OSIP-Project: *PneumoPlanet* – Inflatable Moon Habitat
EXECUTIVE SUMMARY

Team:
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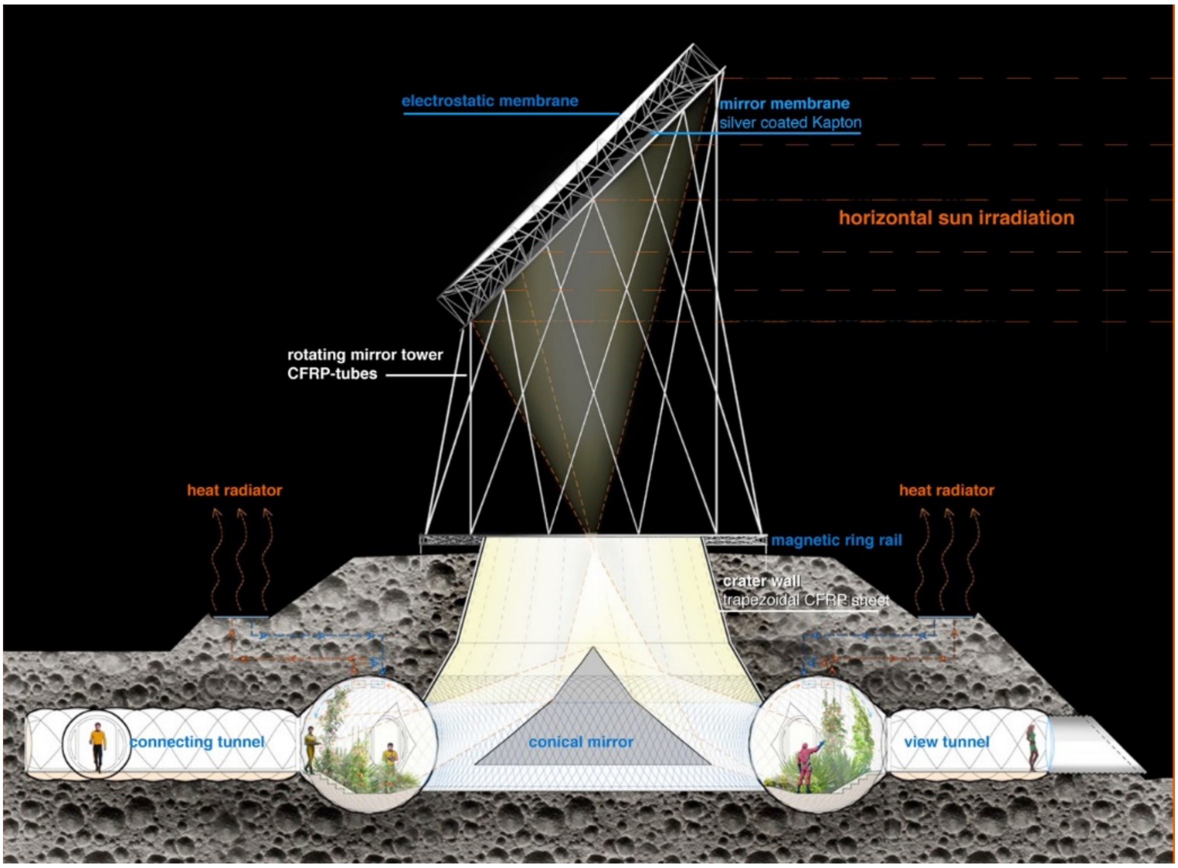
The goal of this study was to develop a design for a lunar habitat in the close vicinity of one of the lunar poles and to demonstrate the feasibility of the suggested design in view of the available resources. The habitat should operate self-sufficiently in the long term by producing and recycling its own oxygen and food inside large greenhouses and almost exclusively by using solar irradiation power.
The concept features a combination of:

