# A Review on Planning of Lunar Structure

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*Abstract*— This project will review on the Planning and Design of a lunar outpost considering major space constraints along with geotechnical and atmospheric properties. Structure selection will be carried based on space performance criteria and resilience to the extreme lunar condition. Based upon the data from various space missions by leading space associations of the USA, China & India and the literature survey a practically possible feasible type of structure will be selected for example steel structure, concrete structure or self-collapsing structure after serviceability made of light weight deteriorate materials. Structure selection will be carried based on space performance criteria and resilience to the extreme lunar condition. The project has mainly focused on National Aeronautics and Space Administration's (NASA) vision to maximise 'In-Situ Resource Utilisation (ISRU)'. The present study will also propose a basic project execution plan for construction with the help of studies available on the mobile preparation of construction materials like concrete, grout etc. on the moon considering manpower constraints and assumptions. Lunar structures are subjected to radiation from Sun which raises requirement of radiation shielding. This challenge can be negotiated by providing a radiation shielding layer of lunar regolith as ISRU on top of the structure.

***Keywords:*** Lunar Regolith, Lunar Outpost, Hexagonal Model, Pentagon Model, Igloo shape, Solidworks, ANSYS

## I. INTRODUCTION

As Moon is the closest celestial body near earth and the amount of exploration and research advancement is reaching at a remarkable level by various space agencies, but even the leading space agencies have managed to execute their historic touchdown to this beautiful celestial body they are still not able to perform a deep in-situ study of Moon because of living environment and most importantly because lack of shelter. The space agencies are in need to extend the duration of visit on Moon, energy production, transmission to communicate with the Earth and daily necessities of crew members.

The development and performance of permanent lunar bases and outpost have to face challenges thrown by the lunar environment and the availability of in-situ resources and construction materials and at last the constraint of transportation of these materials to Moon.

### A. Inflatable Lunar Structures

Inflatable structures can be easily carried to the moon and it does not require transportation of heavy designed parts and erection equipment from Earth. A pneumatic structure was proposed by Land (1985) which supports the regolith shielding layer permanently. Initially, the deflated structure is placed on a levelled surface and then regolith is pushed over it, and then structure inflation work is carried out. The upper part of the structure is ribbed to anchor into the regolith.

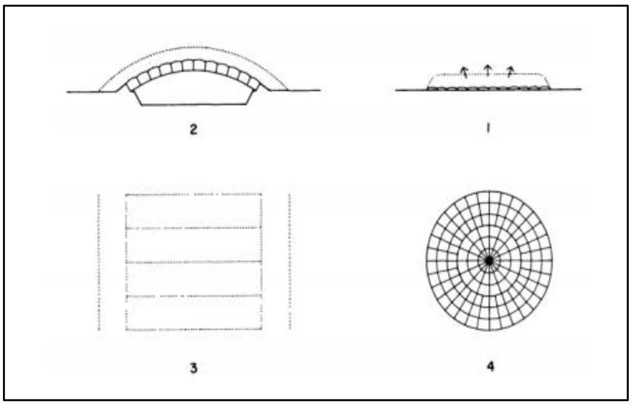


Fig. 1: Base concept, low arch shield with a pneumatic support structure (Land 1985, courtesy of NASA). (1) Deflated structure flat structure flat on the ground. (2) Structure inflated, raising the regolith. (3) Plan showing the concept applied in sections for a concept applied in sections for a continuous low arch shield. (4) Plan showing concept applied in a low domed shield

Roberts (1988) proposed inflatable manned system during Apollo mission. During his study, he proposed a spherical pneumatic structure with the interior rigid structure to support walls and floors. After successful testing of structure extensive research was carried by NASA on optimisation of inflatables.

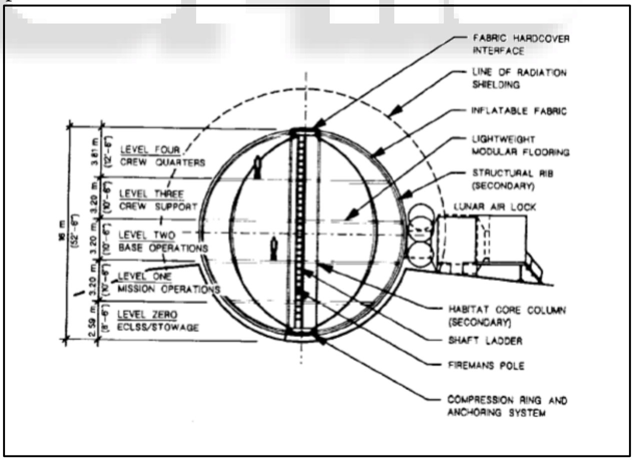


Fig. 2: Cross section of the inflatable Lunar Habitat (Roberts 1988, courtesy of NASA)

Nowak et al. (1992) proposed a pillow shaped, modular inflatable lunar structure. The structure is composed of several basic modules and each module consists of the structural components like roof and floor membranes, external wall membranes, four columns, footings and arched ribs.

