For Assured Production of "KOUNOTORI" Series H-II Transfer Vehicle

YOICHIRO MIKI[*1] KOICHI MATSUYAMA[*2]
KAZUMI MASUDA[*3] HIROSHI SASAKI[*4]

The H-II Transfer Vehicle (HTV) is an unmanned but man-rated designed resupply spacecraft developed by Japan as a means of transporting supplies to the International Space Station (ISS). Since the launch of vehicle No. 1 on September 11, 2009, the HTVs have accomplished their missions three times in a row up to vehicle No. 3 in July 2012. Mitsubishi Heavy Industries, Ltd. (MHI) is managing the production of the HTVs from vehicle No. 2 as the prime contractor, and we are planning to launch another four vehicles up to No. 7. Need for the HTVs is increasing after the retirement of the U.S. Space Shuttle. This paper introduces the efforts taken for the assured production in order to maintain the continued success of the HTVs.

1. Introduction

The H-II Transfer Vehicles (HTVs) have consecutively accomplished the three missions of the No. 1 demonstration flight vehicle in September 2009, the No. 2 first operational flight vehicle in January 2011 and No. 3 in July 2012. As a result of the Request for Proposal (RFP) competition, Japan Aerospace Exploration Agency (JAXA), selected Mitsubishi Heavy Industries, Ltd. (MHI) as the prime contractor for production of the operational flight HTVs as of No. 2. Accordingly, HTV No. 2 and No. 3 were manufactured under MHI's management, leading to success. A wide variety of cargos have been transported by the three HTVs, showing the high versatility of the vehicle. After the retirement of the U.S. Space Shuttle, the HTV has grown in importance as satisfying the need for urgent cargo transport from the National Aeronautics and Space Administration (NASA). Since HTV No. 2, the HTVs have been nicknamed as "Kounotori (White Stork)", and plans call for launches up to HTV No. 7.

2. HTV overview

Figure 1 shows an overview of "Kounotori," and **Figure 2** shows the berthing of the "Kounotory" to the ISS. "Kounotori" mainly consists of four modules: a Pressurized Logistics Carrier (PLC) for transporting pressurized cargo, an Unpressurized Logistics Carrier (ULC) for transporting unpressurized cargo, an Avionics Module with an aviation electronics function, and a Propulsion Module equipped with thrusters to boost itself toward the ISS. The PLC is filled with dry air at one atmospheric pressure to allow ISS crew to enter through the hatch after docking. The ULC has an unprecedented large opening compared with the other existing vehicles, and carries unpressurized cargo such as external experimental equipment that is to be attached to the ISS exposed facilities. After docking with the ISS, the Exposed Pallet with unpressurized cargo is pulled out by a manipulator to install the cargo in the exposed facilities, and then the empty Exposed Pallet is inserted back into "Kounotori." The combined configuration of the Avionics Module and Propulsion Module is called the HTV Bus. It corresponds to the bus module of a satellite, where the basic subsystems of "Kounotori" such as the battery subsystem, navigation and guidance control subsystem, propulsion subsystem, thermal control subsystem and data handling subsystem are residing.

*1 Chief Staff Manager, Space & Integrated Defense Systems Engineering Department, Guidance & Propulsion Division, Aerospace Systems
*2 HTV Project Manager, Space & Integrated Defense Systems Engineering Department, Guidance & Propulsion Division, Aerospace Systems
*3 Deputy Director, Space & Integrated Defense Systems Engineering Department, Guidance & Propulsion Division, Aerospace Systems
*4 Deputy Project Manager,HTV Project Team, Japan Aerospace Exploration Agency

