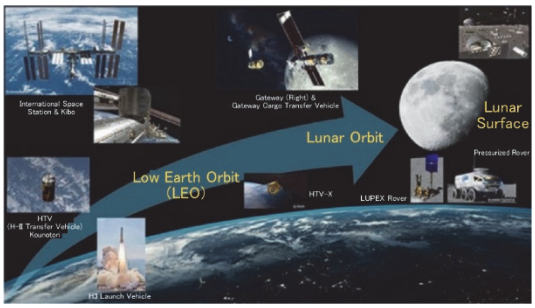
New Business Initiatives for Human Space Exploration in Low Earth Orbit and on the Moon



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Mitsubishi Heavy Industries, Ltd. (MHI) develops diverse space products in three fields: launch vehicle transportation, International Space Station (ISS) and international space exploration, and satellite and data utilization. In particular, in the field of ISS and international space exploration, MHI has been developing transfer vehicles, supporting life science experiments in the Kibo experiment module of the ISS, and undertaking technological development for lunar exploration related to the U.S. Artemis program. MHI is also working on post-ISS commercial space stations and the construction of a lunar base through industry-academia-government collaboration, aiming to contribute to the advancement of the space industry.

1. Introduction

Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) has been involved in the development of various space products primarily in three fields: launch vehicle transportation, International Space Station (hereinafter referred to as ISS) and international space exploration, and satellite and data utilization, such as the Japan's flagship launch vehicles, liquid rocket engines, the Kibo experiment module of the ISS, the experimental equipment used inside the Kibo, and transfer vehicles. Recently, MHI has been exploring new business fields by utilizing its accumulated knowledge and technological capabilities.

Focusing particularly on the ISS and international space exploration, this report presents MHI products related to commercial space stations after the retirement of the ISS scheduled around 2030 (hereinafter referred to as post-ISS space stations) and the Artemis program, an international space exploration program led by the United States' National Aeronautics and Space Administration (hereinafter referred to as NASA), and also introduces MHI's future initiatives in new business fields.

2. MHI's history and future direction in development of space-related equipment

2.1 Development of experiment module and experimental equipment

MHI was responsible for overall integration support and manufacturing of key components for the Kibo experiment module of the ISS, and also handled manufacturing of the experimental equipment installed in the Kibo experiment module and supporting of experiment operations. These MHI contributions to advancing life science experiments in space have been highly evaluated.

The cell biology experiment facility (hereinafter referred to as CBEF), shown in **Figure 1**, is an experimental facility that incorporates a centrifuge within the incubator to simulate gravity from 0 to 2G, in addition to temperature control, humidity control, and CO_2 concentration control functions similar to those of standard ground-based incubators. This is the world's first facility capable of evaluating the effects of gravity alone on experimental samples using its gravity simulation function, which was previously impossible. Since the start of Kibo operations in 2008,

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this facility has been used for various experimental research projects, including not only cell culture but also plant cultivation. In 2020, the additional cell biology experiment area (hereinafter referred to as CBEF-L), which was capable of accommodating centrifuge rotating diameters more than twice as large as those in the CBEF, began operation, expanding the experimental environment.

The mouse habitat unit (hereinafter referred to as MHU), shown in **Figure 2**, is equipment for rearing mice in orbit using the CBEF or CBEF-L. Its main components are cage units that serve as mouse habitation areas (one unit for each mouse), launch/recovery support devices for loading mice during launch and return (one unit for twelve mice), and glove boxes used during maintenance work in rearing such as transferring mice or cleaning cage units. The cage units are attached to the CBEF to evaluate the effects of gravity on mice.

The first mouse rearing mission was conducted in 2016 and achieved the world's first successful outcome of all mice surviving long-term (30 days or more) rearing in the space environment. Since then, nine rearing missions have been conducted to date.

