19th IAA SYMPOSIUM ON BUILDING BLOCKS FOR FUTURE SPACE EXPLORATION AND DEVELOPMENT (D3)
Systems and Infrastructures to Implement Sustainable Space Development and Settlement - Systems (2A)

EUROHAB: CONCEPT OF AN INFLATABLE HABITAT PAYLOAD AS SUPPORT TO CREWED MISSIONS ON THE LUNAR SURFACE OR MARS

Peter Weiss[a], Jean-Jacques Favier[b], Jacques Rougerie[c], Jean-Francois Clervoy[d], , Thibaud Gobert[a], Alexis Paillet[e], Gregory Navarro[e], Pierre Boutte[e], Marcos Eduardo Rojas Ramirez[e], Elizaveta Shashkova[f], Juliette Mollard[f], Miriam Opazo Mendez[f] and Nisheet Singh[a]

[a] *Spartan Space, Rue Lice de Signon, 83170 Brignoles, France, p.weiss@spartan-space.com*
[b] IMT Mines Albi, France,
[c] Rougerie Architecte, France,
[d] Novespace, France,
[e] Centre National d'Etudes Spatiales (CNES), France,
[f] ISAE –Institut Supérieur de l'Aéronautique et de l'Espace, France,
*Corresponding Author

Abstract

Future missions on the lunar surface are planned to set the basis of a sustainable human presence on the Moon. Today there is still a lack of concrete concepts of habitation systems that have the potential to constitute the first elements of a permanent facility. Various architectures have been developed in the past years showing lunar surface bases with large extensions, but concepts of intermediate-size habitats, between Apollo-like landers and large, permanent bases, are still to be found.

EUROHAB is a habitat concept that could serve as a bridge between these two extremes as it could be used with the first coming lunar landings, ahead of a larger lunar basis. A first prototype of EUROHAB will be available for testing as early 2022. It will serve as a new platform for experimenting the new generation of technologies for future human exploration (ECLSS, energy production and storage, etc). It could be used as a testbed in artificial analogue facilities or serve as a mobile basis for analogue missions. EUROHAB is designed for a crew of 2 to 4, and mission durations of 7 to 10 terrestrial days. Besides being a secondary habitat for crewed lunar missions, it can be also considered as a safe haven in case of emergency. The habitat will be transported to the surface by a cargo vehicle, like the one currently under consideration by ESA. It is conceived to fit as a payload of such lander and can be autonomously deployed by inflation on the surface of the Moon. The system remains then on stand-by, telemonitored by a User Support and Operation Centre. It is designed to be mobile and may be moved in the short range of the landing site by either a rover or by repositioning the lander to a spot farer away. Ultimately several habitats could be combined to build a larger facility lunar base.

The paper will present the design of EUROHAB and the current development plan and its subsystems.

Keywords: Space habitat, safe haven, inflatable, moon

Acronyms/Abbreviations

Artificial Intelligence (AI)
Centre National d'Etudes Spatiales (CNES)
Concept of Operations (CONOPS)
Environmental Control & Life-Support System (ECLSS)
European Large Logistic Lander (EL3)
European Space Agency (ESA)
Extravehicular Activity (EVA)
Human Landing System (HLS)
International Lunar Research Station (ILRS)
In-situ Ressource Utilisation (ISRU)
International Astronautical Congress (IAC)
Intra-Vehicular Robotics (IVR)
Peaks of External Light (PEL)
Permanently Shadowed Regions (PSR)
Regenerative Fuel Cell System (RFCS)
Technology Readiness Level (TRL)

1. Introduction

A return to the Moon's surface by human astronauts is planned to take place in the 2024 to 2030 timeframe. Returning to the lunar surface to learn to work and live there with human beings over longer periods of time is a crucial and unavoidable step before departing towards planet Mars. Crewed mission to the Moon will allow to test novel technologies and operations to establish a sustainable presence beyond Earth's low orbit. This new era of human space exploration is exciting. It comes with new actors from various fields: Start-ups from the so-called "New Space" sector, well-established Agencies and entities from emerging countries have set sail towards to Moon. The first coming missions will most probably be robotic exploration missions on the lunar south pole. Those will then be followed by astronauts that will be brought to the surface by systems such as NASA's planned Human Landing System (HLS). The HLS will certainly target rather flat landing sites on the South Pole to avoid any risks with these historic missions. But these sites are not those that have the highest interest in terms of science or in-situ resource utilisation. Therefore "base camps" will be needed that allow a crew to reach from the HLS towards these sites that are several tens of kilometres away. The present paper describes a concept of such a base camp, or Secondary Habitat that could be provided by an international team to coming missions. The concept is based on an inflatable habitat which is conceived as a payload to a Lunar Lander. As baseline development the European Large Logistics Lander (EL3) was taken. Such a system can be brought as payload to the lunar surface, in order to be prepositioned before the astronauts arrive. If the system is designed to survive the lunar day and night cycle, and if the system can be resupplied (robotically or by human astronauts) then such an element could become the first permanent installation on the lunar surface.