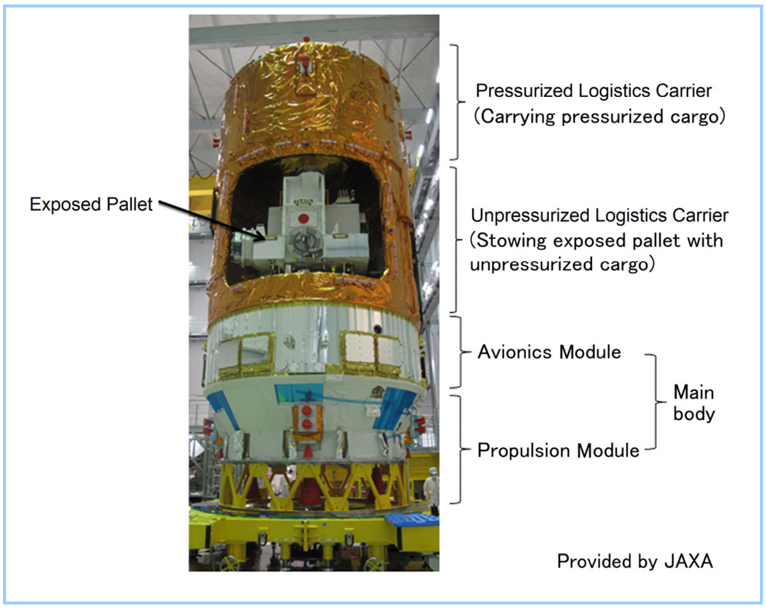


Figure 1 Overview of Kounotori No. 3

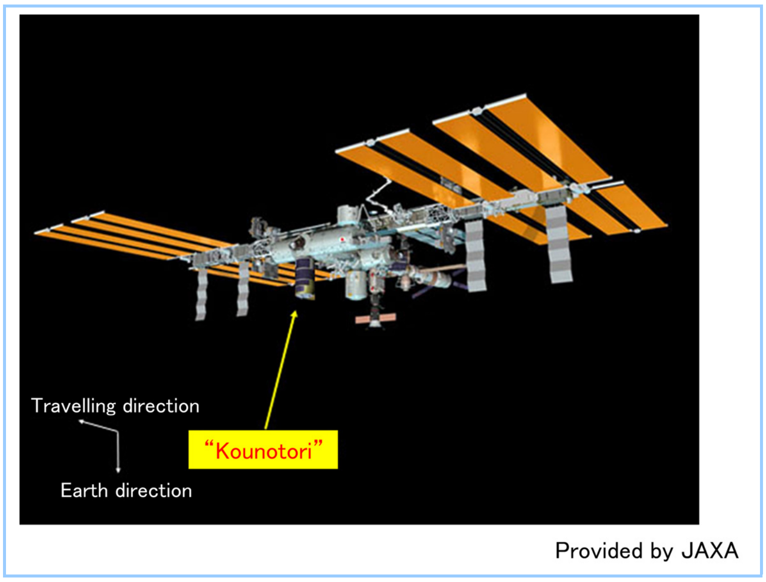


Figure 2 ISS docking position for "Kounotori"

3. Characteristics of "Kounotori" No. 3 and transported cargo

The following primary equipment had been imported from abroad, but were replaced by domestic products for No. 3:

- Main engine and RCS thruster
- Communication equipment (transponder and diplexer)

In addition, the Exposed Pallet for the ULC was replaced with a Multi-Purpose Exposed Pallet, and since the No. 1 and No. 2 operations proved that the Exposed Pallet could be inserted into HTV by robot manipulation by the ISS crew, the retracting mechanism was removed from the Exposed Pallet. Accordingly, in operation, the cargo capacity for loading late just before the launch (called "late access cargo") was expanded.

Next, **Table 1** shows the differences of No. 3 from No. 1 and No. 2.

Although No. 3 has the lowest mass for the pressurized cargo among all three, the actual amount of supplies cannot be judged by mass alone because some equipment has a smaller mass with a larger size. In terms of volumetric capacity, the pressurized cargo of the No. 3 vehicle is no less than the others. The following are the main pressurized cargo items transported by HTV No. 3:

- Food
- Experimental equipment for aquatic organisms (**Figure 3**: A water cistern for Killifish developed by MHI; the Killifish were transported by Soyuz)

- Release mechanism for small satellites (**Figure 4**)
- Three small satellites publicly sought by JAXA
- Re-entry data recorder (i-Ball)
- Two small satellites offered by NASA
- Re-entry breakup recorder (REBR)

Table 1 Comparison between Kounotori No. 3 and No. 1 and No. 2

	No. 1 (Technical demonstration vehicle)	No. 2	No. 3
Volume of supply to ISS			
Pressurized cargo	3.6 tons	Approx. 4 tons	Approx. 3.5 tons
Unpressurized cargo	0.9 tons	Approx. 1.3 tons	Approx. 1.1 tons
Total	4.5 tons	Approx. 5.3 tons	Approx. 4.6 tons
Total mass	Approx. 16 tons	Approx. 16 tons	Approx. 15.4 tons
Target orbit			
Altitude (circular orbit)	347 km	352 km	Approx. 400 km
Orbit inclination	51.6 degrees	51.6 degrees	51.6 degrees
Term of Mission	Approx. 53 days	Approx. 67 days	Approx. 49 days
Term of Rendezvous flight	7 days	5 days	6 days
Term of stay at ISS	43 days	60 days	41 days
Term of departure and re-entry	3 days	2 days	2 days

