**SPACE RENAISSANCE ACADEMY**

# Building a Lunar Base – a proposal

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How can we build an initial lunar base by using current technologies, minimizing costs and providing maximum safety for astronauts ?
Since the space age began less than 70 years ago, the exploration of our moon has been one of the prime goals of space technology and astronautics. If we decide to expand human civilization into space and to use the resources of the solar system, the establishment of a permanently occupied lunar base should be the first step. Prospection and exploitation of lunar resources such as Helium-3 and scarce materials on a cost- effective basis could be a test bed for further space enterprises in the solar system up to moons of Jupiter. Among various possibilities of scientific research, such as geology, artificial ecosystems, human physiology and space medicine, the moon is an ideal location for optical, infra-red and radio astronomy. Last not least the effort to establish a lunar base would start a tremendous economic stimulus for terrestrial economies.
During the last decades various proposals for lunar stations have been made. The early NASA concepts in the 1960ies preferred cylindrical modules, using the payload capacity of the Saturn V launcher (Gatland 1981). Recognising the problems of cosmic rays and micrometeorites some authors like Krafft A. Ehricke, Isaac Asimov et al. , proposed to locate lunar settlements in artificial or natural cavities under the lunar surface, e.g. lava tubes, using inflatable balloons to prepare the construction site (Asimov and McCall 1974; Ehricke 1985; Smolders 1986; Bogen 1993). Studies of inflatable structures on the lunar surface were made e.g. by Vanderbilt et al. and Novak et al. Chow and Lin proposed a lunar base built of double-skin membranes, filled with structural foam (Benaroya 2002). In 2007 Petra Gruber and Barbara Imhof presented a study on bionic (biomimetic) structures (Gruber and Imhof 2007).

Lunar Base, built of inflated modules (NASA)

## Design Criteria for an initial Lunar Base

Any building on the lunar surface is penetrated constantly by high-velocity micrometeorites and hit by cosmic rays. The 11-year cycle of solar flare eruptions can cause lethal danger for humans. The severe temperature cycles, when the sun shines undimmed for 14 days and disappears for another 14 days, can cause material fatigue and brittle fractures on exposed structures and materials.
The average lunar surface temperature is assumed to be about -170 °C in the lunar night and +130 °C during the day (Rükl 1990). The fundamental technologies to erect a lunar base are available since the 1970ies. To minimize risks and costs we assume to use only current and proven technology.

The most important **design criteria** we postulate as follows:

- Maximum safety for humans during construction and habitation; easy escape and rescue in case of damage;
- Structural redundancy and reliability of the entire design;
- Shelter against micrometeorites, cosmic rays, solar flares and temperature cycles;
- Ease of construction: the number of launches from earth and extravehicular work of astronauts should be minimized; robotic vehicles and remote control should be preferred;
- Use of lunar material (regolith), as an in situ resource, especially for shielding;

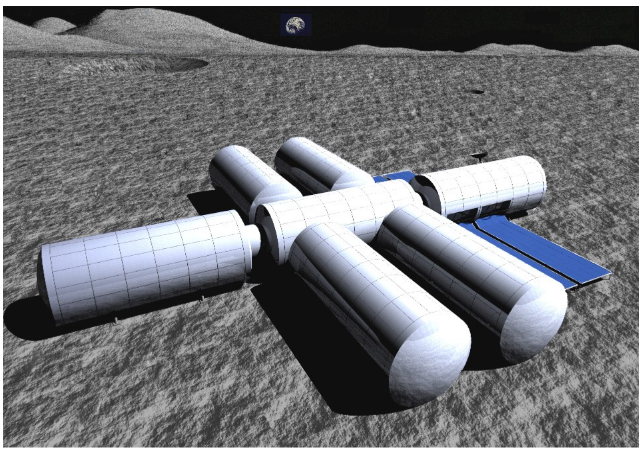
Do e.g. inflatable (pneumatic) structures fulfil the above criteria ? During inflation a pneumatic construction may easily be damaged by small meteorites and cosmic rays. Because of extremely high or low temperatures brittle fractions may occur in the pneumatic skin before it is covered with regolith. To cover inflatables with a 1.0 m thick layer much lunar material and a big crane is necessary. In case of meteorite impact the bubble will deflate immediately. Last not least equipment and furniture can just be put into the habitat through the airlocks. To start any long-term human presence on the moon we need first of all a "site hut" like on terrestrial building sites, easy to assemble and modular. In the long run architects and engineers can use various advanced methods for design and construction of lunar buildings.

## A Modular Lunar Base Design

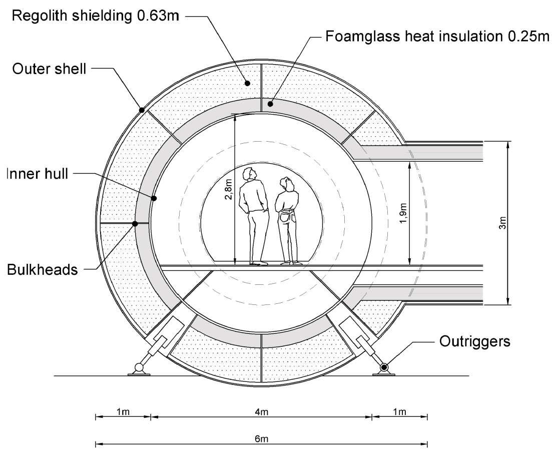
We propose to build the initial lunar station of seven cylindrical modules, each one 17m long and 6m in diameter. Each module is made of aluminium sheets and trapezoidal aluminium sheeting and has a weight on Earth of approx. 10.2 tons, including the interior equipment and furnishing. The outer wall of the cylinders is built as a double-shell hull, stiffened by radial bulkheads. Eight astronauts or scientists can live and work in the station, using the modules as follows:

- 1 Central Living Module
- 2 Living quarter Modules, with private rooms for each person;
- 2 Laboratory Modules for scientific research and engineering;
- 1 Airlock Module, containing outdoor equipment, space suits, etc.;
- 1 Energy Plant Module, carrying solar panels, a small nuclear power source and communication antennas;

The usable living and working area is about 270m² (Energy Plant Module not included).
During assembling the first two or three modules can be used immediately as a shelter for astronauts. After assembling, every module is divided from each other by airlocks or fire doors, which is essential for safety and rescue operations.



Modular Lunar Base, initial stage ( 7 Modules )



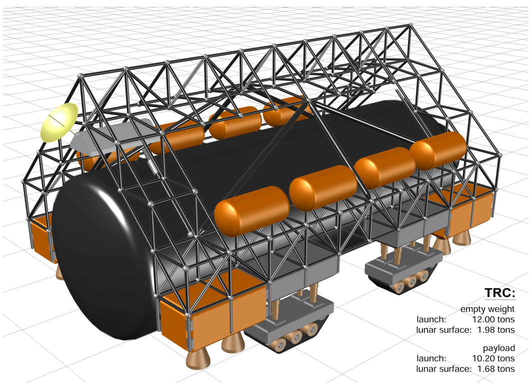

Section of a cylindrical module

To protect the astronauts from micrometeorites and radiation, the caves between the two shells of the outer wall are filled with a 0.63m thick layer of regolith in situ by a small teleoperated digger vehicle. Using lunar material for shielding the payload for launching can be minimized. The initial Stage 1 can be inhabited by eight astronauts. The station can be enlarged by stages, finally becoming an “urban structure” for some dozens of inhabitants.
In a former study “Design and Construction of a Modular Lunar Base”(Grandl 2010) the author has compared the proposed double-shell structure with single-shell designs and inflated structures focussing on thermal protection during the lunar night. Assuming an external temperature of -170°C, and +21°C and 60% humidity of air inside the habitat the calculations in this study showed the advantages of the double-shell system:

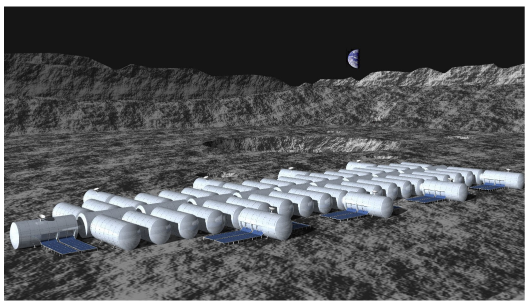
**Table 1.** Thermal protection and temperature distribution (Grandl 2010)

| structure | regolith shielding m | thermal insulation m | thermal conductivity W/m²K | inner surface temperature °C | internal temperature °C |
|---|---|---|---|---|---|
| double-shell | 0.65 | 0.25 | 0.0942 | + 19.2 | + 21.3 |
| single-shell | 0.70 | 0.08 | 0.3375 | +13.0 | + 20.9 |
| inflatable | 1.00 | - | 1.1800 | - 6.7 | + 21.0 |

On the inner surface of the pneumatic skin condensed water will occur and freeze. The temperature difference between inner surface and internal air is approx. 27°C. A single-shell hull with 0.08m foamglass insulation, covered with 0.7m regolith will cause condensed water on the inner surface at 60% humidity of air. In this case the temperature difference between the inner surface and the internal air will be approx. 8°C - uncomfortable for humans. The calculations demonstrate the conclusive advantage of the proposed double-shell structure, which provides a comfortable climate inside the habitat. The temperature difference between inner surface and air is about 2°C -similar to a terrestrial building (Grandl 2010).
The proposed light-weight aluminium design by using thin metal sheets and trapezoidal sheeting and stiffened by radial bulkheads enables us to reduce the payload mass of one cylinder to 10.2 tons, including the furniture mainly made of carbon fibre material. For launching one can use e.g. SpaceX reusable rockets, the European Ariane 6 or similar Russian or Chinese launchers. To land the modules on the lunar surface we propose a Teleoperated Rocket Crane, which is assembled in lunar orbit. This vehicle can land, move and assemble the modules on the lunar surface. The entire landing and assembling process is operated by remote control from a manned Lunar Orbiter. For finishing the astronauts can descend to the lunar surface using a small Manned Lander.




Teleoperated Rocket Crane (TRC), landing and moving a module on the lunar surface



Extended Lunar Base

Due to the modular design, which provides standard weights, measures and sizes for all components of the Lunar Base Project, international cooperation is easily possible.
In a second step of lunar settlement after some years of accommodation and the establishment of mining and industry on the moon, advanced structures, like inflatables, domes of lunar "concrete" or the use of lava tubes will be a challenge for architects and engineers (Benaroya 2018).

"Selenopolis" , a city under the lunar surface, envisioned in a painting by Krafft A. Ehricke;   credit: The Schiller Institute, Washington DC

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