The present paper will describe the concept of EUROHAB, its technical design and concept of operations; but it will also describe how this system is developed as a platform for analogue trials for its roadmap towards the Moon. The prototype platform is showcased at the Exhibition Hall of IAC in Dubai.
The prototype that was developed by SPARTAN SPACE will be delivered to SPACESHIP FR @ CNES for future tests. The present paper also gives an vision on subsystems that can be included in such a habitat platform. SPARTAN SPACE and CNES worked on this particular point which is reported in this paper.

Figure 1: Artists View of EUROHAB being visited by astronauts during a lunar EVA.

2. Concept of Operations

Russia and China have revealed during the Global Space Exploration Conference GLEX in Saint Petersburg, Russia their plans to set up an International Lunar Research Station (ILRS). NASA's ARTEMIS programme is already on track to bring human astronauts to the South Pole of the Moon. The following concept of operations is formatted to the US NASA ARTEMIS programme; but the principle could also be applied to support other nations' missions to set up permanent facilities on the surface.

ARTEMIS is targeting the lunar South Pole in order to explore this geological spot on the lunar surface and in order to exploit the quite unique environment with regions that are permanently exposed to sunlight (Peaks of External Light PEL), or Permanently Shadowed Regions (PSR) inside craters that might host water ice as potential ISRU component. The South Pole seems to be the best spot to start a human settlement on the Moon [1]. These spots are however not the best landing sites since they a located in terrain with steep slopes; partly located on the Far Side of the Moon which might not allow direct communication with Earth. It is therefore probably that the first humans that walk again on the Moon will be landing near the surroundings of the Shackleton crater in a plain located earth-wise (towards crater Shoemaker). Other landing sites are discussed in the paper of

Gawronska et al. [2]. The image below shows a theoretical landing site of the HLS for illustration; it is to be noted that a realistic landing site would be located most probably farther from the crater rim.
A problem that might arise is that the ARTEMIS CONOPS foresees that EVA can be performed in a range depending on the equipment the astronauts have: 2km away from the human lander when they are by foot, 10km with an unpressurized rover and 12km with a pressurized rover [1]. This will require a compromise between landing site safety (including aspects such as communication) and reachability of spots of interest (such as PEL and PSR). EUROHAB presents a solution to this dilemma because the habitat can be pre-positioned (without crew) on an intermediate distance between the foreseen landing spot and the sites of interest. The chart in Figure 2 is based on a slope estimation of the Lunar and Planetary Institute: Areas marked in red have high slopes while areas marked in green are relatively flat. This paper does not intent to discuss in detail possible future landing spots; two positions are marked here as "HLS 1" and "HLS 2" based on following criteria:

- Being located as close as possible to the South Pole
- Being located on the Near Side of the Moon (potential communication reasons)
- Being located in relatively flat areas (green spots on the chart)

Spots of interest (for science and ISRU) are marked by white arrows. Those are mainly PSR inside Shackleton where water ice might be collected, and PEL on the crater rim west of Shackleton where solar arrays could supply energy throughout the lunar day and night cycle.
Taking into account a possibility to leave the HLS at a distance of 10km (thus by using a non-pressurized rover which seems to be the likeliest scenario for coming missions) astronauts will not be able to reach spots of interest. EUROHABs pre-positioned on strategic locations would allow to extend the radius of intervention. In the case of a problem astronauts could find refuge inside the secondary habitat. These "base camps" could serve as intermediate base to reach locations farer away. Since these habitats are landed by a robotic vehicle (without crew onboard) more risky landing spots can be targeted.
It is obvious that such habitats could also serve as shelter in the case of a malfunction with the human lander; astronauts can rescue themselves inside the habitat to wait for help. EUROHAB could also serve as storage facility for equipment and samples.