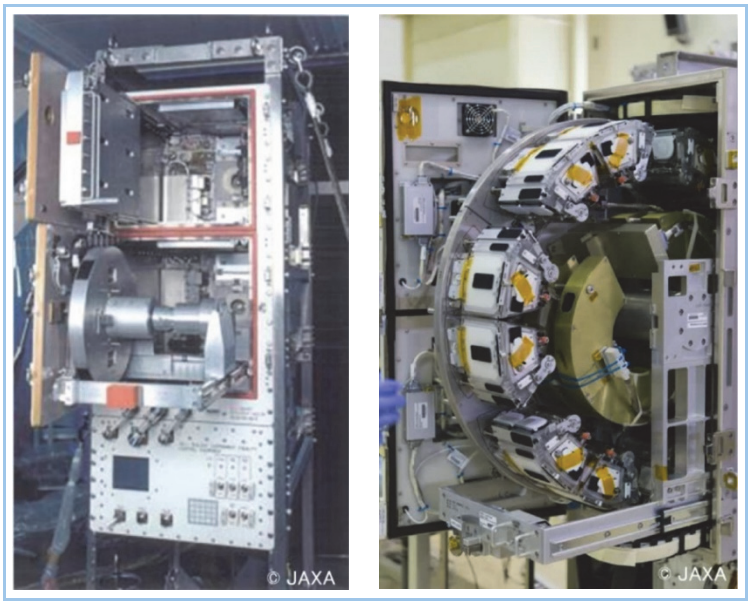

Figure 1 Cell biology experiment facility (CBEF and CBEF-L)

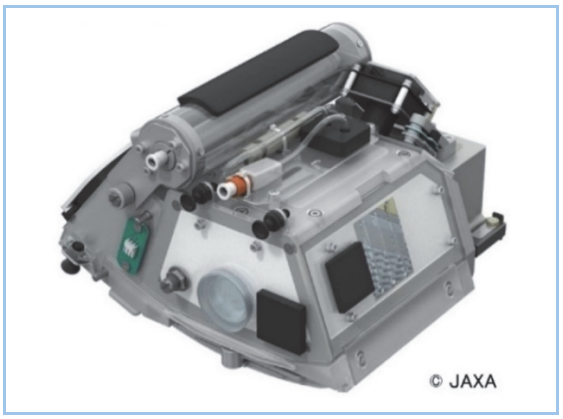

Figure 2 Mouse habitat unit (MHU) case unit

2.2 Development of cargo transfer vehicles

MHI participated in the development of the cargo transfer vehicle Kounotori (HTV), nine of which successfully delivered cargo to the ISS by 2020, and has been involved in the development of its successor, the new space station cargo transfer vehicle (hereinafter referred to as HTV-X). Under a development contract with the Japan Aerospace Exploration Agency (hereinafter referred to as JAXA), MHI is responsible for the system design, cargo loading, launch site operations, operational preparations, and development of the pressurized module (PM) for HTV-X [(1)]. The first HTV-X is currently undergoing preparatory work at the JAXA Tanegashima Space Center for launch within fiscal year 2025. Furthermore, based on these experiences, MHI is cooperating with JAXA's study of the Gateway cargo transfer vehicle, which will be responsible for cargo resupply

to the Gateway – a human lunar orbital platform.

2.3 Development of lunar exploration equipment

MHI has been participating in domestic and international projects by utilizing its knowledge and technologies in space development, advancing efforts toward the challenge of lunar exploration [(2)]. First, as part of the Artemis program led by NASA, the development of the Environmental Control and Life Support System (hereinafter referred to as ECLSS) for the international habitation module (I-HAB) of the Gateway lunar orbiting outpost is being advanced under JAXA's leadership. The ECLSS is a system that supplies air for the crew and removes CO_2 and noxious gases, maintaining the living environment in a closed space. It is an essential technology for future lunar settlement and Mars exploration.

Next, the development of an exploration rover for the Lunar Polar Exploration mission LUPEX, a collaboration between JAXA and the Indian Space Research Organization (ISRO), is underway, aiming to collect data on the quantity, quality, and other aspects of water in the lunar polar regions. The exploration rover is scheduled for launch aboard an H3 launch vehicle in the mid-2020s. Furthermore, the technologies and data gained from the ECLSS development and the exploration rover are expected to be utilized in the development of the crewed pressurized rover being advanced by Toyota Motor Corporation under the supervision of JAXA. MHI will cooperate by utilizing spacecraft integration technology and space environment resistance technology.

3. New business initiatives in low Earth orbit

3.1 HTV-XC and Japan Module

It is expected that the primary operators of services utilizing post-ISS low Earth orbit space stations will shift from government to private entities. In the United States, multiple private companies are advancing the conceptual study and development of post-ISS space stations. Against this backdrop, the Space Strategy Fund was established at JAXA in 2024. In cooperation with Japan LEO Shachu, Inc., which was selected as a development contractor for two themes: Technology for an internationally competitive and autonomous/flexible cargo resupply system, and Low-Earth-orbit autonomous flight module system technology, MHI is advancing studies on post-ISS cargo transfer vehicles (hereinafter referred to as HTV-XC) and the Japan module. **Figure 3** illustrates the HTV-XC and Japan Module.

