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Requirement definitions of deployable structures and R&D of unmanned setup system on Luna surface

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MAKE BEYOND
つくるを拓く

Today's Contents

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1 Background of Study

By the Japanese Ministry of Land, Infrastructure, Transport and Tourism（MLIT）

Space construction innovation project 2023

FY2023 Research & Development List

MLIT Ministry of Land, Infrastructure, Transport and Tourism MEXT

Technical Category	Technology Classification
Technology I	Unmanned Construction (Automatic and Remote)
Technology II	Production of Building Materials
Technology III	Simple Facility (Deployable Structure)

Cabinet Office Stardust Program (Strategic Program for Accelerating Research, Development and Utilization of Space Technology)

2 Development Objectives

■In the initial stage of lunar surface development, the number of people and materials are limited.

■Aim to reduce the amount of materials transported and to be compatible with unmanned construction operations (automated construction).

Clarify the performance requirements and installation methods based on the demands of each exploration phase.

Select the most effective target structure and conduct research on automatic deployment and unmanned installation.

As examples of current developments, an automatically deployed multi-purpose tower (power generation, communication, etc.) and a deployable structure for pressurized spaces will be presented.

Assumed area: near the South Pole

Structures

Specific selection of deployable type structures to be developed

【Target】 needed as facilities in the early stages of lunar development.

↓ ↓ ↓ ↓

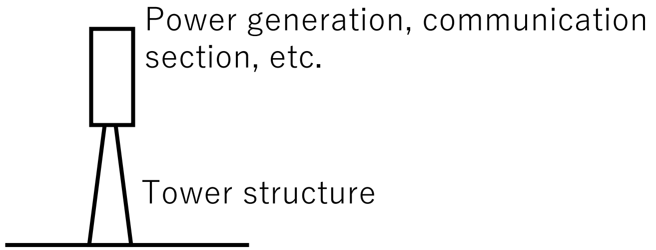
【Materials/structure】 Materials and structure that meet lunar environmental conditions/performance requirements.

【Function】 Deployment function suitable for automatic deployment and unmanned setup

【Target】 The following two types were selected.

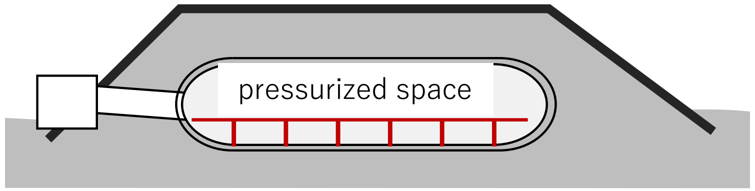
■Unpressurized structure

Tower-like deployable structure for multi-purpose functions such as power generation, communication, etc.



■Pressurized structure

Deployable habitat module for a small number of people in the early stage of lunar surface development.



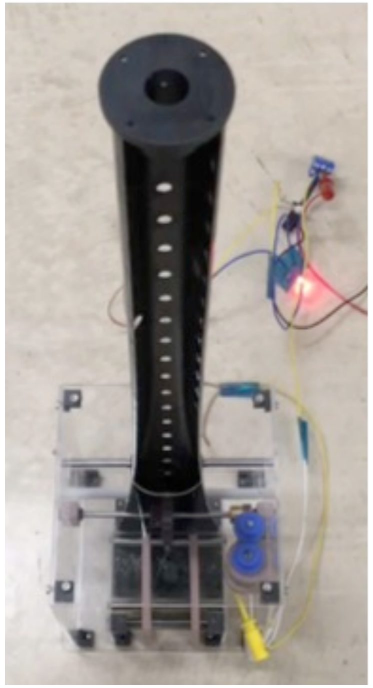
4 Study of Unpressurized Structure

4.1. Selection of Structure Type

■The lunar surface is subjected to low gravity acceleration. A multifaceted evaluation was conducted based on sufficient strength for the support load and ease of deployment.

As a result, a bistable extension boom made of carbon fiber reinforced plastic (CFRP) was selected for the tower extension structure. This boom can be rolled up to serve as a pillar structure and can be stored in an extremely compact.

■In order to ensure structural strength
and well-balanced extension with a relatively thin boom,
three booms and Solar Array Panels (SAPs)
are arranged in a triangular pillar shape.
SAPs are installed on top of the tower to generate solar power,
which is one of the most important functions
of a multi-purpose tower.