 

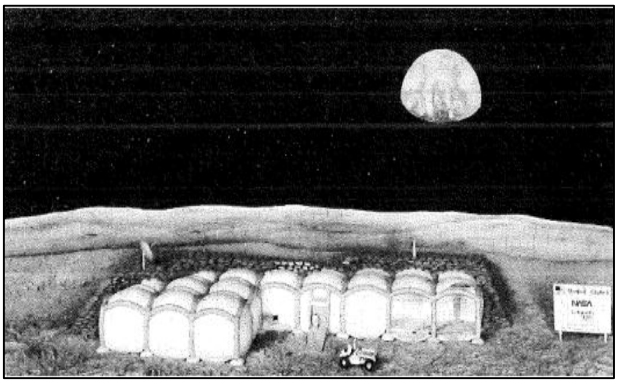

Fig. 3: Physical model of inflatable lunar base (Nowak et al. 1992)

Bionic concepts were investigated by Gruber et al. (2007) that can be applied to deployable structures. They explained that the structures may fail in the lunar environment if it is used to cover the large scaled area. They concluded that the deadweight limits concept application on Earth, but this can overcome for lunar structure due to the Moon's acceleration due to gravity. The lunar habitat design was inspired by wing folding principles and the geometry of ladybirds.

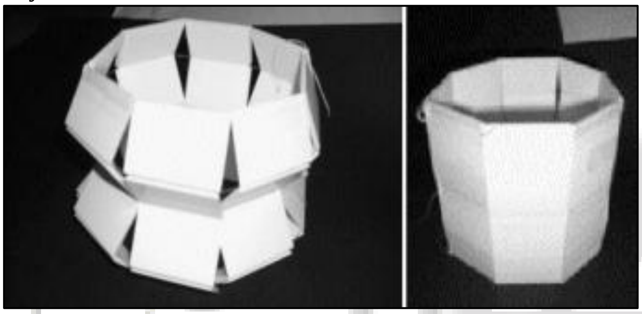

Fig. 4: Working model showing deployment process (Gruber et al. 2007)

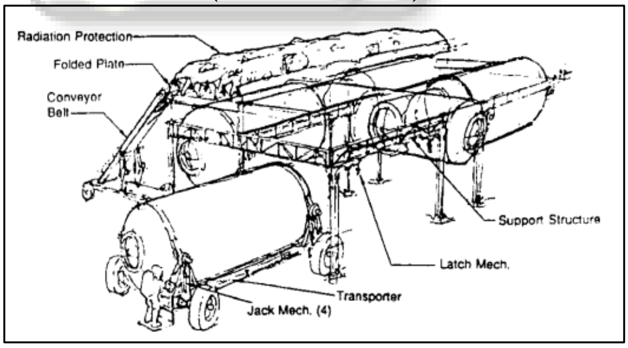


Fig. 5: Modules for lunar base (Griffin 1990)

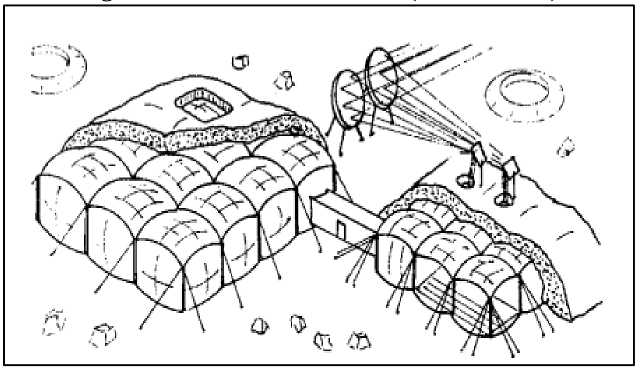

Fig. 6: Inflatable structure (Vanderbilt et al. 1988)

### B. *Rigid Lunar Structures*

Studies including design and analysis have been carried out rigid structures and numerous structural designs have been proposed. Kaplicky and Nixon (1985) investigated the use of direct derivatives of module types being developed for the Space Station. The structure is a series of modules grouped into a complex under a regolith shielding envelope. The envelope is configured as a shallow, flat top mound of loose regolith supported by a continuous tension membrane that is connected to a regular grid of telescopic columns and supported by tapered beams (Figure: 7).