For the HTV-XC, aiming to realize a cargo transfer service to post-ISS space stations based on the HTV-X, automated docking and proximity communication will be developed. For the Japan Module, an active thermal control system (ATCS) and life extension technologies will be developed in addition to the items mentioned for the HTV-XC, taking long-term operation into consideration.

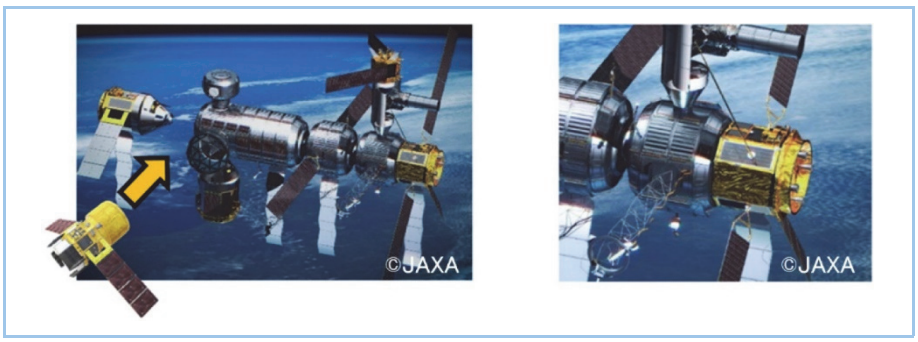

Figure 3 HTV-XC and Japan Module

3.2 Experimental equipment

MHI is advancing the development of experimental equipment with an eye toward installation on the post-ISS space stations. While the MHU introduced in Section 2.1 was designed so that it would be maintained by the crew, the single-CTB mouse automated rearing transporter (hereinafter referred to as SMART), shown in **Figure 4**, is being developed to reduce crew operation time. This labor-saving small animal rearing device eliminates the need for maintenance during the rearing period by improving the water supply tank and feeder and has additional functions to monitor water and food intake and biological data.

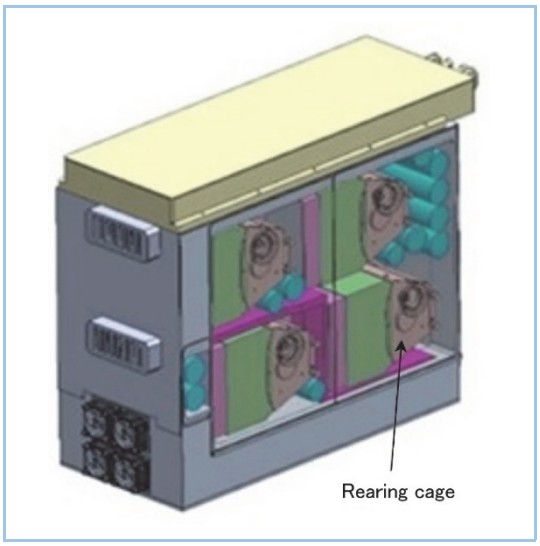

Figure 4 Single-CTB mouse automated rearing transporter (SMART)

4. New business initiatives on the Moon

4.1 Overall concept of lunar base

MHI is developing an overall concept for a lunar base. This concept aims to establish the foundation for supporting human activities on the Moon, and an architecture that considers both transportation systems and base systems is being built. The lunar base infrastructure consists of diverse elements including habitation areas, energy supply, resource utilization, and transportation services. From this wide array of elements, the transportation, base, and the integrated operations are identified as key factors, and the overall architecture is built around three pillars: space logistics, human base and activity support, and digital integrated operation. **Figure 5** shows the overall concept of the lunar base.