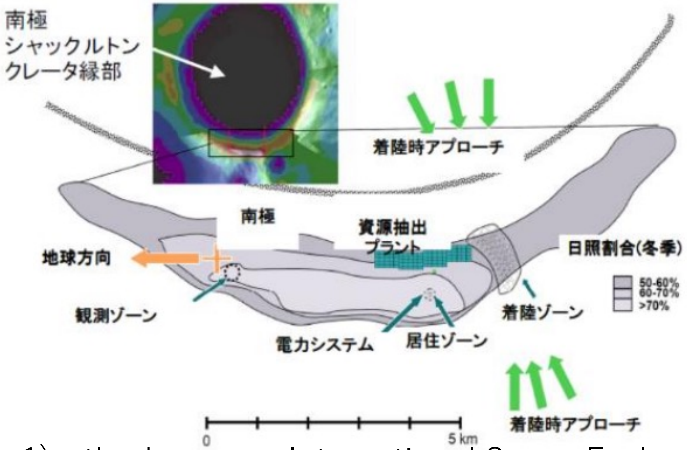
Carbon Fiber Reinforced Plastic
Bistable Extension Boom

4.2 Examination of tower height required for solar power generation

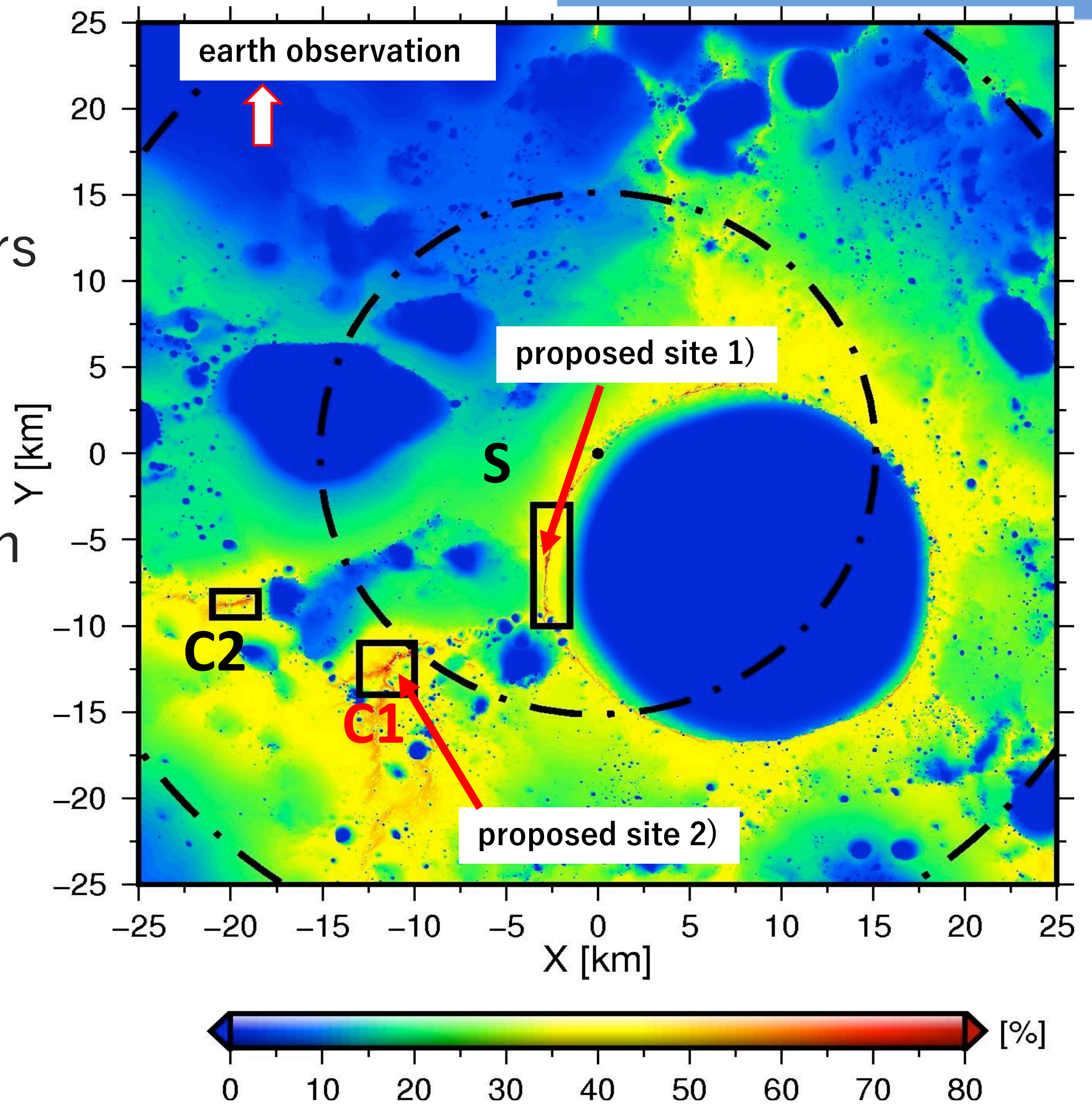
■The relationship between tower height and hours of sunlight was examined based on the following two references.

