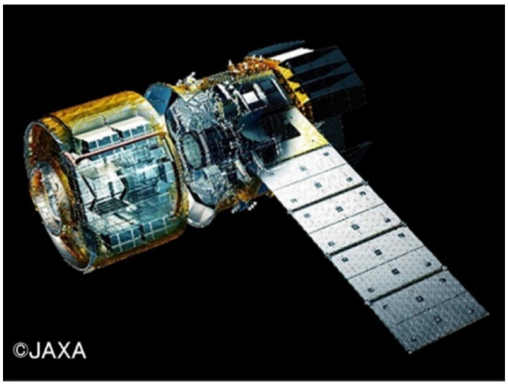
Development Status and Future Plans of Next Generation Cargo Transfer Spacecraft HTV-X



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The development of next generation cargo transfer spacecraft HTV-X is steadily progressing toward the launch of the first unit. Currently, the detailed design has been completed and the spacecraft manufacturing has begun. One of the key points in designing HTV-X is to address diversifying cargo requirements. Mitsubishi Heavy Industries, Ltd. (MHI) has carried out design invents by detailed design that meets the constraints of the spacecraft structure form, then conducted step-by-step prototype tests, and confirmed that these requirements can be satisfied. HTV-X will be used to deliver supplies to the International Space Station (ISS) and a plan to use an advanced version of this spacecraft to contribute to resupply of the lunar orbit crewed base (Gateway), which is being promoted mainly by the United States, is also under consideration. This report presents the development status of HTV-X, the results of the detailed design and efforts for a future plan related to an advanced version of this spacecraft.

1. Introduction

Since the operation of the International Space Station (ISS) has been extended up to 2024, next generation cargo transfer HTV-X to ISS, is being developed as a successor of HTV. The first HTV-X is planned to be launched with the H3 launch vehicle in JFY 2022[(1)].

Like HTV, HTV-X has a highly-reliable spacecraft and is intended to deliver supplies on a regular basis in order to share common system operation costs for ISS operation. However, the surrounding situation has changed compared to the time when HTV was developed, and the cargo requirements have been diversified. For example, three private resupply spacecraft (Cygnus, Dragon and Dream Chaser) selected for the CRS2 (commercial resupply service 2) program launched in 2019 by NASA in the United States are capable of meeting demand for delivering cargo payloads with various transport constraints such as small animals. In response to this, a benchmark analysis of the capacity of private resupply spacecraft was conducted and the development specifications of HTV-X were determined so that it can provide equal or better service with the greatest exposed and pressurized cargo carrying capacity that exclusively enables the transport and disposal of large inboard racks and other capabilities (**Table 1**).

Currently, the detailed design of HTV-X has been completed and it has been confirmed that the system requirements including the capacity of cargo transport, which is the most important role of a resupply spacecraft, can be satisfied and the spacecraft manufacturing has begun. In this report, Chapter 2 explains the outline and development status of the HTV-X, Chapter 3 describes the results of the detailed design with respect to the cargo requirements and Chapter 4 reports the future prospects for the use of HTV-X in international space exploration.

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Table 1 Comparison of capabilities and services of transfer vehicle to ISS

Item	Japanese transfer vehicle	Private transfer vehicle selected by U.S. commercial resupply service (CRS2)			(Reference) Requirements from CRS2
	HTV-X	Cygnus (produced by Northrop Grumman)	Dragon (produced by Space X)	Dream Chaser (produced by SNC)	
Appearance					-
Loading/disposal capacity (total of pressurized and exposed)	◎5,820kg [No.1]	3,754kg	3,307kg	5,500kg	-
Pressurized cargo Loading capacity/type	○4,070kg ◎Advantage: Transport/disposal of large rack [1] [only1]	3,754kg	2,507kg	5,000kg	2,500kg to 5,000kg
Exposed cargo loading capacity/type	◎1,750 kg, 4 cargo payloads ◎Advantage: Large cargo capacity [No.1]	Disposal only	800kg	1,500kg	500kg to 1,500kg (1 to 3 cargo payloads)
Pressurized cargo recovery capacity	△Available: Dealt with by the same small collection capsule that is mounted on HTV7	Not available	Available	Available	1,500kg
Cargo service	-	-	-	-	-
Late-access cargo[3] reception timing and loading capacity	24 hours before launch ○Power receiving cargo equivalent to 2CTB[2] + Cargo 3CTB Loaded in the main hatch area	24 hours before launch Total amount: Unknown (including power receiving cargo 4CTB) Loaded in the main hatch area	24 hours before launch Standard cargo around 5CTB Loaded in the side hatch area	Reception timing: Unknown Loading capacity: Unknown Loaded in the side hatch area	24 hours before launch, 6CTB to 10CTB
Resource provision to power receiving cargo[4]	○28 V power supply, 75 W/ch, 2 ch Ethernet communication	75 W/ch, 4 ch RS-422/RS-485 communication	28 V power supply, 75 W/ch, 6 ch 1553B/Ethernet/ RS422 communication	Power supply and communication: Available (details unknown)	-

