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Updated design concepts of the Moon and Mars Base Analog (MaMBA)

Christiane Heinicke[a,*], Leszek Orzechowski[b], Marlies Arnhof[c]

[a] *University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), Bremen 28359, Germany,* christiane.heinicke@zarm.uni-bremen.de
[b] *Wroclaw University of Science and Technology, Poland*
[c] *ESA—Advanced Concepts and Studies Office, European Space Research Technology Centre (ESTEC), Noordwijk, the Netherlands*
* Corresponding Author

Abstract

Important milestones have been reached in the recent past in the launches of commercial, re-usable rockets and spacecraft and particularly heavy-lift launch vehicles. These could help pave the way to the realization of the Moon Village, a concept of an international presence on the Moon that is promoted by ESA's DG. Even though the Moon Village itself refers to the community behind a future a presence on the Moon, visual conceptions of it usually depict a collection of rovers, humans, and, perhaps the largest pieces of equipment, habitats.

Over the last decades, many habitats have been built and inhabited to provide an analog environment of the Moon or Mars. The main purpose of these habitats are usually terrestrial simulations. That is, today's habitats may provide an adequate laboratory environment for human factor studies, training purposes and subsystem technology testing, but they would not function on the surface of either Moon or Mars.

They typically share the following features that render them unusable for an actual mission off our home planet: They are not pressure tight, provide no adequate shielding against space radiation, many consist of a single space or have a single central module, which may render the habitat unusable after just one single catastrophic event, and they are not designed ergonomically. In addition, despite the fact that most habitats have a dedicated laboratory space, these labs often suffer from a rather arbitrary selection of lab instrumentation.

The habitat planned within project MaMBA is intended to provide a first prototype that could function on the Moon. This habitat is developed at the ZARM in Bremen, Germany, and comprises five to six connected, but independent modules. In its final state, the habitat is intended to serve for testing technologies such as life support, power systems, and remotely operated set-ups communication. For the described project phase, we focus on the development of the scientific module, which will contain a laboratory to be used by mainly geologists, biologists. In order to provide efficient and functional workstations for the laboratory, they will be designed ergonomically in collaboration with geologists and biologists.

We will present an update on the project MaMBA and the progress on its overall layout. We focus on the selection process of the scientific equipment, the design of the interior layout, our first-iteration of an effective radiation shield and the concept of the pressure vessel.

Keywords: human habitat, prototype, Moon, Mars, MaMBA update

1. Introduction

Now that the International Space Station has been operational for almost 18 years, the spaceflight community is eager to move on. ESA's director general is promoting the Moon Village concept and with the most recent presidential directive NASA is preparing for a return to the Moon, too. Some more ambitious companies are aiming even further, to Mars.

Nevertheless, no concrete plans exist yet for the time when astronauts reach the surface of the Moon or the proposed next step, Mars. A number of test habitats have been built during the last decades and inhabited for various durations, among them the American experiments HI-SEAS [1] and HESTIA [2,3], or the Chinese Lunar Palace 1 [4,5], to name a few.

All existing test habitats share one fundamental approach: they are built for terrestrial simulations, and not for a lunar or Martian environment. In most cases, they are used for human factors or operational studies, like NASA's HERA or HI-SEAS. Others are more directed towards testing specific technology, like the BLSS of the Lunar Palace 1. But none could be modified to function as a habitat prototype.

The most common flaws that would need to be overcome are (by essentially re-designing the concept, rather than making minor changes): single or central module design, non-pressure resistant geometry, open resource loops (esp. air and water), no adequate radiation shield (and no concept how such a shield could reasonably be added), poorly functional laboratories. In some cases the design is such that it becomes unusable for crew members suffering from temporary or permanent disabilities, either following an accident or due to deteriorating physical health.

2. Goals and Updated Timeline

Project MaMBA (Moon and Mars Base Analog) aims to build the first functional habitat (prototype), drawing from lessons learned at existing habitats. During the construction phase and after the whole habitat it set-up, it may serve as a test facility for mission critical technologies such as life support systems, power systems, communication systems, and others.