1) High elevation point in the lunar base shown in the Japanese International Space Exploration Scenario (Draft) 2021 version (left figure)

2) High elevation point in the C1 area shown in the existing paper (right figure)

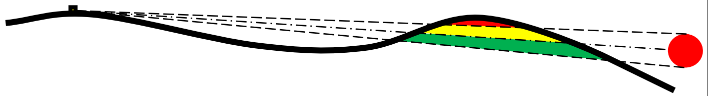


1) the Japanese International Space Exploration Scenario (Draft) FY2021 version



Reference：Illumination conditions at the lunar poles: Implications for future exploration, 2017/6/29

4.2 Examination of tower height required for solar power generation



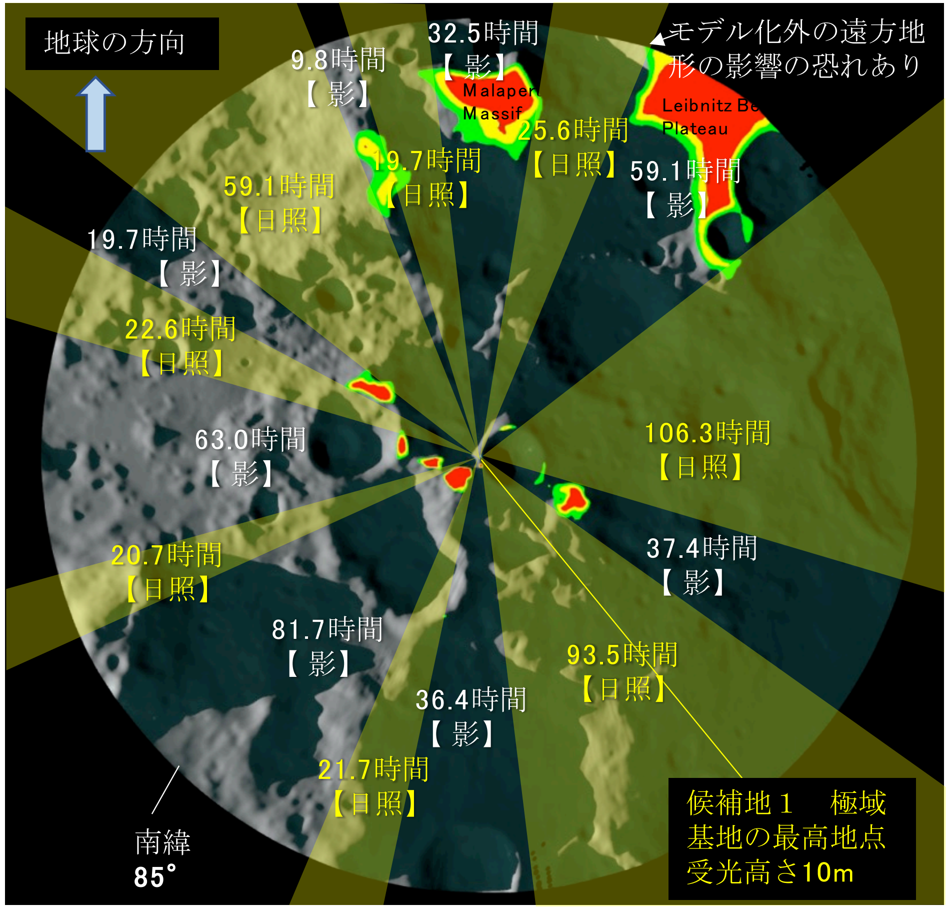
Red: all of the sun is hidden
Yellow: 1/2 of the sun is hidden
Green: a little of the sun is hidden

■Topographic data for the lunar South Pole region (90° S to 85° S) were generated from JAXA's KAGUYA observation data. By gradually increasing the height, the sunlight periods get longer.

As a result, we found that if the SAPs height is increased to 10 m or more, it is possible to get high power generation effect without much influence from the nearby topography.

In this study, the highest point of the tower was set at <u>12 m</u>.

■The power can be generated more than 50% during the winter solstice, even when the sun of height is at the lowest altitude, and more than 80% on average per year.