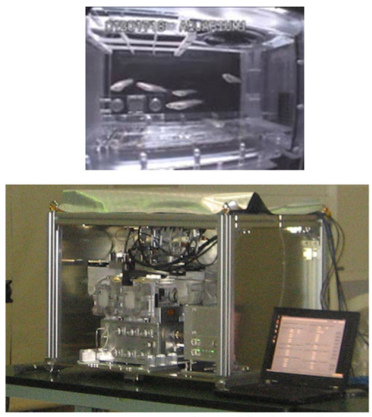


Figure 3 Experimental equipment for aquatic organisms

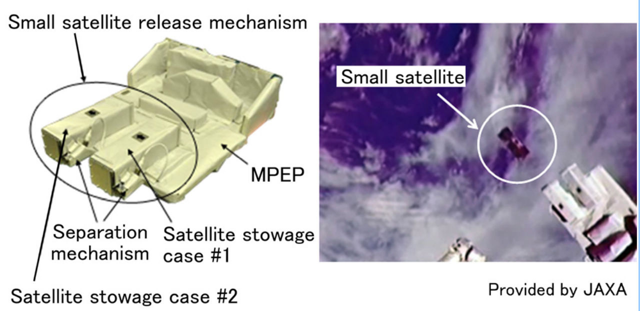


Figure 4 Small satellite release mechanism and image of release

Other than the above, vehicle No. 3 also transported spare units for the ISS that were urgently required due to malfunctions, a catalytic reactor (part of the water reclamation system) requested by NASA and substitute coolant water cycling pump for the Japanese Experiment Module (JEM).

Uniquely, "jumping spiders," became the first living organisms delivered by Kounotori. They will be experimentally observed as to how they catch flies under a zero-gravity environment.

Kounotori also transported NASA's SCAN Testbed (intersatellite communication test system) and JAXA's Multi-mission Consolidated Equipment (MCE: port-sharing experiment module) as unpressurized cargo. An Extravehicular Activity (EVA) support robot called REXJ, the Robot Experiment on JEM, was also mounted in the MCE as shown in **Figure 5**.

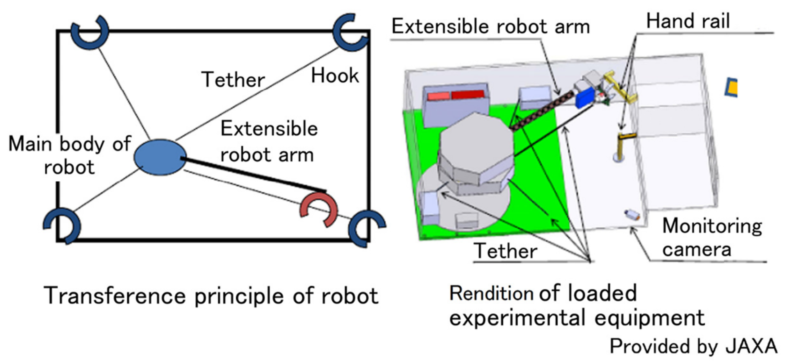


Figure 5 EVA support robot (REXJ)

4. Efforts for continued mission successes

4.1 Manufacturing framework for operational flight vehicles

The development and integration of the demonstration flight vehicle No. 1 was managed by JAXA. As for vehicle No. 2, although the manufacturing responsibilities of each manufacturer have not changed since No. 1, MHI integrally managed the manufacturing as shown in Figure 6, with the completed vehicle delivery responsibility for JAXA. However, the Exposed Pallet remains the JAXA-furnished property just like unpressurized cargo because it can have different configuration for each mission and is delivered to MHI with unpressurized cargo loaded.