The base is designed for a crew of 6, and will consist of 6 modules plus 2 airlocks at its base configuration. Each module is an upright (rigid) cylinder; the corridors between are formed by (inflatable) modules which are docked to the cylinders via pressure-tight doors. In case of emergency, each module can be locked off separately; during normal operation the inflatables provide extra space for storage. Due to the three-legged symmetry of the cylinders which allows up to 6 exits, the base can readily be extended to incorporate more modules.

We chose the cylinder diameter such that it can be transported with launch technologies currently under development—even though rigid shells are more difficult to transport, we believe that they are in turn much easier to set up than inflatables. This is particularly true for the laboratory module, where the use of pre-integrated modules facilitates the set up tremendously. As the Lunar Base Handbook [6] so eloquently puts it, anything that can be integrated on Earth, should be integrated on Earth, where work is not hampered by the vacuum and dust environment on the Moon.

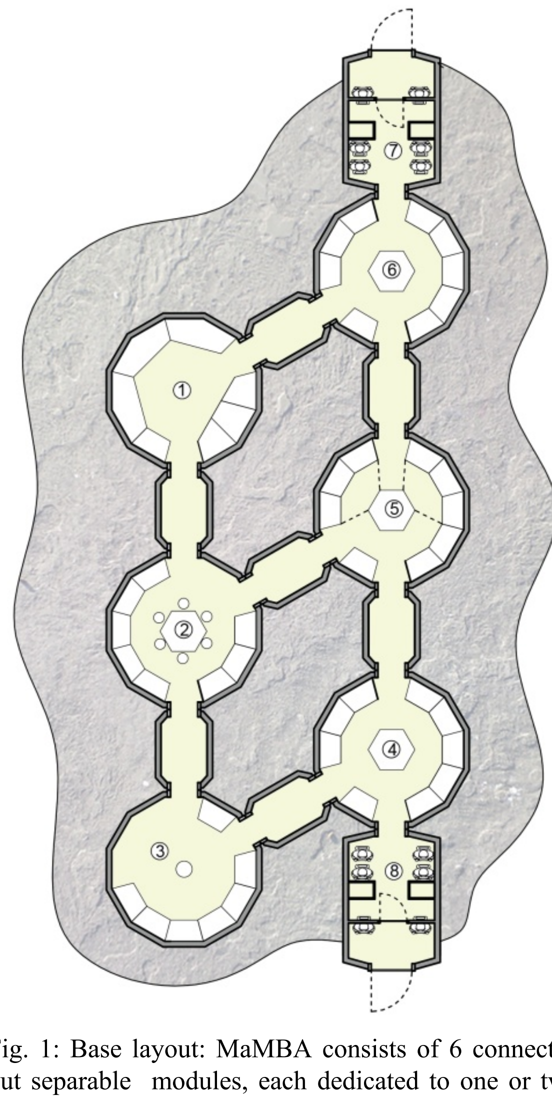

Fig. 1: Base layout: MaMBA consists of 6 connected but separable modules, each dedicated to one or two specific functions: (1) sleeping module, (2) kitchen module, (3) leisure module, (4) greenhouse/ gym, (5) laboratory module, (6) workshop, (7,8) airlock. Note that the right side of the base is dedicated to work, while the left side is reserved for leisure.