Direction of sunshine during winter solstice (h=10m)

Sunshine Simulation

4.3 Basic Design of Multi-Purpose Tower

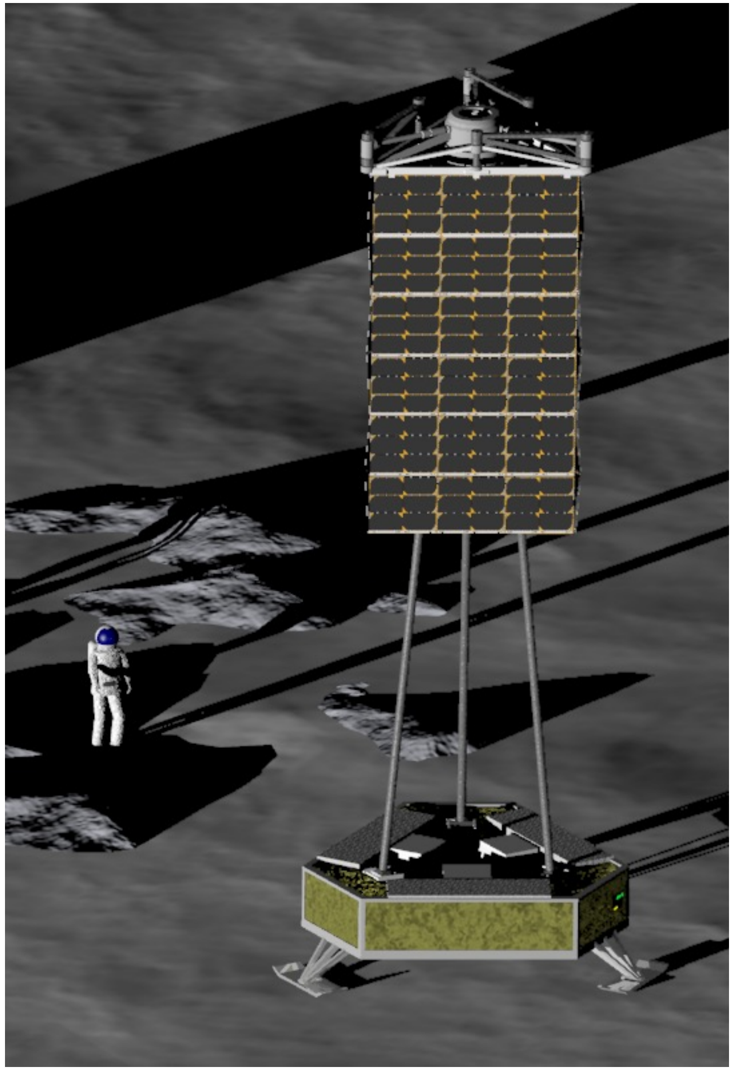
■The SAPs are attached to the top of the CFRP bistable boom columns and the columns are extended, thus placing the SAPs in a higher position. The SAPs are folded and deployed with the columns extension. The dimensions of the tower before deployment shall fit into the rocket fairing.

Power for the deployment will be provided by the on-board batteries or by power generated on the base.

■A boom winding mechanism using motor-type actuators, which also serves as a pillar structure, will be placed on the legs.

By controlling the movement of each actuator, the tower can stand vertically even on a slope.

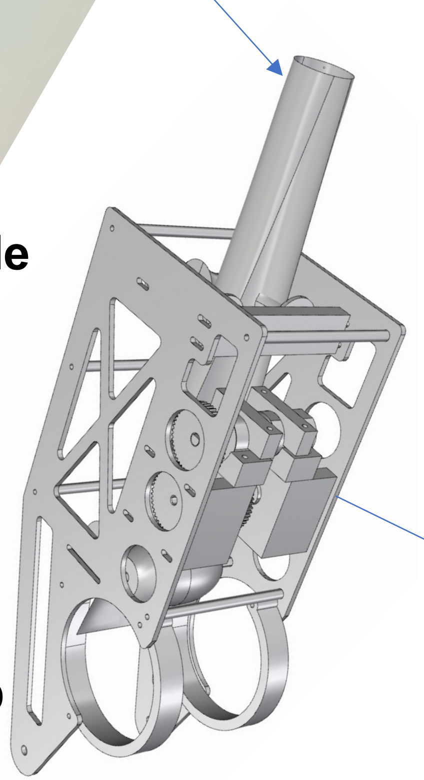
SAPs will be deployed almost vertically because the sun's altitude in the polar regions is close to the horizontal plane.