(Legend) ◎ : No.1, Only 1 level, ○ : Equivalent to others, △ : Inferior to others
Supplement 1: Large rack: International standard type rack for cargo mounting (2 m × 1.05 m × 0.86 m). Can be transported/disposed of without assembling/disassembling in ISS only by HTV-X.
Supplement 2: CTB: Cargo transfer bag
Supplement 3: Late-access cargo: Cargo to be loaded immediately before launch
Supplement 4: Power receiving cargo: Pressurized cargo that requires power supply

Source: JAXA

2. Development status of HTV-X

(1) Outline of spacecraft

Figure 1 shows the changes from HTV to HTV-X. In contrast to HTV, which consists of four modules, HTV-X consists of two modules: a pressurized module (PM) that accommodates inboard supplies (pressurized cargo) and a service module (SM) that integrates the exposed cargo loading function and the flight function. Unlike HTV, HTV-X locates the PM on the lower part (launch vehicle side) and the SM on the upper part, which makes the SM structure lighter and improves the transport capacity[2].

Moreover, HTV-X has the ability to execute services to provide on-orbit demonstration opportunities in addition to the ability to transport cargo payloads. Experimental equipment is basically loaded on the upper part of the SM together with exposed cargo payloads, but it can be flexibly loaded in other areas according to the mission requirements. HTV-X can, after the delivery of supplies to ISS, provide experimental opportunities for up to 1.5 years from the time of leaving ISS to the time of re-entry (**Figure 2**).