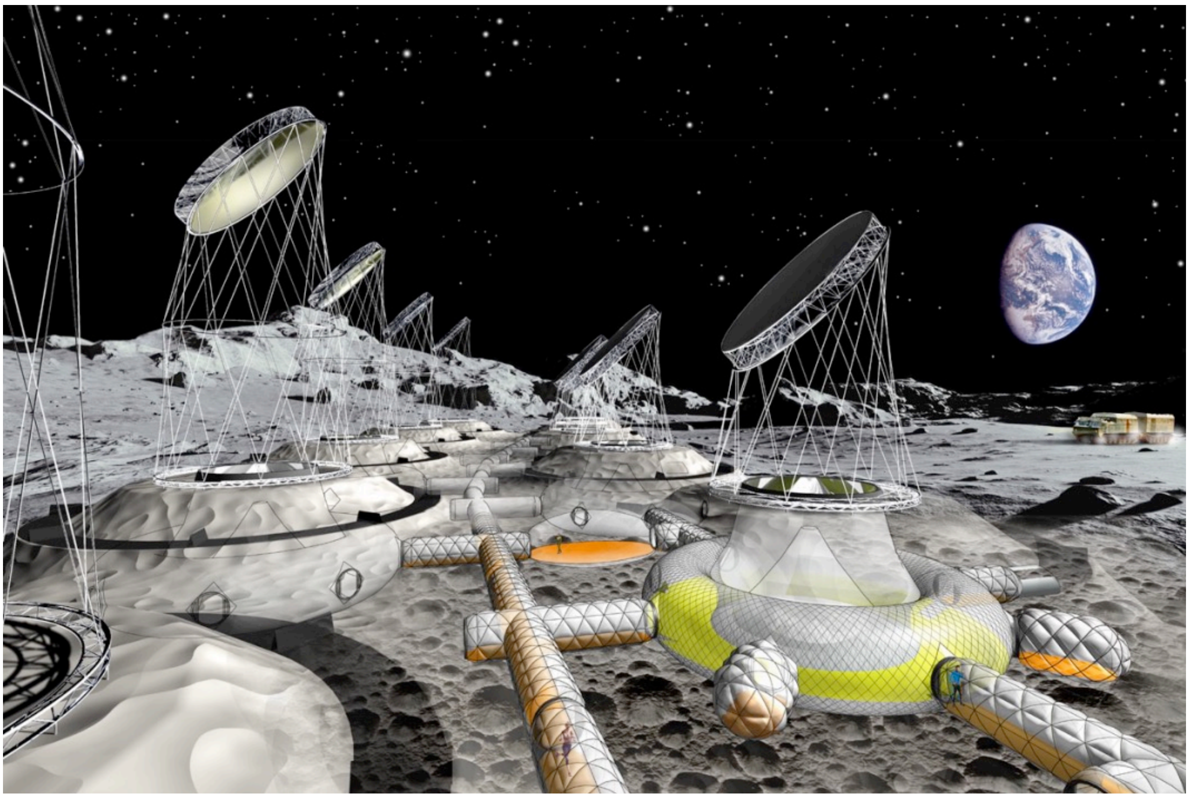
1. Prefabricated ultra-light inflatable structures.
2. Covering the inflated structure with a 4 -5 meters thick layer of local loose regolith for efficient protection from extreme temperature, meteorites and cosmic radiation.
3. The use of mirrors that move towards the sun and bring visible sunlight into the greenhouses.

As a first step, we identified the best suitable sites for the building of such a habitat both near the south pole and near the north pole of the Moon. Based on data from NASA's *Lunar Reconnaissance Orbiter* (LRO) and on illumination models by Gläser et al. (2015, 2018), we identified the region C1 near the south pole and the area H0 near the north pole as best suited places for a habitat. These sites offer optimal illumination conditions and are in the close vicinity of PSR's (*Permanently Shadowed Regions*), which have a high probability to contain near surface water ice. Moreover, suitable landing places in the near vicinity are available. The rim of the Shackleton crater itself, which often has been suggested as a site for the erection of a lunar polar habitat in previous studies, may not be a suitable place, because of the steepness and ruggedness of the terrain, which also includes possible mechanical instability of the ground. In order to evaluate the accessibility of solar irradiation over time, we calculated the solar illumination profile at the two sites both at the very surface and in a height of 10m and 20m, where the mirrors for the redirection of the horizontally infalling solar rays towards the lunar surface are mounted. We calculated that the longest period of uninterrupted total darkness is 11 days at the north polar H0 site, while at the south polar C1 site it is only 4 days. During the dark periods the electric power is served by batteries and/or fuel cells.