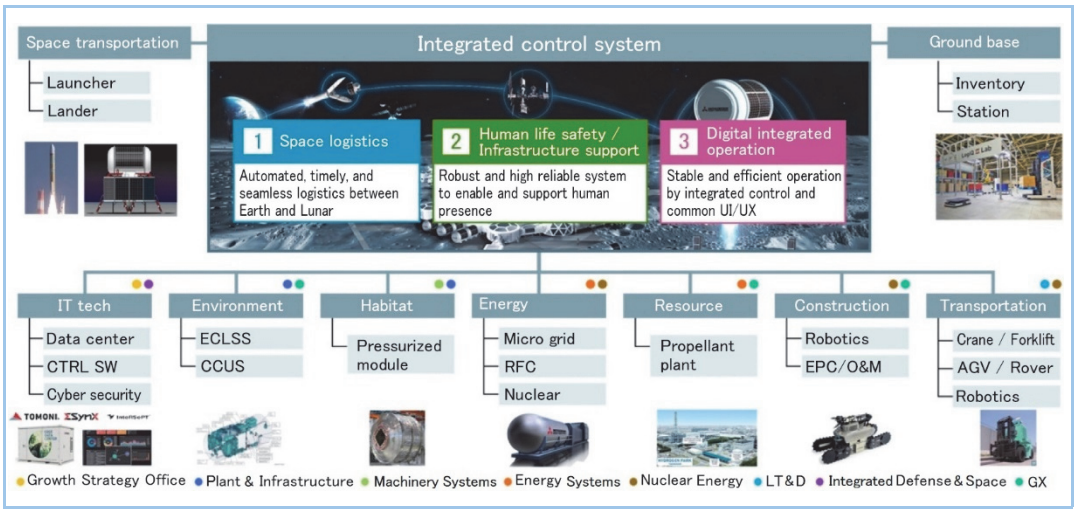

Figure 5 Overall concept of lunar base

4.2 Efforts toward realization of lunar base

The realization of a complete lunar base cannot be achieved by a single company or organization, including MHI, alone. Therefore, it is necessary to overcome barriers among industries and companies through industry-academia-government collaboration, the participation of non-space companies, and other means. MHI, having both space technology and broad infrastructure system technology, has established internal cooperation between different business domains as well as organizations that horizontally integrates across product and business areas, including the Research & Innovation Center, and is able to advance the development of the concrete overall concept by serving as the hub.

Furthermore, to advance technology verification and business hypothesis validation activities

based on open innovation by engaging both internal and external stakeholders, MHI is currently establishing a research and development demonstration area at the YHH (Yokohama Hardtech Hub) located within the Honmoku Plant, aiming to depict everything from the significance and purpose of lunar development to its vision, systems, and components working together as a single system, under the Lunar Park Yokohama concept. **Figure 6** shows the Lunar Park Yokohama concept. It brings together the results of internal and external research and development, contributing to enhancing the maturity of the lunar base concept and systems.

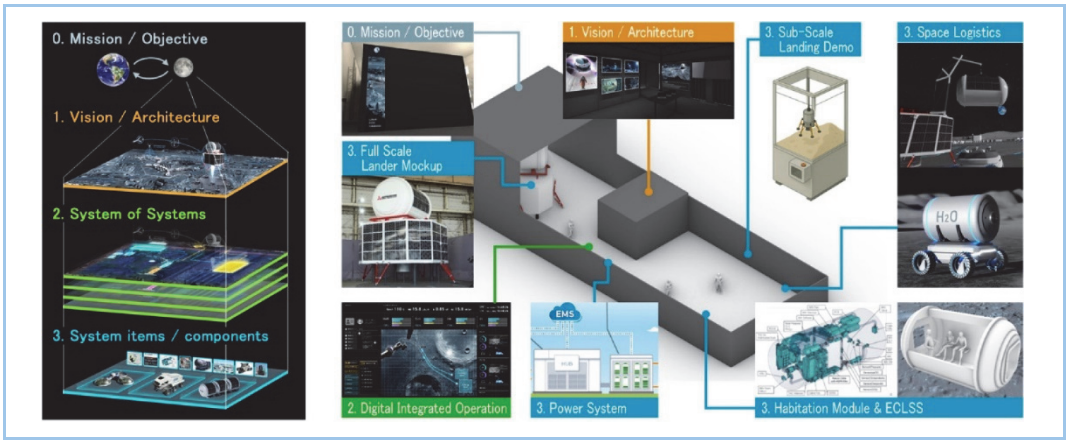

Figure 6 Lunar Park Yokohama concept

5. Conclusion

This report presents MHI's efforts in the space business related to the ISS and international space exploration, along with its product development history. MHI has steadily built a track record while acquiring and accumulating technologies. It will continue to contribute to the development of the space industry by pursuing new businesses, aiming to serve as a hub that promotes collaboration both internally and externally for post-ISS space station projects and lunar exploration activities under the Artemis program through maximizing the utilization of its developed products and technologies.

References

(1) Daisuke T et al., Development Status and Future Plans of Next Generation Cargo Transfer Spacecraft HTV-X, Mitsubishi Heavy Industries Technical Review Vol. 58 No. 4 (2021)

(2) A New Era: Challenges in Lunar Exploration and Manned Lunar Orbital Base Development -- Expanding mankind to live in space by making use of our unparalleled heritage of space technologies --, Mitsubishi Heavy Industries Press Information. (2023)