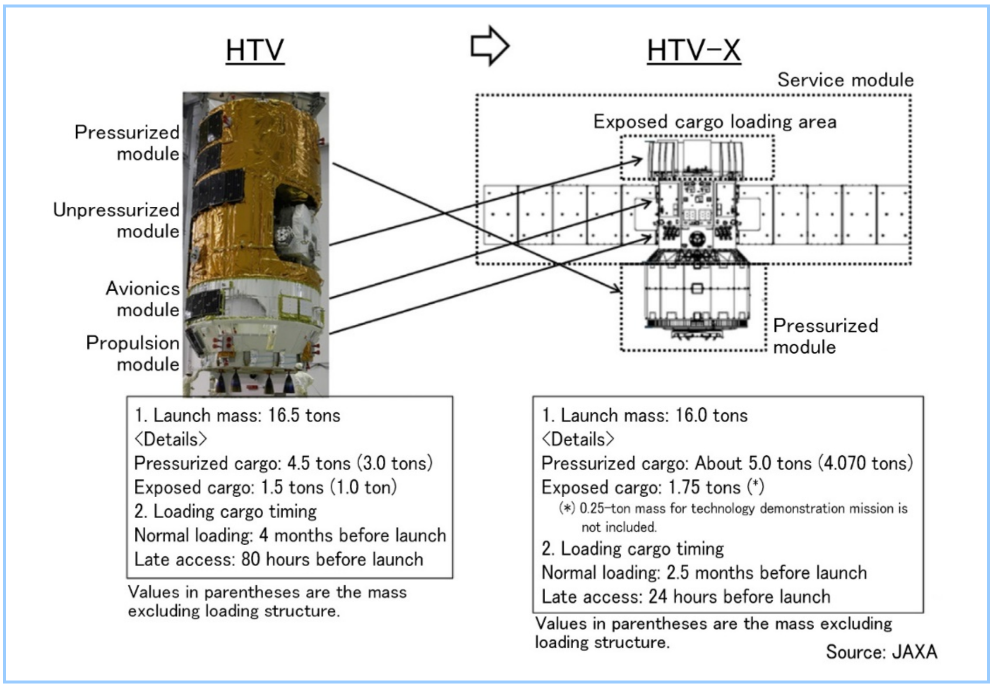


Figure 1 Outline of HTV-X spacecraft

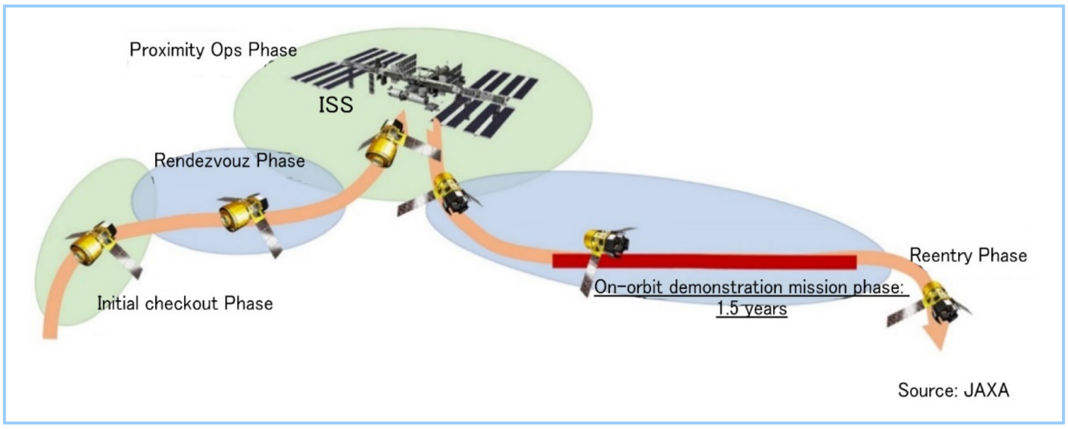


Figure 2 Outline of HTV-X operation

(2) Outline of development status

Figure 3 illustrates the development organization. Under the Japan Aircraft Exploration Agency (JAXA) development contract, MHI are in charge of the development of the system (system design, loading of cargo/experimental equipment, launch site work and operational preparation) and the pressurized module (PM) of HTV-X. Mitsubishi Electric Corporation is in charge of the development of the service module (SM).

The detailed design that can satisfy the mission requirements and system specifications has been completed and the maintenance design phase has commenced. PM and SM have started manufacturing. At the same time, as the entity in charge of the system, we are proceeding with system tests to conduct verification in an assembled form where the PM and SM have been combined, the planning of launch site operation and the refinement of each operational document.

In response to the fact that in 2020 JAXA has selected the experimental equipment to be installed on the first HTV-X, we started the design of the installation of the equipment on HTV-X. Since experimental requirements such as flight altitude and attitude differ depending on the experimental equipment, it is planned that the experiments will be conducted in a certain order after leaving ISS (refer to **Figure 4**). Currently, we have completed the design review for the installation of the experimental equipment and have started manufacturing and are preparing for testing the interface between the experimental equipment and HTV-X.

In order to maintain the development plan despite the deterioration of parts availability and restrictions on face-to-face meetings due to the COVID-19 disaster, we have arranged and changed the processes and are using IT technology to conduct remote meetings.