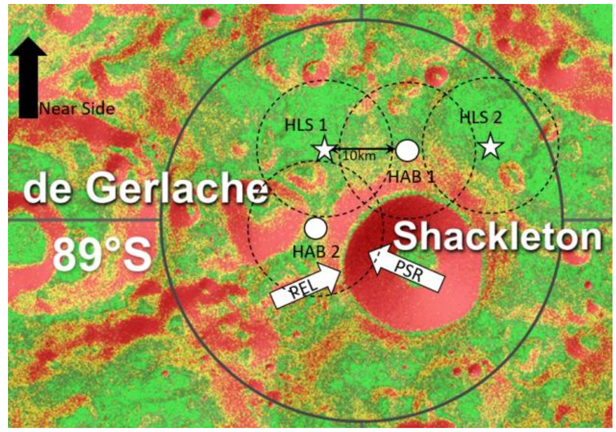

Figure 2: Concept of operations of EUROHABs pre-positioned on specific spots to support EVA [Peter WEISS based on chart developed by the Center for Lunar Science and Exploration, slopes derived from LRO's LOLA 10-m elevation product - NASA Goddard Space Flight Center]

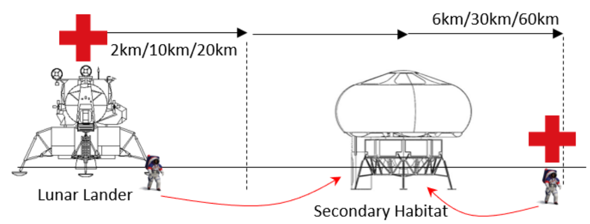

Figure 3: Eurohab as a secondary habitat to extend EVA range or to serve as "Save Haven" in case of a misfunction with the HLS

3. Habitat design

The proposed habitat concept is based on a "habitat-as-a-payload" design developed by SPARTAN SPACE. The system is brought to the surface by an unmanned, automatic lander and arrived there it will stay on stand-by and the inflate before the crew arrives.
The benefits of inflatable structures are well recognized, and the technology is reaching a high TRL level [3] and ESA member state entities have a certain expertise in the design and development of such systems [4]. Moreover, ESA is finishing a detailed analysis on the use of such materials in lunar environment [5]. Material solutions exist not only for textiles that can withstand space environment but also the lunar surface environment (contact with dust). The complete habitation system is designed to fit within a weight margin of 1,5t in order to fit into the EL3 requirements [7]. The image below gives the dimensions of the system, also in comparison with the Lunar Lander of the Apollo Programme.

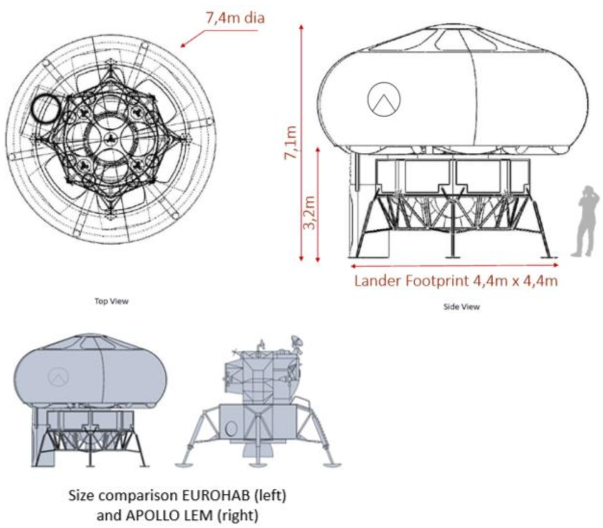

Figure 4: Eurohab dimensions and size compared to Apollo's Lunar Module

The following scheme shows the inflation of EUROHAB: The system will land in a folded configuration and then inflate before the astronauts arrive.

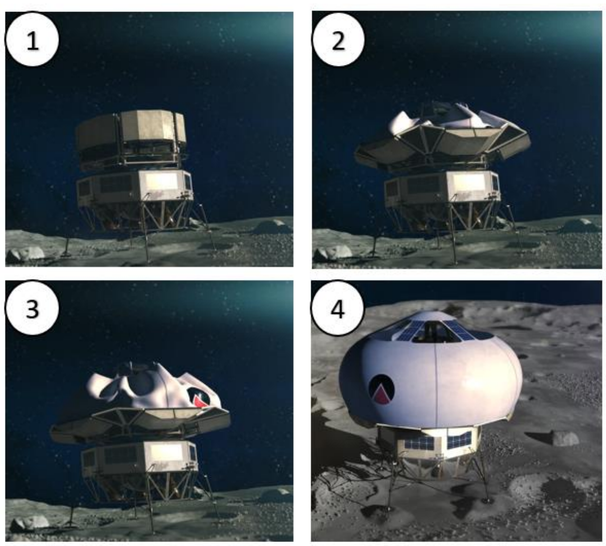

Figure 5: Artist rendering of the inflation of the habitat after arrival [SPARTAN SPACE and SUPERHEROS]

The habitat payload is placed on its host-lander (which can be an EL3 but also similar vehicles such as Astrobotics Griffin Lander, or even totally different platforms such as a rover). It includes a main inflated volume with an observation platform on the top. An extendable (inflated) airlock on the bottom will provide access to the outside and also serve to reduce the intrusion of dust inside the habitat itself. Multifunctional racks are integrated in the petals. Those will host elements related to the life support, connectable from the outside for refuelling and also elements related to EVA and sampling (such as tools, sample containers and glove boxes).