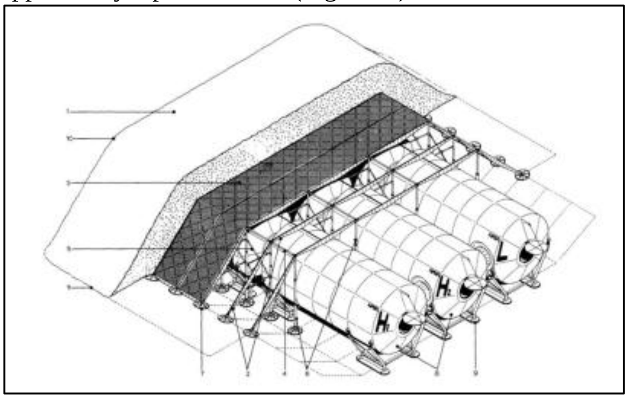

Fig. 7: Cutaway illustration of superstructure envelope system (Kaplicky 1985, courtesy of NASA)

Lin et al. (1989) investigated a precast – prestressed concrete lunar structure of 120 ft diameter and 72 ft height (Figure: 8). Their structure required 8000 tons of concrete, 110 tons of prestressing steel and 250 tons of reinforcement bars. But an estimated 36 tons of hydrogen would have had to be transported to the Moon to make the concrete.

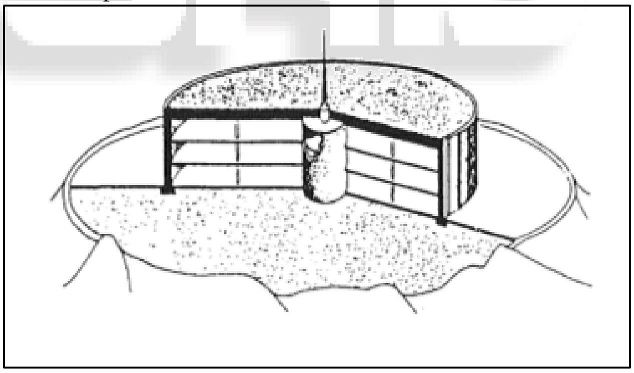

Fig. 8: Three-level concrete lunar base proposed by Lin et al. (1989)

In another research work, King et al. (1990) proposed a structure using the liquid oxygen tank portion of the space shuttle external tank that would be modified in low Earth orbit before transport to the Moon.

A dome shape shell structure made of cast basalt (regolith) proposed by Aulesa (2000) that is to be covered by 5.4 m of unconsolidated regolith as radiation shielding. The base location is selected at a mountain in the lunar South Polar Region at 0º longitude, 86º South latitude because Sun never completely sets and the Earth is visible every time.

Ruess et al. (2006) considered the lunar extreme environment and availability of the materials on the Moon. They proposed the detailed design of a group of igloo-shaped structures made of cast regolith (Figure: 9). They recommended a design volume (living and working areas) of

120 m3 per person for a lunar habitat based on research of long-term habitation and confined spaces.

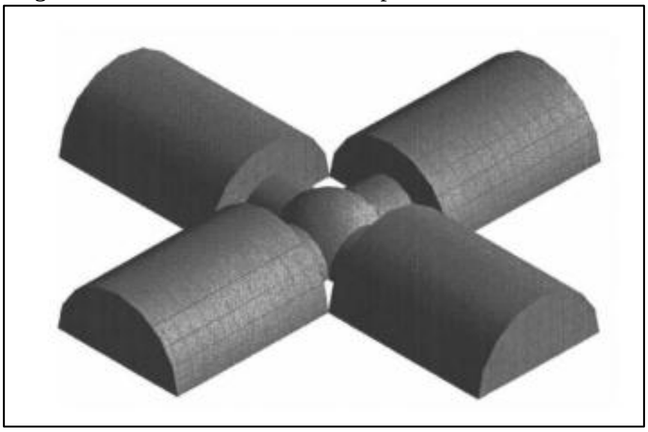

Fig. 9: Proposed lunar structure by Ruess et al. (2006)

Meyer and Toutanji (2007) also investigated the possibility of lunar concrete structures in which concrete can be manufactured without water. They proposed an arched-panel habitat made of sulphur-lunar regolith concrete (Figure: 10).

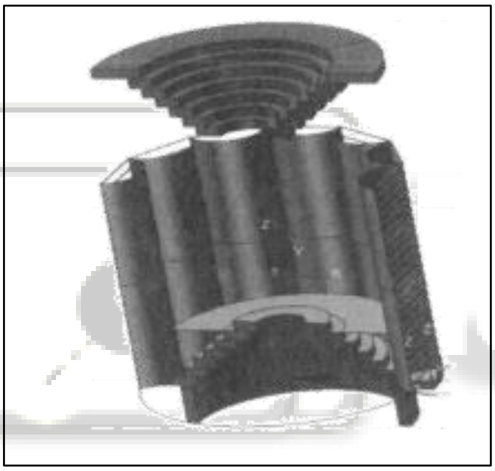

Fig. 10: Arched-panel habitat proposed by Meyers and Toutanji (2007)

A lunar concrete structure study Matsumoto et al. describes that the module consists of the frame and detachable panels used in lunar outposts provides a large space. The configuration of the module is achieved by post-tensioning of these panels preferably made of concrete. The cast in-situ module will simplify the construction process and provide airtightness to the module. Erection of the modules is carried out using mobile cranes.