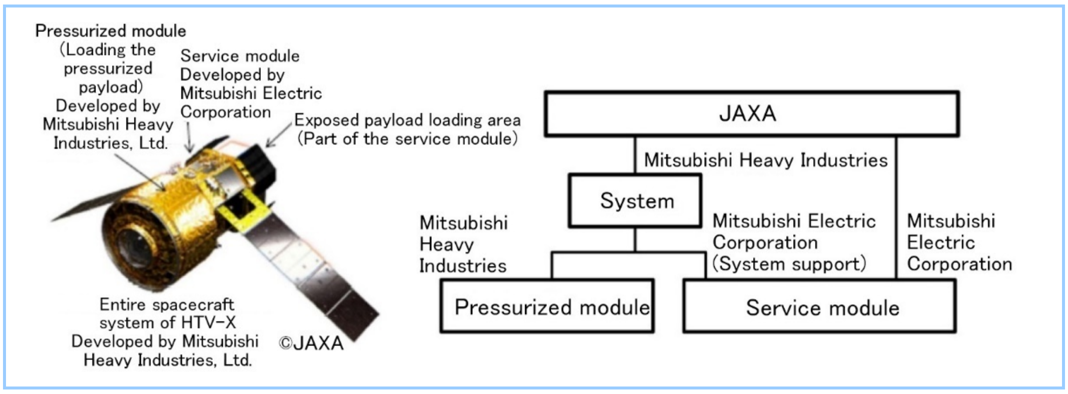


Figure 3 HTV-X development organization

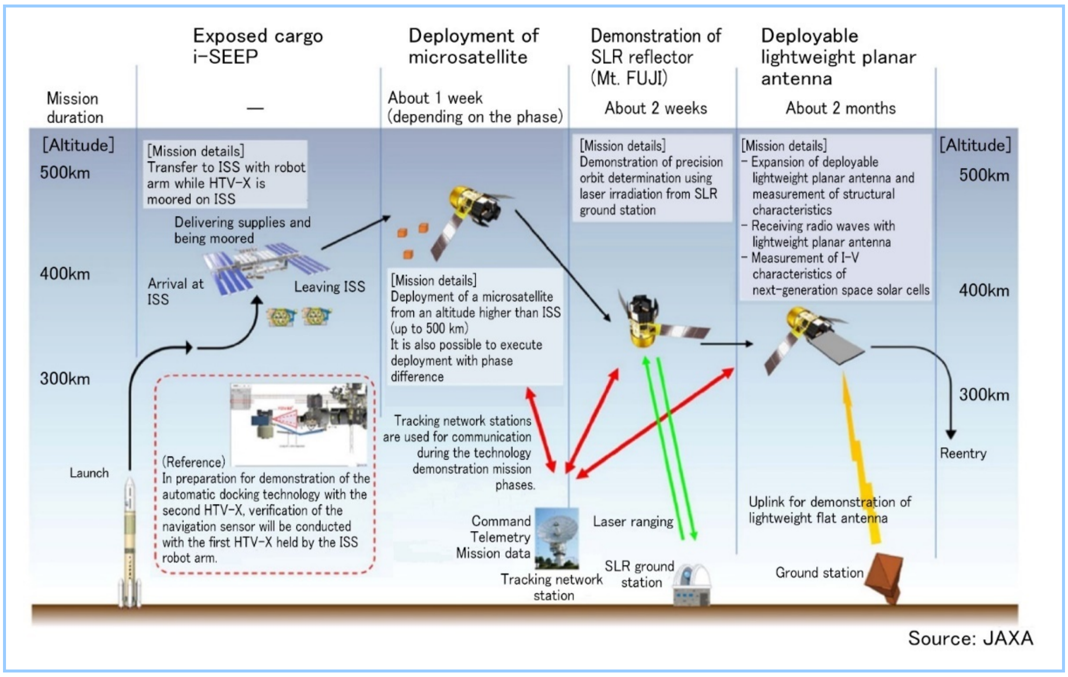


Figure 4 On-orbit demonstrative experiment plan for the first HTV-X

3. Results of detailed design for satisfying cargo requirements

3.1 Cargo loading

(1) Cargo loading plan

The PM has a pressurized space with a volume of 39 m^3 and can accommodate up to 313 standard bag-sized cargo payloads and up to 2 cargo payloads that require power supply (hereinafter referred to as power receiving cargo) such as small animal transport devices. Due to the large quantity, the work of loading all cargo payloads takes several weeks. Therefore, the cargo loading timing during launch site work is divided into three parts in order to deal with cargo payloads with time constraints including power receiving cargo payloads.

In the first cargo loading, the majority of cargo payloads will be loaded onto the lone PM module as normal access. In the second and third cargo loading, cargo payloads with time constraints will be loaded after all modules of HTV-X are assembled and mounted on the launch vehicle. This is called late access and such cargo payloads are scheduled to be received and loaded three days before and twenty-four hours before launch (**Figure 5**).

In the case of HTV-X, unlike HTV, the PM that accommodates pressurized cargo payloads is located at the lower part. Therefore, openings are provided on the launch vehicle fairing and the payload attach fitting (PAF) in order to allow access from the bottom side of the PM for late access (Figure 5).

At the time of late access twenty-four hours before launch, in addition to cargo loading, form finalizing for flight including leak inspection after closing the hatch, final inspection of external equipment, etc., will also be carried out. In order to complete the work before the launch vehicle starts moving to the launch pad, we are trying to shorten the work time through approaches including changing the leak inspection method and reducing the amount of external equipment. Furthermore, in order to reduce the risk of launch delays due to problems such as procedural mistakes during late access, it is planned that a late access demonstration will be conducted using the PM and ground support equipment.