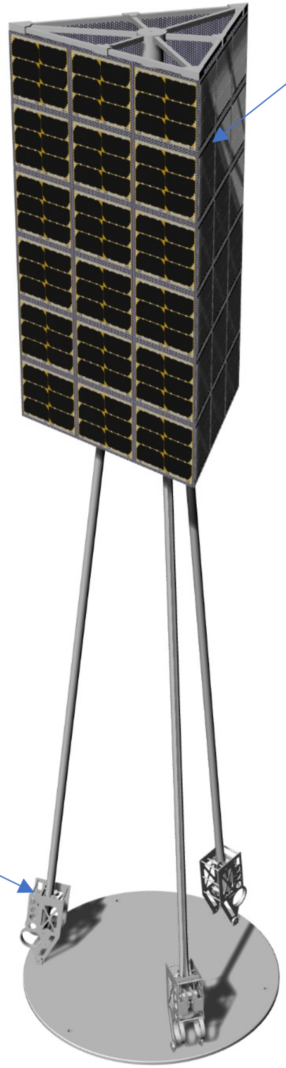
Multi-purpose tower (h=12m)

4.4 BBM test of multipurpose tower (1/6 of actual tower)

CFRP Bistable Boom



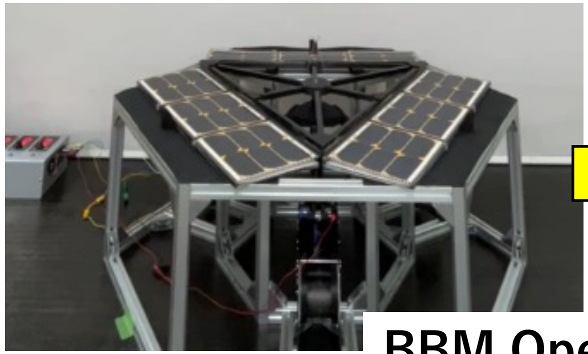
Pillar support structure and boom take-up mechanism