The habitat structure consists of room modules that can be connected to extend the habitat. The main inflatable modules are toroidal greenhouses with a minor diameter of about 5.20m and a major diameter of 22.20m. These greenhouses are connected among each other by a tunnel system and additional modules for living and working areas are attached to their outer side. The habitat can start with one greenhouse unit and grow by adding more greenhouse units. In our document we suggest a "village" consisting of 16 greenhouse units that are placed in a double linear arrangement, in order to minimize mutual shadow casting among the mirror towers, when the Sun moves along the lunar horizon. Greenhouses, living areas and connecting tunnels are all made of double-layered inflatable foils, while the towers carrying the upper mirrors are a low weight construction consisting of carbon fibre tubes. Moreover, a redundancy of the corridors keeps the parts connected even if some parts are destroyed in an accident. The regolith layer that covers the inflatable modules acts as a very effective thermal isolation between the interior of the greenhouses and the surrounding environment, as has been verified by a numerical model in the frame of this project. The upper mirrors reflect the nearly horizontally arriving sunlight into an artificial crater at the geometric centre of the torus, from where it is directed into the greenhouse via another conical mirror and through a window consisting of two transparent foils. In order to save weight, all mirrors are made of silver-coated foils, which are bent into the correct shape by electrostatic charging. The solar illumination power entering a greenhouse unit via the mirrors is about 65 kW during the illumination phases. While this power is necessary to optimally facilitate photosynthesis, it would quickly overheat the greenhouse without an active cooling radiator. In our design, the cooling system operates with ammonia and water as working fluids. In this way, the temperature inside the greenhouse can be kept close to 26°C during the illumination phases.

During dark periods, the active cooling is switched off and mirrored roller blinds cover the window in order to limit heat losses to a minimum. As part of the study, some investigations on the materials to be used for the inflatable structures and the mirrors were performed. As foil material for the inflatables, we suggest *TPU* or *Mylar*, while for the reinforcement-ropes *Dyneema* is a suitable material.





Next, the needs for materials and consumables were estimated and ways for a suitable recycling system were proposed. We suppose a 35% oxygen, 64% nitrogen, and 1% CO_2 atmosphere at 0.5 bar pressure inside the greenhouses. Altogether, it appears possible to create in the long term a closed system, in which each greenhouse unit produces enough food to nourish a crew of two humans without the need to import additional food from earth. Generally, we create in a small scale a complete sustainable ecological cycle as we (should) have on Earth. Oxygen is produced by the plants in the greenhouses, which in turn use the CO_2 exhaled by the crew for their photosynthesis. Additionally, excrements plus non-edible parts from plants are composted into fertile soil again. During dark periods excess CO_2 is temporarily stored in a cryogenic container. The whole life cycle is basically driven by solar illumination power. Photovoltaic panels fixed to the rotating mirrors produce the necessary electro-power.

We checked, which of the existing or planned spaceships could be used to transport the material and astronauts to the lunar site, where the habitat should be built. The low weight and the modular structure of the components are a large advantage compared to other proposals. While the *SpaceX Starship* would clearly be able to transport the necessary components to the Moon, our concept could also be realised with the help of smaller rockets like the Ariane-64, in combination with the planned *European Large Logistics Lander*. The planned Lunar Gateway is not absolutely necessary to realise our moon habitat concept, but in case it is being built, it can also be a part of the mission.

We also evaluated and compared our design with two other recent and carefully developed lunar habitat designs:

1. The *Moon Village* by SOM-Architects, which features a nearly "ready to use", rigid and partly inflatable structure and
2. the *Lunar Outpost* by Foster & Partners, that consists of an inflatable structure covered by a 3D-printed shell.

In comparison, our *PneumoPlanet* design features by far the lowest payload per m^2 of usable area, the most effective protection from cosmic particle radiation, and the lowest energy requirement for the construction process and in operation. Additionally, it is the only concept of all published until now, that provides a complete ecological cycle for self-sufficient production of food and oxygen.

A logical continuation of this study would be to build a prototype on earth, which can be used to investigate various details of the suggested components in more detail. Examples are: the performance of the electrostatic mirror foils, the life cycle inside the greenhouses, or the material properties of the inflatable foils and the transparent foil through which the solar illumination enters the greenhouse.