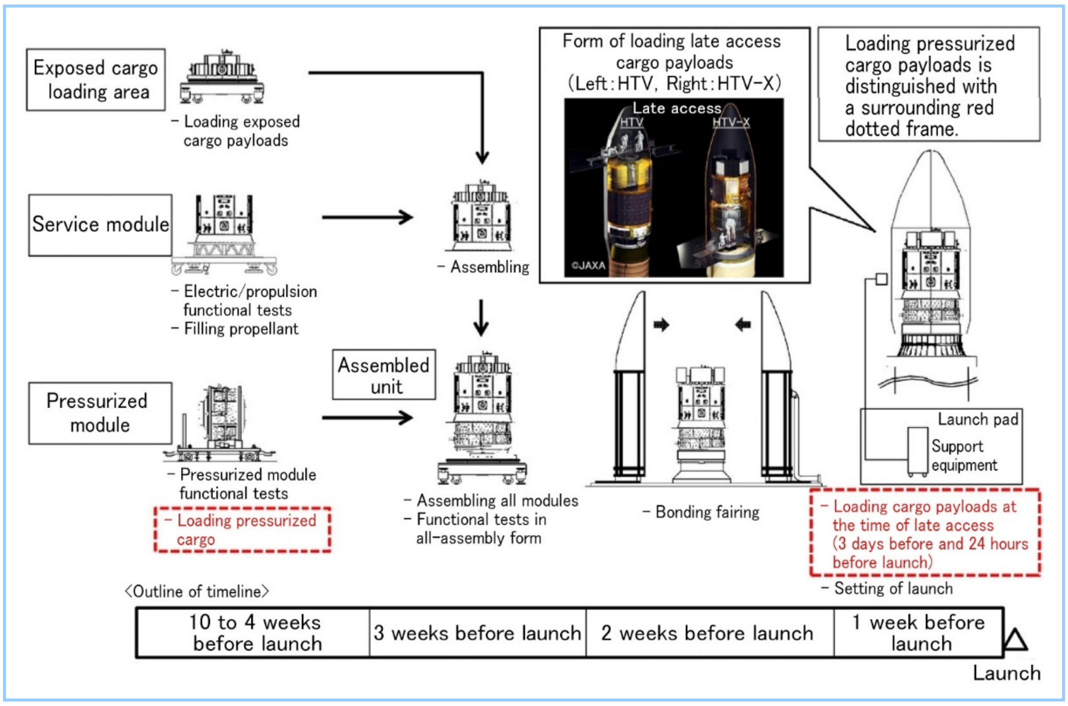


Figure 5 Outline of HTV-X launch site work and loading work of late-access cargo

(2) Design of loading layout

Late-access cargo payloads such as power receiving cargo payloads will undergo check-out and packing work performed by the cargo user until immediately before launch. In order to meet the time constraints associated with this, late-access cargo payloads will be placed closest to the hatch so that they can be loaded last among all cargo payloads (**Figure 6**). In order to prevent the opening/closing of the hatch from being hindered, a new loading structure was provided in the passage space in the center of the PM in the layout design. This structure was designed to be detachable so that the passage space can be secured after the cargo payloads are unloaded in orbit. In addition, a simple-to-operate lock pin system was adopted as the fixing method of this structure instead of fixing with bolts and nuts in order to allow astronauts to perform on-orbit attaching/detaching operation easily and to shorten the work time at the time of late access. This design allows astronauts to access late-access cargo payloads first after arriving at ISS, minimizing the process from receiving on the ground to unloading in orbit.

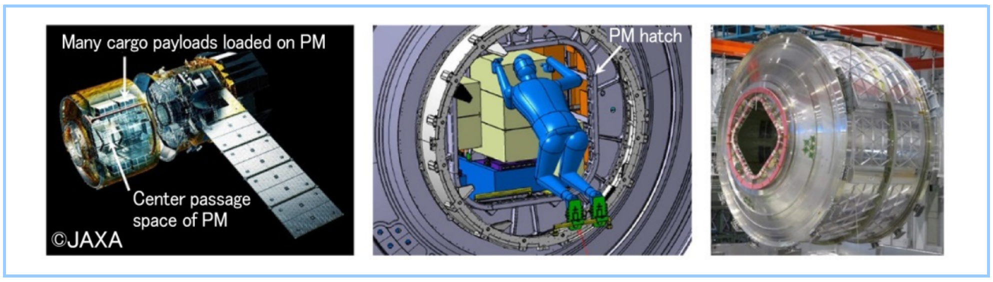


Figure 6 Loading form of pressurized cargo payloads (Left: Perspective view of PM, Center: PM hatch access work, Right: PM main structure of first HTV-X)

(3) Development of ground support equipment (GSE)

Late access includes entering through the opening of the fairing/PAF and operating in the narrow space between the launch vehicle and the PM. In order to enable this work, the ground support equipment (GSE) as shown below is being developed.

- A scaffold that can be easily placed/removed in a short amount of time and can accommodate multiple workers. since standing directly on the launch vehicle is not allowed.
- A cargo loading device for loading cargo payloads weighing up to 90 kg through a small opening in the fairing.
- A lifter for lifting cargo payloads weighing up to 90 kg through the PM hatch (1 m x 1 m) in the narrow space on the work scaffold.