EUROHAB will not be crewed over the majority of its lifetime on the surface. Typical mission durations -as foreseen today- are in the range of 7 days with 2 crew members to a maximum of 30 days with a crew of 4 [7]. In this mode the habitat needs to be operated from Earth or from the orbiting GATEWAY. Shortly before the start of a mission, the habitat will be prepared to host the astronauts. In the non-crewed stand-by mode it will regenerate energy to recharge itself for the habituated phase (which will be more energy consuming). Also, it needs to survive lunar nights.

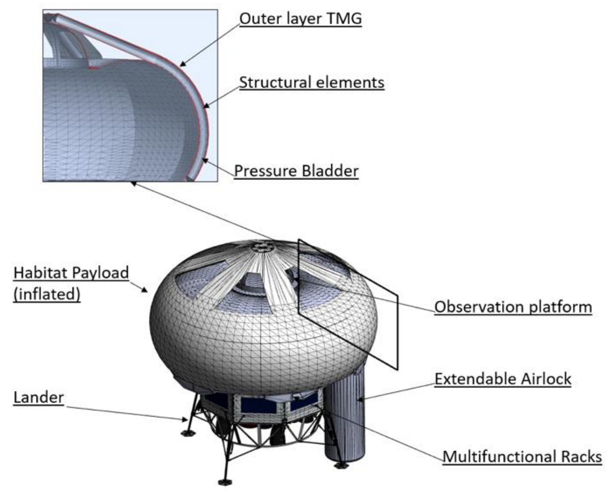

Figure 6: Elements of EUROHAB

The following chart shows a possible energy management for such habitat: While being in stand-by mode the habitat will recharge its energy storage in a slow and constant manner. The main outcome of this consideration is that a secondary habitat needs to include a large energy storage system rather that a large energy production capacity (e.g. solar array size can be modest but the system needs to be able to store energy over longer periods of time). SPARTAN SPACE is investigating with AIR LIQUIDE and the French CEA to derive a possible energy management system for such future habitats based on regenerative fuel cells RFC and flexible solar cells that can be integrated in the inflatable.

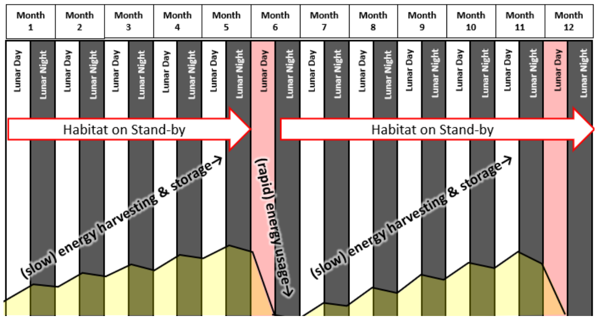

Figure 7: Energy production and consumption in a secondary lunar habitat such as EUROHAB.

CNES and SPARTAN SPACE worked together on various aspects of the subsystems of EUROHAB. The objective of this work is to derive a system that can be used for multiple missions. A "throw-away" habitat concept would not be a sustainable approach. One of the major aspects to be considered here is the Environment Control and Life-Support System (ECLSS). The ECLSS shall meet many requirements to ensure the crew's survival in the lunar environment. These will be provided by mature technologies that have already been tested in space, such as Li-OH cartridges or oxygen storage in canisters. The challenge and the major interest of EUROHAB lies in saving space and energy, which is why all the resources will not be recycled but stored and then treated on the lunar base. Nevertheless, the project aims to make optimal use of essential resources such as water, which is why the habitat will be equipped with an innovative system for recycling part of the grey water, i.e. the condensate from the humidity in the air.

4. An analogue test platform

A prototype has been developed in cooperation with AIR LIQUIDE, CEA, ARCHES, JACQUES ROUGERIE FOUNDATION and CNES in Grenoble based on the EUROHAB concept. The system is positioned on a lander mock-up (with an agnostic design) which is financed by ESA. The habitat itself is a functional demonstrator. The system is designed to be modular to allow the integration of different subsystems in the future. Non-flight hardware was used for this first demonstrator. The objective is to deliver to CNES a system that can serve future field trials and technology demonstration. Possible subsystems that can be tested in the platform are

- ECLSS
- Energy production, storage and management
- IVA robotics and AI
- Communications
- Dust management and mitigation
- Radiation protection
- ISRU and habitat refueling
- IVA and EVA training
- Confinement and analogue trials

The following series of images shows the current state of the demonstrator development: (1) Artist view of the final version of the habitat shown in the workshop. (2) Habitat platform and (3) Lander mock-up in real size. The system will be showcased during the IAC, Dubai in the Exhibition Hall.