### *C. Concrete Production on Moon*

Lunar concrete consisting of 10% thermoplastic polymer (polyethene) and 90% of lunar soil by mass, addressed in previous studies by Tai Sik Lee et al. (2015), is feasible for construction on Moon due to maximum use of in-situ resources by proving heat for concrete manufacturing using solar cells. The strength gained for this concrete was nearly 12.6 MPa to 12.9 MPa within 5 hours.

Also, further studies by Toutanji et al. (2012) conclude that concrete consisting of 35% Sulphur and 65% of lunar soil by weight has a compressive strength of 31.0 MPa after 24 hours at room temperature whereas hydrated cement concrete with 0.43 w/c ratio gives 24.2 MPa compressive strength. Addressing radiation problems, the study says that Carbon and Hydrogen are considered to be good radiation shielding materials, hence a concrete sample consisting of an even small fraction of these two elements would provide some amount of radiation protection. A concrete wall made of sulphur and lunar soil would need to be thicker than a wall made entirely of lunar soil simulant to provide the same amount of protection.

Sublimation of Sulphur concrete study by Grugel and Toutanji (2008) predicts that for the volume fraction of aggregate between the two concrete samples (57% and 69.6%), 4.4 and 6.5 years respectively would be needed to sublimate away a 1-cm deep layer from the concrete samples. Sulphur sublimation rates were predicted to change dramatically over a temperature range from 15 to 120$^{o}$ C. Finally, it was shown that the much lower vacuum on the moon would contribute only slightly more to the sublimation rates determined from the ground-based experiments.

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## II. Past Results & Conclusions

After the analysis and design, it can be concluded that construction on the moon is possible but this analysis was done for research purpose but practically the cost of construction will be very high. The construction in uneconomical and the amount of concrete required to cast one plate is 4 $m^3$ so overall 64 $m^3$ of concrete will be required to cast a single unit. On an average this concrete is equal to the volume of concrete in 19000 cubes of 150 mm so roughly we can estimate the amount of concrete needed. From the reaction table we can say that the horizontal reaction should be the governing one as Fx > Fy but for foundation design, we have only considered Fy and we have not taken horizontal force which needs some advancement. So in further designs, it is recommended to design such a structure which can nullify the horizontal forces and make the support take more axial load so that we can use the entire bearing strength of soil. Because of this, our moments have been increased a lot and the structure is failing in overturning check. Also, it is interesting to note that the bearing capacity of lunar soil has very high values as compared to soils on earth so we can take its advantage in further research work. Also, there is no seepage in the soil which further adds an advantage to analysis. There is no seismic effect so this load can be entirely ruled out.

Further, we can conclude that the structure is not responding to prestressing load as much we expected it to be. This can be because the forces have been applied on the released nodes and hence the effect has been reduced. So, we need to think some different technique to strengthen our plates or we can try different types of the profile for prestressing in later studies. Because after this much amount of prestressing force the maximum plate stress is 58 MPa and our concrete the only take the stress of 31MPa so slightly higher grade of concrete will help us.

We need to develop the roof of the structure need to be developed because it may happen that the roof can regulate moments in plates thereby reducing the stresses in plates.

## III. Methodology

After studying the geotechnical and atmospheric data collected by Moon missions of various countries like US, China & India, concrete structure will be more feasible and hence from available literature on behaviour of cement in moon environment a proper method will be proposed for concrete production and strengthening its tensile properties on moon. Analysis work will be carried on ANSYS taking difference of acceleration due to gravity in account. Then panel and footing design will be executed based upon geotechnical properties of lunar soil. Further, compiling work will be carried out to propose a detailed project execution plan.

During the literature survey, we came across many proposed lunar structures. We also have done considerable study on the materials which can be used for construction of lunar structures. The most important loads to be considered for lunar structures are thermal loads (due to temperature range of 95K to 390K) and internal pressure loads along with self-weight. We will be focusing on conducting thermal and pressure analysis on the proposed structures in ANSYS. Based on the results of the analysis, changes will be made to the designs to arrive at a design which will be structurally safe and also provide adequate working space for the astronauts. The structures will be created in Solidworks and then exported to ANSYS.

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