In particular, we have no on-HTV experience of loading cargo by lifting, so we made a prototype lifter and a full-scale mockup (model) of the PM of HTV-X and conducted a prototype test with the participation of actual workers (**Figure 7**). As a result, items that would be reflected in the design of GSE could be obtained, such as providing a fixing method to prevent the lifter from tipping over when pushing cargo on the lifter into the loading structure.

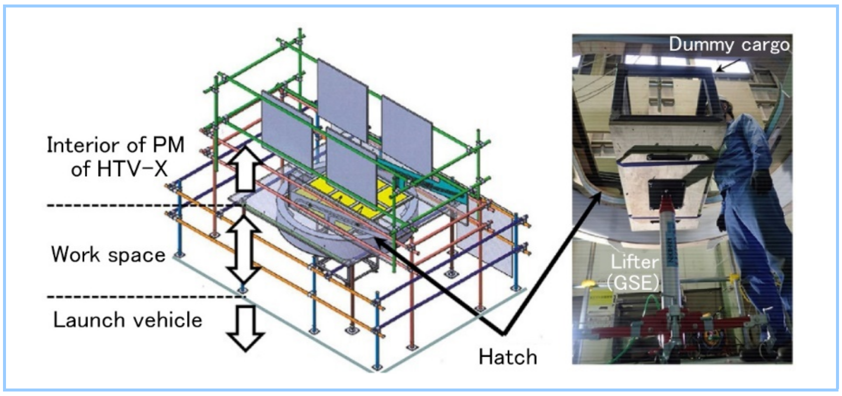


Figure 7 Cargo lifter prototype test (Left: Appearance of full-scale PM mockup, Right: Photo of lifting work)

3.2 Power supply to cargo

Electric power for power receiving cargo payloads is supplied from the cabin control unit (CCU) of the PM. NASA demands strict power quality for the power supply function in order to allow the function to be used for a wide variety of cargo payloads.

Ready-made DC/DC converters (commercially available components for space use) do not meet the power quality characteristics (impedance, power noise, inrush current, etc.) requirements for use inside the CCU, so we newly developed a DC/DC converter dedicated to HTV-X. In order to prevent rework, the development was carried out in the following three stages.

(1) BBM (breadboard model): It was confirmed by using BBM that the impedance requirement, which was particularly strict, had been satisfied by reviewing the feedback circuit system of the secondary output of the DC/DC converter, tuning the circuit constants, etc.

(2) EM (engineering model): An EM was manufactured based on the BBM and tested in combination with a simulator that simulated cargo power supply characteristics. Based on the data acquired in this test, the interface was adjusted with NASA and it was confirmed that the design was valid.

(3) PFM (proto flight model): If by any chance an interface inconsistency occurs at the time of late access, which is conducted immediately before launch, postponement of the launch is inevitable. Therefore, a joint interface test using a power receiving cargo and a CCU, both of which are flight models, is planned to be conducted.

3.3 Cargo thermal control

Power receiving cargo payloads generate heat of up to 150 W. Like HTV, HTV-X is based on a passive thermal design that does not have a heat exhaust device in order to maximize the cargo capacity. Under such a design constraint, in order to prevent deviation from the permissible temperature due to the heat generated by the power receiving cargo itself, the design feasibility was ensured by taking the following two measures.

(1) Lowering the initial temperature

Normally, since satellites do not have openings on the PAF, air circulation inside the PAF and the entire fairing is limited, so the fairing air conditioning effect is limited. Focusing on the fact that power receiving cargo payloads are loaded near the boundary between the PM and PAF, the in-PAF circulation of air cooled by fairing air conditioning was simulated with an analysis model that incorporated the PAF opening, which has a shape unique to HTV-X. By increasing the degree of analysis simulation and pursuing the cooling effect, the temperature of the power receiving cargo could be lowered and the design feasibility could be ensured (**Figure 8**).