The system weights below 1t in order to be transportable by a helicopter to remote sites for future analogue tests. The analogy to a lunar surface operation will be the following: on the moon the habitat will arrive per lander on the surface and the crew will arrive later (by the HLS). For the planned analogue simulations, the system will be brought to the site by a helicopter while the crew arrives later (by a second helicopter). In both scenarios the habitat will be operated via a remote-control centre.

Figure 8: (from top to bottom) Artists view of the final demonstrator in the workshop, habitat platform and lander in real size.

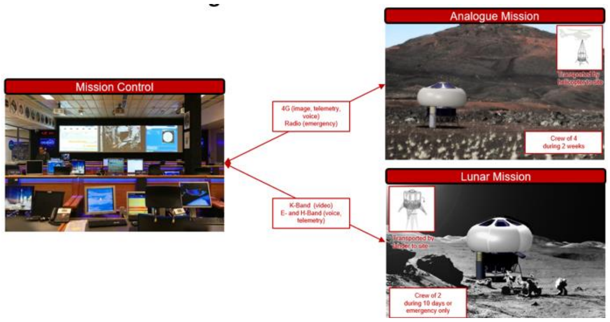

Figure 9: Habitat operation on analogue sites and on the lunar surface.

6. Conclusions

The paper presents the development of a novel concept for a secondary habitat supporting future crewed missions on the lunar surface. The EUROHAB project also includes the development of a prototype system that can serve to test and validate technologies and operations on Earth. Such a system could be an international contribution to programs like ARTEMIS.

Acknowledgements

The authors of this work would like to thank the various entities that are supporting our start-up during this development: AIR LIQUIDE and the team of GARAGEFAB, CNES (contract number 210508/00) and the team of SPACESHIP, ESA (contract number 4000134957/21/NL/PA/eg), CEA, ARCHES and the University of Strasbourg and the Jacques Rougerie Foundation.

References

[1] Cohan, D. (2020) NASA Exploration EVA System Concept of Operations Summary for Artemis Phase 1 Lunar Surface Mission, retrieved from https://www.nasa.gov/sites/default/files/atoms/files/topic_1-_eva_lunar_surface_concept_of_operations.pdf on June 6th, 2021

[2] A. J. Gawronska, Barrett S. J., Boazman, C.M. Gilmour, S.H. Halim, Harish, K. McCanaan, A.V. Satyakumar, J. Shahj, H.M. Meyer, D.A. Kring, (2020) Geologic context and potential EVA targets at the lunar south pole, Advances in Space Research, Volume 66, Issue 6, Pages 1247-1264.

[3] S. Häuplik-Meusburger, K. ÖzdemirKürsad Özdemir (2021) Deployable Lunar Habitation Design, in Moon: Prospective Energy and Material ResourcesEdition: 1Chapter: 20.Deployable Lunar Habitation DesignPublisher: Springer-Verlag New York, LLC Editors: Viorel Badescu.

[4] F. Fenoglio (2015) From ISS to Exploration, NanoRacks Workshop, Leiden (NL), Dec. 2015, retrieved from http://nanoracks.com/wp-content/uploads/23-Franco-Fenoglio-Thales.pdf on June 2nd ,2021.

[5] P. Weiss, M. Peer Mohamed, T. Gobert, Y. Chouard, N. Singh, S. Schmied, M. Schweins, T. Stegmaier, G. T. Gresser, G. Groemer, N. Sejkora, S. Das, R. Rampini, M. Hołyńska (2020) Advanced Materials for Future Lunar Extravehicular Activity Space Suit, Advanced Material technologies https://doi.org/10.1002/admt.202000028.

[6] ESA (2019) Project Pextex: materials for lunar spacesuits, retrieved from http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/Project_Pextex_materials_for_lunar_spacesuits on June 2nd, 2021.

[7] ESA (2020) European Large Logistics Lander retrieved from http://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/European_Large_Logistics_Lander on June 2nd, 2021

[8] ISECG (2020) Global exploration roadmap, supplement August 2020 Lunar surface exploration scenario update, retrieved from https://www.globalspaceexploration.org/wp-content/uploads/2020/08/GER_2020_supplement.pdf on June 2nd, 2021