REQUIREMENT DEFINITIONS OF DEPLOYABLE STRUCTURES AND R&D OF UNMANNED SYSTEM ON LUNAR SURFACE. Y. Fuchita, Y. Takeuchi[1], Y. Miyazaki[2], K. Higuchi[3], R. Sakai and A. Watanabe[4], [1]Obayashi Corp.(2-15-2Konan,Minato-ku,Tokyo,Japan, fuchita.yasuhiro@obayashi.co.jp, takeuchi.yoshitaka@obayashi.co.jp), [2]JAXA(3-1-1 Yoshinodai, Chuo-ku, Sagamihara-shi, Kanagawa, Japan, miyazaki.yasuyuki@jaxa.jp), [3]Muroran Inst. of Technology(2-17-17, Nagata-cho, Chiyoda-ku, Tokyo, Japan, higuchi@mmm.muroran-it.ac.jp), [4]Sakase Adtech Co., Ltd.(14-10 Shimoyasuda, Maruoka-cho, Fukui-ken, Japan, r-sakai@sakase.co.jp, a-watanabe@sakase.co.jp)

Introduction: It is a common requirement for any lander or rover that the energy source for lunar activities is limited to fuel and storage batteries from the Earth and local power generation. The objective of this development is to develop a deployable structure that can generate electricity to power other facilities and rovers once compact and lightweight materials reach the lunar surface.

On this study, the deployable structure is envisioned as a tower-like structure to be installed in the polar regions, so it can be used not only for power generation but also for communication to the Earth. We will also introduce our efforts to develop a deployable structure for pressurized space using the mechanism of the deployable structure.

Feasible deployable structures: From various deployment structure candidates, feasible deployable structures were selected. The optimum structural form for the special environment of the lunar surface, such as vacuum and low gravity, was considered, with the conditions of automatic deployment and unmanned setup.

In the initial stage of lunar surface development, various facilities (shelters, lunar base modules, energy and infrastructure-related facilities, etc.) subject to deployable structures were evaluated from various aspects such as technical difficulty, transportation cost, compatibility with lunar surface installation, and early development feasibility, and deployable structures that are worth developing were selected. As a result, the unpressurized structure was selected as a tower-like structure to be used for multiple purposes such as power generation and communication. For the pressurized structure, a habitation module for a small number of astronauts was selected. Table 1 shows an overview of the selected deployable structures.

Table 1. Overview of selected deployable structures

Type	Deployable structure
Unpressurized structure	Tower-like structure for multi-purpose such as power generation, communication, etc.
Pressurized structure	Deployable structure for residential module

Unpressurized structure: A survey was conducted on deployable structures based on domestic and international papers and published information. Although many methods of deployable structures have been reported, most of them are designed to be installed on a satellite.

On the other hand, even though the gravity on the lunar surface is low, gravity acceleration is always applied. Therefore, the deployable structure must be strong enough to withstand the dead weight and support load, and must be stably installed on the lunar surface. We conducted a multifaceted evaluation of various candidate deployment mechanisms in terms of light weight, rigidity and strength, space saving for mounting, power saving for extension, high reliability (simplicity), and mass production and cost. As a result, the bistable

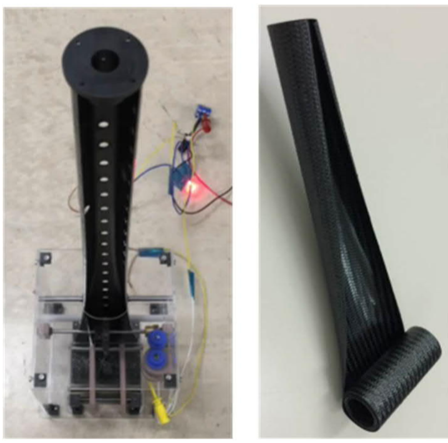

Figure 1. Bistable boom of CFRP[1]

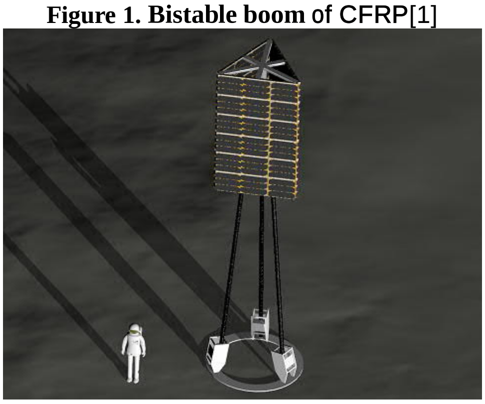

Figure 2. Multipurpose Tower

boom[1] (Figure 1) made of carbon fiber reinforced plastic (CFRP), which received the highest overall score, was selected for development of a multipurpose tower incorporating this mechanism.