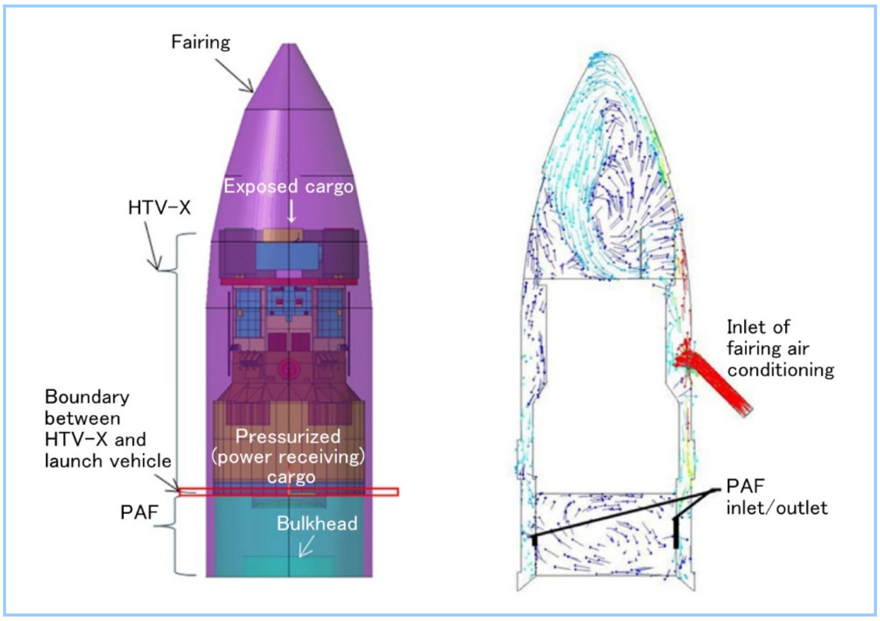


Figure 8 Analysis of fairing air conditioning (Left: Overview of analysis model, Right: Air conditioning analysis result)

(2) Suppression of temperature increase during flight

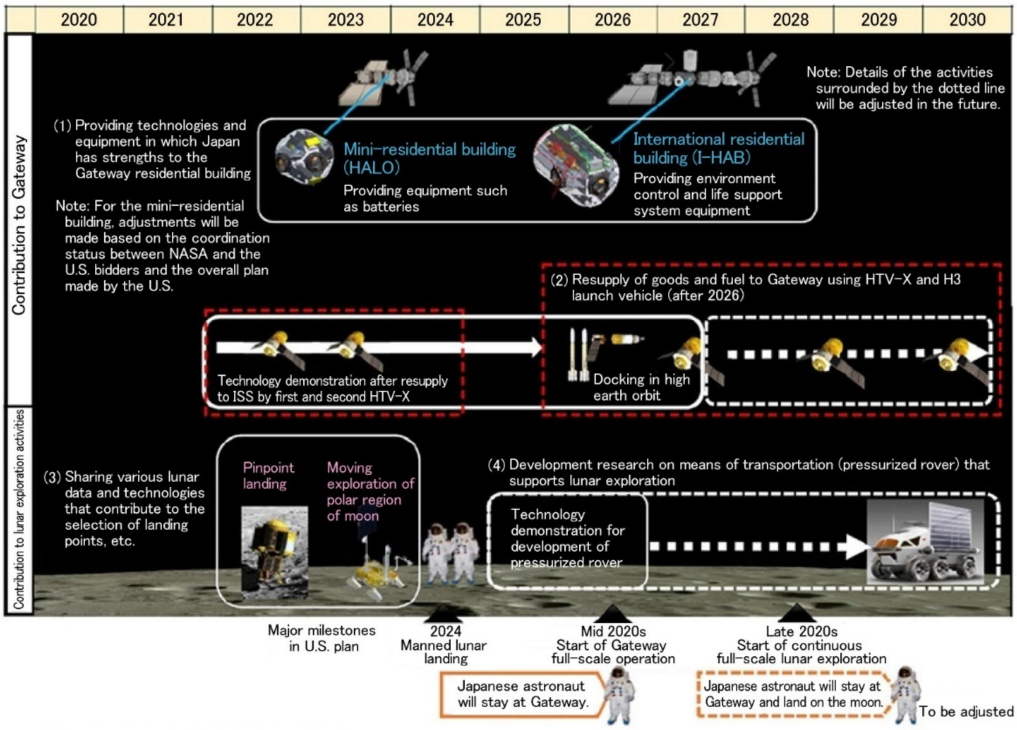
HTV had a body-mounted solar cell panel and was always oriented toward the earth with a constant attitude. However, HTV-X uses an expandable panel in order to improve the power generation efficiency and takes two postures during flight: an attitude oriented toward the sun for power generation and an attitude oriented toward the earth for communication. When HTV-X takes an attitude oriented toward the sun, the PM may be exposed to sunlight, which causes the power receiving cargo temperature to increase. The simple conditions in the case of an attitude always oriented toward the earth similar to HTV lead to overly harsh evaluation, so the excessive margin was deleted by setting the thermal analysis conditions to be closer to the actual environment, reflecting the actual flight attitude sequence conditions. Furthermore, unlike HTV, the multi-layer insulation around the outside of the PM hatch near power receiving cargo payloads has been removed to improve heat dissipation. As a result, the temperature increase of power receiving cargo payloads could be suppressed and the temperature profile could be maintained within the allowable temperature range.