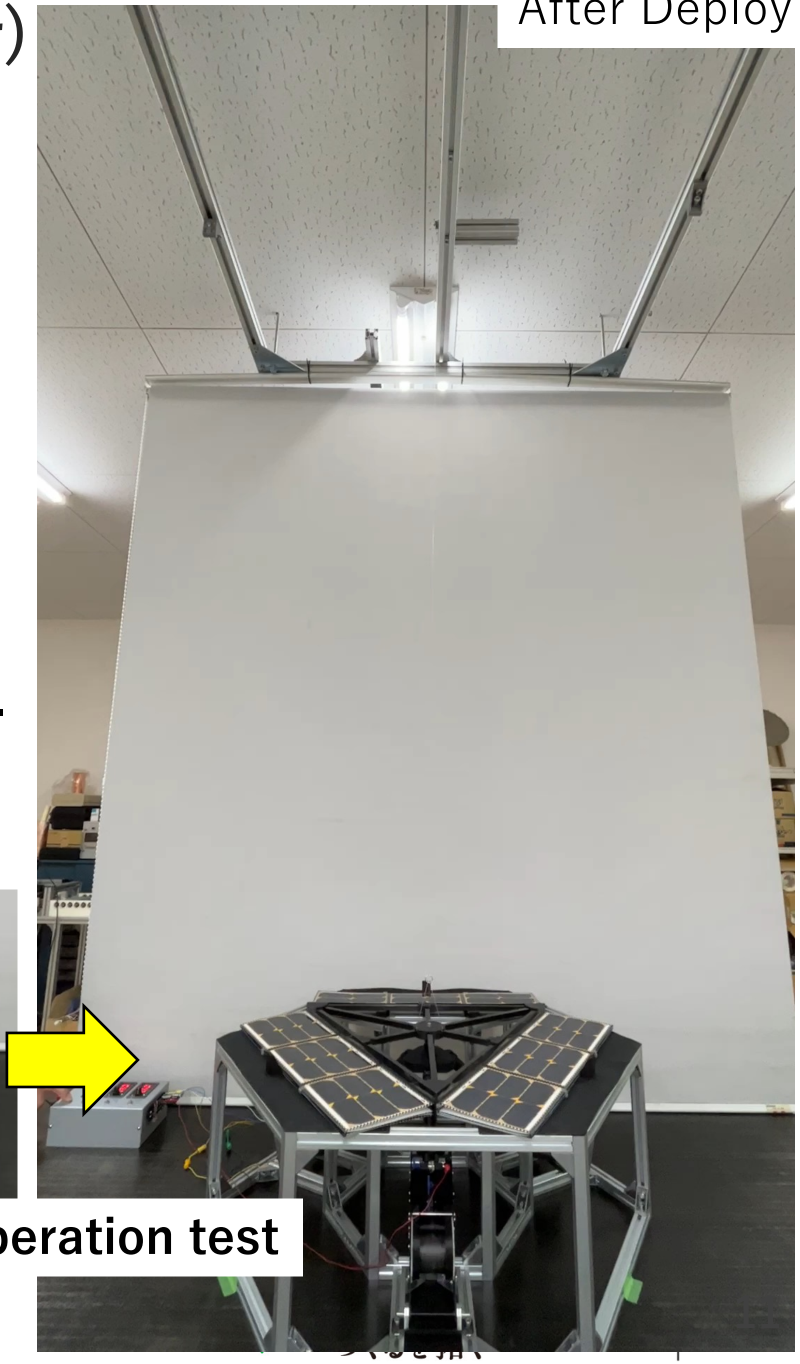


Thin-film solar cell

Since the gravity of the Earth is about 6 times greater than that of the Moon, the stress and strain acting on this BBM structure are equivalent to those of the actual lunar surface.

Overview of BBM Height 2.0m
Actual Height 12.0m





After Deploy

BBM Operation test

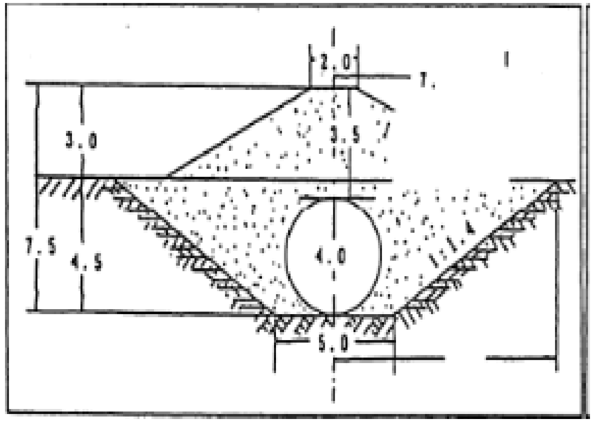
Bread Board Model

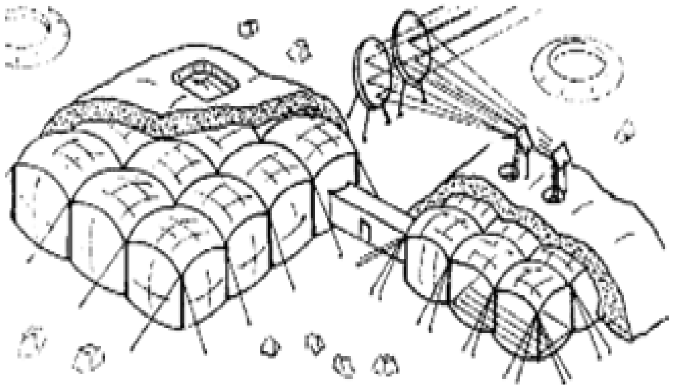
5 Study of Pressurized Structure

5.1 Selection of Consideration Targets

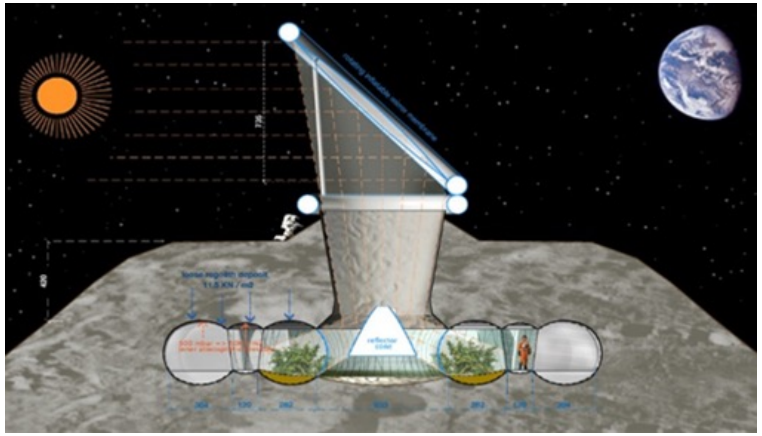
■For the deployment-type residential module, an inflatable structure using a membrane structure is assumed. Our study assumes a 5-meter soil cover. The soil cover provides protection against temperature, cosmic radiation, micrometeorites, space debris, etc.

■Based on previous considerations, the thickness of the regolith layer is set to be 3 m or more for insulation and radiation shielding, but it has been increased to 5 m to account for margin thickness.