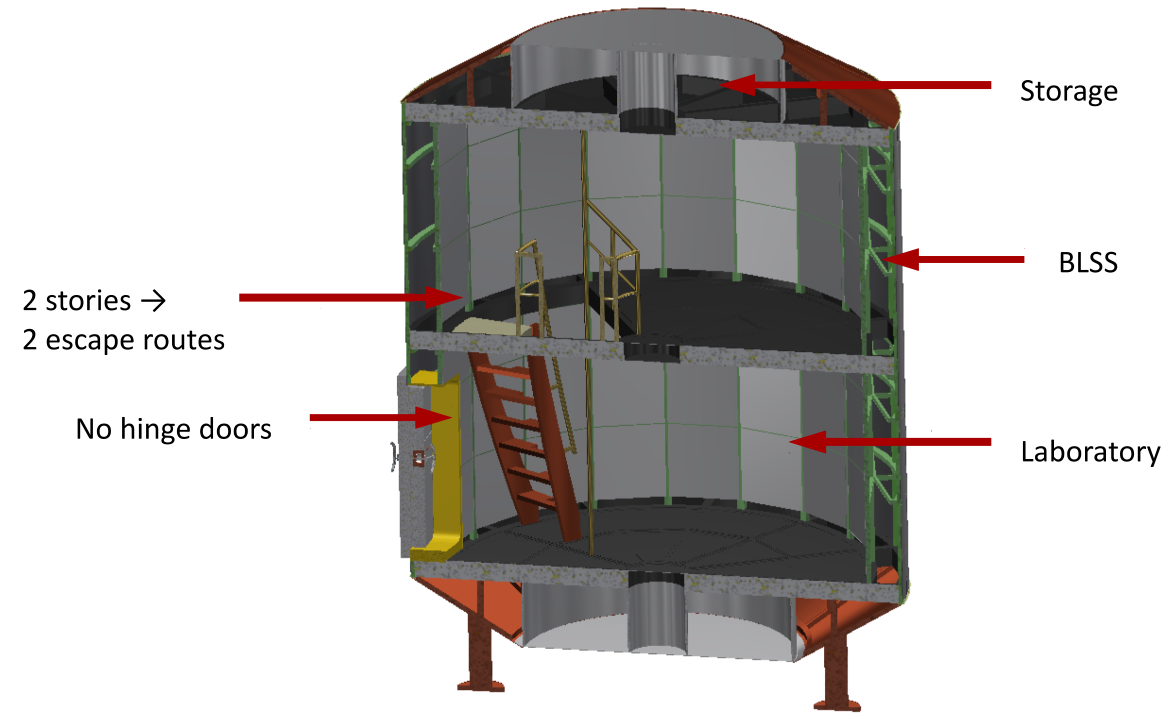

Fig. 2: Concept for the laboratory module shell. The module will consist of two stories, like the other work modules. The bioregenerative life support system is integrated into the walls, where a large surface area is available. The main (=first) floor contains the laboratory.

Being the core of any scientific surface mission, the science module will be the central module. This not only means that the module will be at the center of the habitat, but it is also the first to be developed and tested. It is planned to set up a mock-up of the laboratory module starting later this year, with first testing to commence during next year.

In the following years, the mock-up shell shall be replaced by a functional shell, that is a pressure vessel with integrated life support system.

Once the laboratory module is fully functional, it will serve as the blueprint for the other modules, in particular with respect to the outer shell design and integrated life support system components.

It should be noted here that the goal of the project is *not* to develop all critical system components, but rather to integrate existing systems wherever possible and to provide an infrastructure for high fidelity tests of said components. Collaborators for these subsystems are being sought both in academia and industry, and internationally.

3. Base Layout

In its base configuration (shown in fig. 1) the habitat shall consist of six modules, which are arranged such that expansion is geometrically possible. In base configuration, one half of the base is dedicated to leisure activities (sleeping, eating, relaxing), while the other half is dedicated to working (laboratory, greenhouse and gym, workshop; airlocks). Generally, the work modules will have two stories each for efficient use of volume, while the leisure modules will have a single story. The resulting high ceiling will help astronauts battling the feeling of confinement.

All modules have at least two exits; and the entire base has two airlocks. The docking mechanism between the modules shall be designed such that each module can be locked off (perhaps even detached from) the remainder of the base. With the interconnected modules, it is possible to reach any other module or leave the base from everywhere inside the base should the circumstances require to do so.

4. Pressure Vessel

Each module consists of an outer pressure shell, with 2 or 3 exits. The shell will be metallic, i.e. rigid, so that life support system, electronic system, racks, etc. can be integrated before launch.

Since life support systems for long-duration missions need to be (bio-)regenerative, and such systems often (not always) rely on algae or bacteria for oxygen production, it is advisable to integrate the life