4. Future prospects for the use of HTV-X in deep space exploration

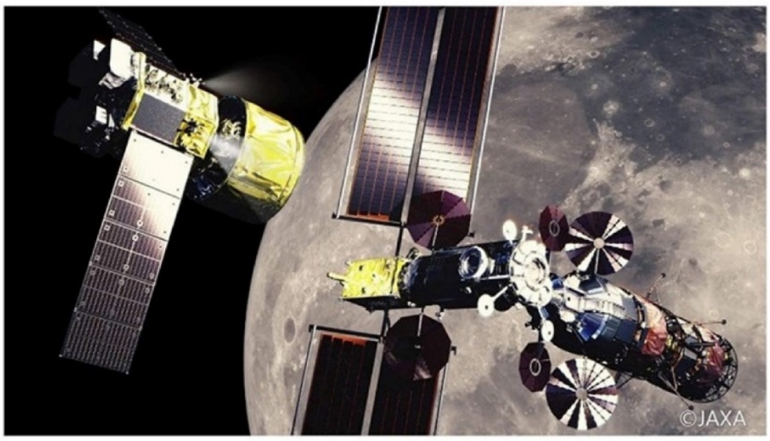
In order to expand the area of human activity, the United States is promoting the Artemis program, which aims to realize sustainable activities on the moon, in cooperation with participating countries. A plan to use an advanced version of HTV-X for the Japanese contribution to resupply to the lunar orbit crewed base (Gateway), which is a base element of the architecture of that program, is being discussed by the Space Development and Utilization Subcommittee of the Ministry of Education, Culture, Sports, Science and Technology (**Figure 9**).

At least in the early stages of construction of Gateway, the duration of an astronaut's stay is limited to up to 30 days and autonomous operation of resupply spacecraft is required compared to

ISS, in which astronauts are always present. For this reason, it is necessary to adopt an autonomous automatic docking method instead of a docking method using a robot arm that requires operation by an astronaut like that of HTV-X. Therefore, it is planned that the second HTV-X will be equipped with an automatic docking demonstration device and technology acquisition will be made through a demonstrative experiment of automatic docking with ISS.



Excerpt from "International Space Exploration Initiatives" (Ministry of Education, Culture, Sports, Science and Technology) for 37th Space Development and Utilization Subcommittee ISS and International Space Exploration Subcommittee (September 11, 2020).
Descriptions about HTV-X are surrounded by the red dashed line.



Source: JAXA

Concept of resupply to Gateway using advanced version of HTV-X

Figure 9 International space exploration initiatives discussed by the Space Development and Utilization Subcommittee (upper side) and concept of resupply to Gateway using advanced version of HTV-X (lower side)

For cargo resupply to Gateway, a pressurized cargo quantity equivalent to HTV-X and a pressurized cargo power supply 10 times or more that of HTV-X are required. In order to realize the former, we are working on weight reduction by applying a composite material to the pressurized structure to maximize cargo transport volume. In order to realize the latter, we are considering adding a heat exhaust function by providing a radiator, etc., in the pressurized area.

While the Artemis program is progressing, the possibility of extending the operation of ISS is increasing. The NASA Authorization Act approved by the U.S. Senate on June 8, 2021 calls for the extension of ISS operation from 2024 to 2030. Since resupply is essential for ISS operation, it is quite possible that Japan will continue to use HTV-X for resupply. Based on these surrounding conditions, we are considering to partially incorporate the aforementioned composite material structure and heat exhaust function, and pre-demonstrating them by utilizing a chance of an additional HTV-X.

5. Conclusion

This report introduced the fact that we have completed the detailed design of HTV-X so that the cargo requirements that have been diversifying due to changes in the surrounding conditions are met and that HTV-X has a more advanced spacecraft than the HTV. In the future, in order to achieve the mission of the first HTV-X, MHI will proceed with manufacture of the PM and as the entity in charge of the system, steadily implement the system tests to conduct verification in an assembled form, the launch site operation including cargo loading and the preparation of operational documentation. In addition, aiming at contributing to resupply in the Artemis program and utilizing the opportunities to verify technologies with HTV-X, we will proceed with the examination of necessary new technologies and continue to the further development and improvement of transport technology from low earth orbit to the vicinity of the moon.

References

(1) The Material 60-5, Space Development and Utilization Subcommittee, Subcommittee on Research Planning and Evaluation of the Council for Science and Technology, (#60 February 9. 2021)

(2) Daisuke Tsujita, et al., Development of HTV-X, Mitsubishi Heavy Industries Technical Review, Vol. 56, No. 1 (2019)