Rutaers University(USA) Proposal



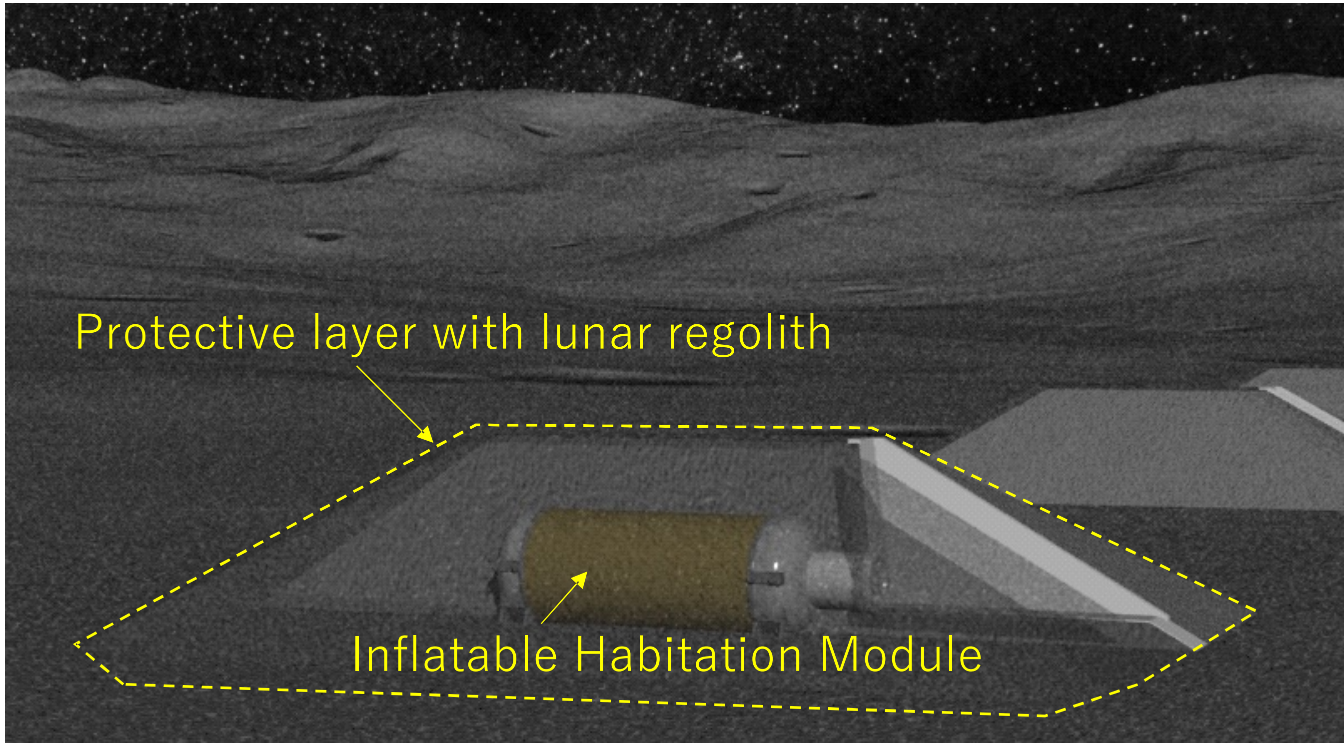
Habitat Initiative ESA

5.2 Lunar Regolith as a Protective Layer

■The lunar regolith layer is used as a protective layer to provide insulation, radiation shielding, and protection against small debris (substituting MMOD layer with lunar natural materials).

The membrane inflatable structure section ensures pressure resistance and airtightness. The shape is maintained by the weight balance between the internal pressure and the soil cover thickness.

■Assuming soil pressure distribution and shape stability of the regolith, the stress and strain conditions outside the inflatable structure were determined. This will allow us to determine the stable shape of the regolith layer and the stress-strain state of the membrane during that time.



