based on achieving maximum flexibility in order to prepare for any potential configurations that will be required.

Scale-wise, the habitat is designed to house crews of up to four people with dimensions similar to those of the Columbus module, only exceeding it in length. Its external structure is based on methods used in the shipping industry in order to provide a pressurized and hermetically sealed environment at reduced costs. This enables FLEXhab to provide a test bed for the Environmental Control Life Support Systems (ECLSS) developed in Europe.

FLEXhab's primary airlock is designed to be connected to Luna, the Lunar surface dome, where EVAs and robotic tele-operations will be carried out. (Figure 2). It is envisaged that FLEXhab will be used for testing regolith mitigation techniques. The habitat's overall design incorporates modular extension capabilities, and the project is designed in three phases over its evolution in time. Each phase incorporates an additional module, thus expanding EAC's simulation capabilities.

The FLEXhab modules are based on the size restrictions of the Columbus module to increase the project's feasibility. The modules are designed as follows:

1. Core Module: Work stations and EVA operations.
2. Habitation Module
3. Greenhouse Module

In order to maximize flexibility with a restricted volume, transformable types of architecture were looked to as a precedent, both in terrestrial architecture and in space habitat design. In particular, the focus was on different types of dynamic folding and sliding architectures that are used in the design of small living spaces, and on mobile architecture. Its initial concept is based on the Random Access Frames (RAF) prototype developed by JPL as an alternative to standard ISPR (International Standard Payload Rack) for use on board the International Space Station in a micro gravity environment (13).

The FLEXrack will house payloads as well as workstations, which are being incorporated into the FLEXrack design. Such spaces can be folded out from the rack structure, as can sleeping style cocoons and leisure spaces for the crew (Figures 3 and 4). The FLEXrack architectural design allows for several internal configurations to be achieved depending on the activity being carried out by the FLEXhab users, maximizing free volume and flexibility for EAC's analogue mission requirements.

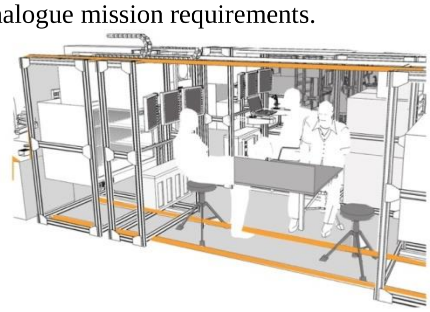

Fig. 9_Sliding Configuration Options. O. Punch, 2016.

VII. SMART LIGHTING FOR FLEXHAB AND OTHER SIMULATION FACILITIES

Living in an artificial environment without access to the natural solar light, has a strong influence on the circadian clock of humans. Light is the most powerful synchroniser of human internal biological clock. The environmental conditions, however, are different in an extraterrestrial environment, such as in low Earth orbit, deep-space or on the Moon. The exposure to the sunlight in space is influenced by the specific location of the habitat in relation to the Sun, as well as by specific habitat system, determining the amount of the crew's exposure to radiation. Therefore, disruptions in sleep-wake cycles have been common among astronauts. In addition, the lack of sunlight is known to induce Seasonal Affective Disorder (SAD), manifesting through fatigue, concentration and memory problems, decreased mood, obesity and many other deseases. Artificial simulators of solar light have been developed and still improved versions appear on the market, however there is still lack of accurate studies on specific light wavelengths influencing neurochemical signalling in the central nervous system. Smart sunlight simulators together with cyclic lighting systems are designed for FLEXhab and other extreme and isolated einvironments to investigate rhythmic neurotransmitter circuits in human brain during future analog missions.

Specific wavelengths of light and specific polarized filters will be used to act on input pathways of biological clock and time perception centers in the central nervous system. Analysis of neurotransmitter levels will be performed during future analog missions.

Fig. 10. Color palette used to simulate terrestrial day, dawn and dusk lightning. Programmed RGB LED strips together with spotlights will simulate various times of a day (14).

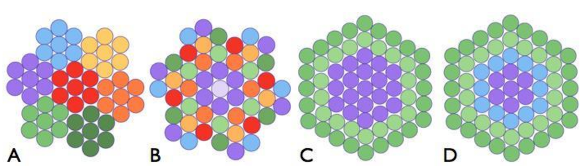

Fig. 11. Various designs of LED setups to obtain different types of lightning: *spectral spotlights* with seven various types of light wavelengths in clustered (A) and dispersed (B) configurations, *circadian spotlights* with UV, blue and green activation spectra (C, D). © Kolodziejczyk, 2016.

VIII. CONCLUSION

The projects presented here are under development and are currrently able to accommodate new input and feedback from the IAC audience and other readers. The aim of this paper is, in particular, to present a concept and proposal for further development of the simulation facilities and to receive suggestions from potential collaborators, industry partners, and clients who may be able and willing to work with this facility.

The main focus of the proposal is on feasibility, to be achieved by using modules with dimensions that are supported by the actual launch capability used for the ISS, and on the presence of a dome to increase the habitat space and improve human well-being through elements such as a smart lighting system.

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Fig.12. M.A.R.S. Astronauts 2016, Poland, © Mariusz Slonina 8.2016

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SUGGESTED READING

on line at: www.extreme-design.eu