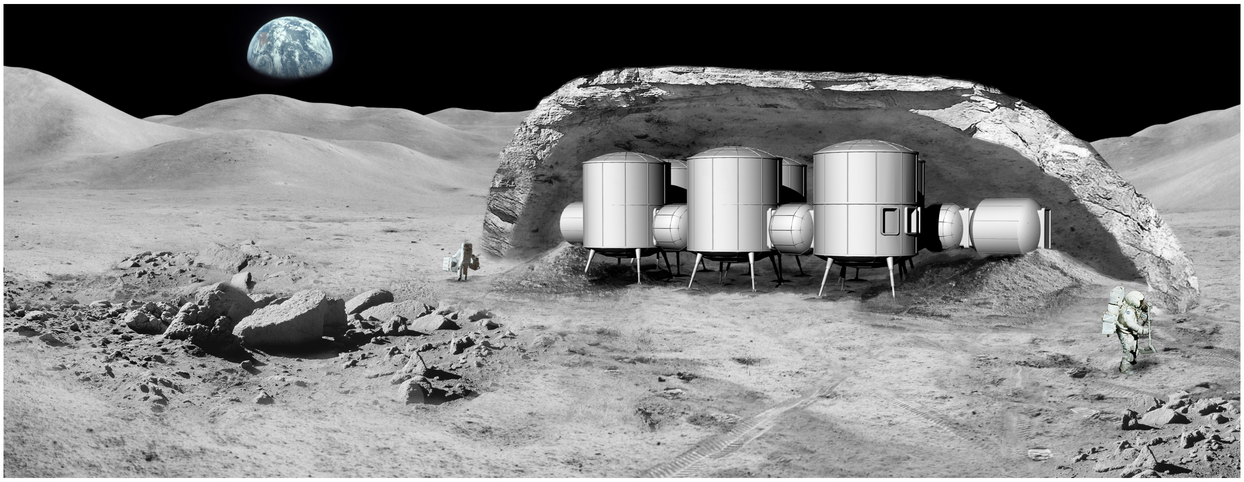

Fig. 3: Artistic depiction of the habitat on the lunar surface, protected from radiation by an artificial cave.

support system into the wall of the pressure vessel. This way, the large surface area of the wall can be utilized for efficient illumination of the algae/bacteria.

In order to allow access to the life support system for maintenance and repairs, the covers and racks in front of the walls are easily removable.

5. Radiation Shield

There is no additional radiation shield integrated into the pressure vessel. Instead, it is envisioned that the entire base is placed inside a cave. This may be a natural cave. However, lunar caves that have been found so far are lava tubes with access through skylights with dozens of meters of depth. Besides, such lava tubes have only been found in equatorial regions, whereas it may be more advisable to set up the (first) lunar base near the lunar South Pole. Therefore, we suggest to erect an artificial cave, i.e. a thick wall around the base. This wall may double as protection against (micro-) meteorites. If large enough, it may also serve as a garage for rovers not currently in use. Similar to terrestrial caves, it is expected that the artificial cave weakens the temperature extremes during the day-and-night-cycles around the base.

The shield should be erected robotically; however, since there are plenty of great projects dedicated to creating structures on the Moon from lunar regolith, the construction of the shield itself is not part of this project. Nevertheless, we are investigating which geometries and thicknesses may be best for our specific base setup.

6. Transportation and Dust Mitigation

There is no doubt the base must be set up robotically on the Moon. It is also clear that the landing site cannot be the same as the final location of the base. We are therefore particularly interested in collaboration with experts in robotics.

Another concern for erection of the base is the sealing of the separate modules and the connections between the modules (and the airlock), particularly after exposure to the lunar dust environment.

We do not have a concrete strategy for dust mitigation yet, but are currently exploring several options.

7. Laboratory and Interior Design

The laboratory will be equipped with instrumentation for geological, (astro-)biological, medical, and materials sciences research. The selection of this instrumentation will be made based on the recommendations developed by representatives of each of these disciplines; these recommendations are published in a companion paper and special session at this conference.

In addition, we are modifying the concept of racks for ergonomic use in a planetary environment, i.e. in gravity. The underlying assumption we made is that, similar to life in microgravity, astronauts will soon adjust to their new environment. Instead of hopping around as during the Apollo missions, astronauts are expected to find the most energy-efficient way of moving, perhaps walking similarly as on Earth. In particular, we expect astronauts to require a similar work station layout. We are therefore developing a three-component rack system that can be used as (1) standing-height work desk, (2) hanging rack similar to a kitchen cupboard, allowing the base inhabitants to work on the work desk (1) ergonomically, and (3) a combination of the above that provides room for equipment from the floor to the ceiling.

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