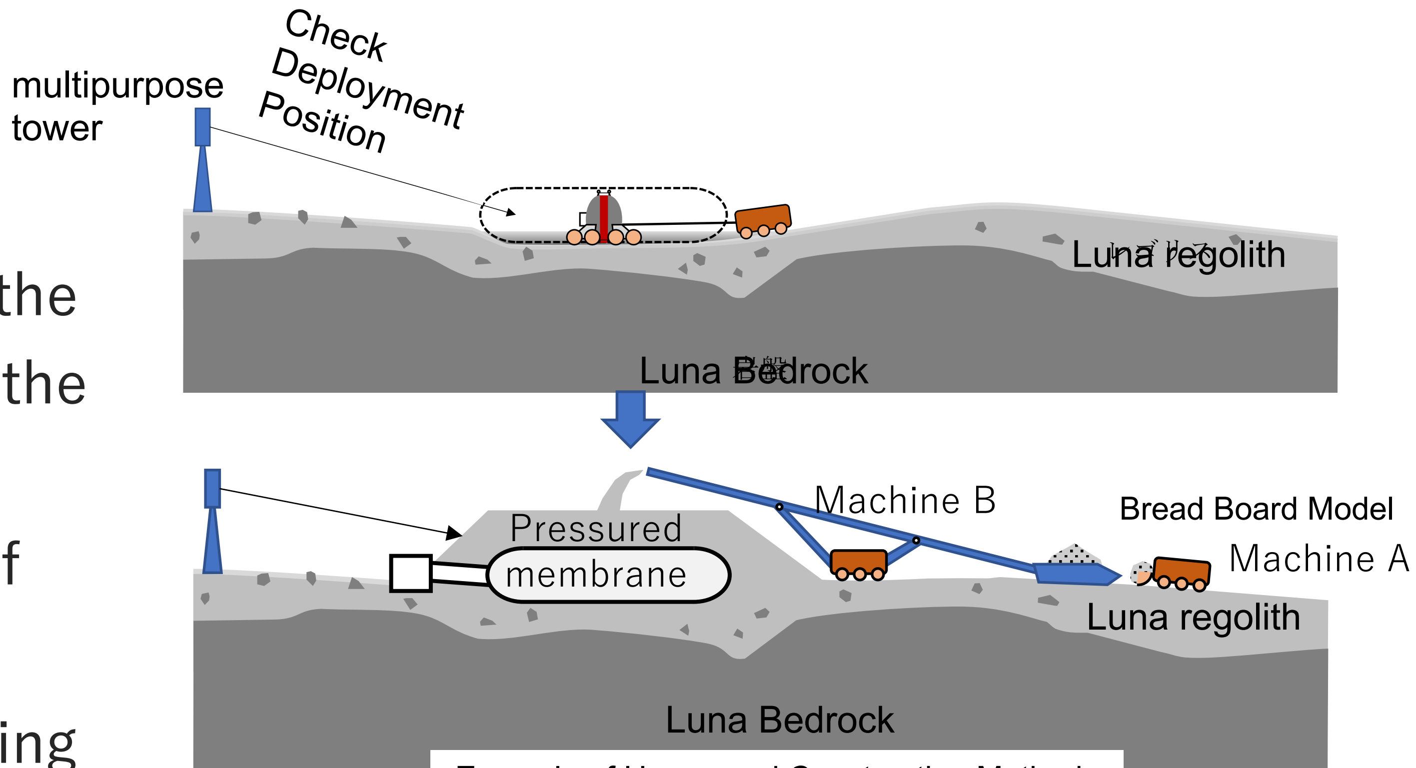
5.3 Construction Feasibility Study of Buried Inflatable Structures

■The very surface layer of the regolith is considered to be loose. The ground surface in the extension area of the inflatable structure is leveled almost horizontally and the inflatable structure is deployed.

Next, the hatch, as an entrance/exit airlock, is installed.

Then, loose regolith is collected from the surrounding area and covered 5 m to the outside of the inflatable structure.

Analysis has confirmed the stability of the 5 m soil cover.



Example of Unmanned Construction Methods

■In the current study, a method is being devised that allows the floor and wall plates to be deployed simultaneously as the internal frame is deployed. Development of lunar excavation machinery is also expected, but in this case, an inflatable structure is installed on the ground.

6 Current Status and Future Progress

■Ongoing Considerations:
⇒Improving the performance and feasibility of the multi-purpose tower structure
⇒Ensuring stability of the buried inflatable structure and investigating methods for constructing internal living spaces:

- In order to increase the efficiency of the power generation, we are considering deployment of the SAPs in the same plane and tracking the sunlight.
- 12-meter full-scale experiment on the ground is considered difficult because the gravity is too large (of 6 times).

■Ultimate Goals of the Project:

- Practical application of deployable structures on the Moon, MLIT will try to apply them under severe disasters.
- Internal structure particle method to the chemical and horizontal can examine the soil cover membrane pressure.

7 Acknowledgement and Conclusion

This effort is part of the Space Construction Innovation Project of the Japanese Ministry of Land, Infrastructure, Transport and Tourism(MLIT). Our collaborators, JAXA, Muroran Institute of Technology, and Sakase Adtec. We will continue to deepen our study.

We focus on the initial stages of lunar development, where the number of stayable people and the amount of deployable materials are limited. Our research aims to reduce material transportation and streamline on-site construction through the automated deployment and unmanned installation.

In this report, the current development examples of an automated deployable multi-purpose tower and a deployable structure for pressurized environments were introduced. The research will continue to explore more specific designs and structural forms.

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Thank you very much