Two sites were selected as cost-effective locations in the vicinity of the polar base near the lunar South Pole, as indicated in Japan's International Space Exploration Scenario (Draft) 2021[2]. Assuming that a multi-purpose tower equipped with SAPs (Solar Array Panels) would be built near the top of the high elevation, we conducted a sunshine simulation considering the surrounding topography and the trajectory of the sun. As a result, a cost-effective height for the multi-purpose tower was set at about 10 meters.

It was also found that a total of four 12-meter-class towers, including one near the top, could communicate with almost the entire slope of Shackleton Crater without considering the diffractive nature of radio waves.

The main structure of the towers was fabricated using a triangular pyramidal framework based on a bistable extension boom made of CFRP with a motorized extension structure of variable shape.

Since the sun's altitude in the polar region is nearly horizontal, the solar panels are deployed nearly perpendicular to the lunar surface when deployed. A folding mechanism is adopted for compact storage. In the proposal reported here (Figure 2), the SAPs are folded into non-rotating triangular columns.

Since the BBM is tested on the earth, the dimensions of the BBM are 12m/6=2m, assuming a gravity ratio of 6 times that of the lunar surface, so that the stress strain acting on the structure is equivalent to that on the lunar surface. The height of the unit before deployment was reduced to about 1/10 of the height after deployment because the SAP can be folded before deployment.

Pressurized structure: The pressurized structure covers the deployable structures for habitation modules shown in Table 1. Inflatable structures using membrane structures have been considered for many deployable habitat modules in space and on the surface of planets/satellites. In each case, strength to withstand internal pressure and airtightness to seal the air are considered. These can be handled with thin membranes or fibers, making them highly collapsible.

Compared to pressure resistance and airtightness, protective functions such as thermal insulation, radiation shielding, and debris protection require protective layers with a certain thickness. There is a proposal to construct these protective layers with multi-layered membranes as artificial materials, but this would increase the thickness of the layers, which would reduce the foldability, and would also increase the amount of materials required for transportation. On the other hand, a method that leaves these protective functions to natural materials that exist on the Moon is also being considered. This method can reduce the weight of the inflatable structure itself and ensure its foldability, but the thickness required to maintain the function of the protective layer made of natural materials and its construction method have not been clearly established.

In this study, we examined the feasibility of a buried inflatable structure that uses regolith, a natural lunar material, as the protective layer, rather than membrane material itself, which is still under development.

Lunar regolith has been studied for its heat insulation and radiation shielding functions, and it has been estimated that a regolith equivalent thickness of 3 m or more is required for a long-term human habitation zone on the Moon[3].

In the buried inflatable structure, an inflatable structure that is a pressurized space is buried in the lunar regolith. When the pressurized space is buried underground, the pressurized space must not be crushed by earth pressure. However, since the lunar surface is a pressurized space under a vacuum environment and the gravity is 1/6 of that of the earth, even if there is a 5 m earth cover, the internal pressure exceeds the earth pressure based on the thickness plus the safety factor. Therefore, there is no risk of the space being crushed by the soil pressure.

The construction equipment required for this method is a loader-type machine with a bucket-shaped soil drainage plate in the front and a conveyor belt-type machine that is long enough to drop regolith onto the inflatable structure.

Summary: In this report, we introduced an automatically deployed multi-purpose tower (for power generation, communication, etc.) and a deployment structure for a pressurized space.

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References: [1] Akito Watanabe, Development of an Extension Boom for Space, Journal of the Japan Society for Aeronautical and Space Sciences, Vol. 64 No. 12, pp. 347-351, 2016. [2] Space Exploration Systems Engineering Unit, International Space Exploration Center, Japan Aerospace Exploration Agency: Japan's International Space Exploration Scenario (Draft) 2021, EZA-2021013, 2022.3. [3] Lunar Environment (Focusing on regolith), JAXA Space Education Center.