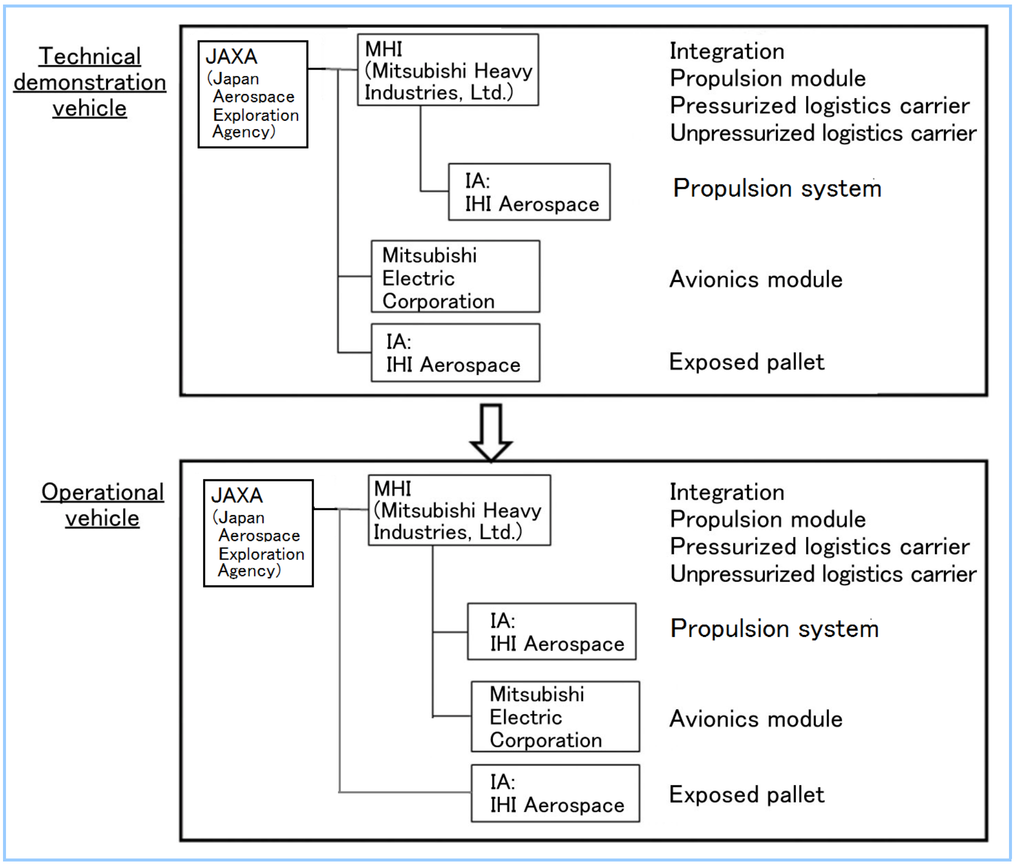


Figure 6 Change of manufacturing regime from technical demonstration vehicle to operational vehicle

4.2 Effort for assured manufacturing of operational flight vehicles

In order to assured the reliable manufacturing of sustained operational flight vehicles, MHI focused on the following four items:

(1) Establishment of cooperative framework with each relevant company
(2)Consolidated procurement of parts and materials
(3) Strengthening manufacturing and quality management
(4) Providing more reliability and efficiency to launch-site operation

(1) Establishment of cooperative framework with each relevant company

A relationship of mutual trust between MHI, JAXA and partner companies is the most significant aspect of the project. The primary members of each party gather in regular meetings once each month in order to communicate, share information and achieve unity in the promotion of the project under a common perspective. In the meetings, scheduling, the procurement status, technical concerns and non-conformances are discussed to clarify problems and provide solutions. In addition, MHI also holds a monthly coordination meeting with Mitsubishi Electric Corporation and IHI Aerospace (IA) individually to confirm the work progress and to adjust individual issues.

(2) Consolidated procurement of parts and materials

The long-lead items and parts for which costs can be lowered through consolidated procurement were procured all at once for six shipset for the vehicles from No. 2 to No. 7.

Those items included imported equipment and electronic parts, some of which are no longer produced. Accordingly, this decision contributed to ensure the stable manufacturing of the vehicles, in addition to reducing costs.

(3) Strengthening manufacturing and quality management

The most significant role for the production prime contractor is to responsibly coordinate manufacturing, including the hardware manufactured by partner companies, in an integrated fashion. To satisfy this role, MHI promoted the management of partner companies in the following matters:

(a) Configuration management

A primary principle for the production of vehicles is to not change the configuration after the completion of development and flight demonstration. However, a configuration change will be inevitably required when accommodating the discontinuation of parts and materials, improving the design and manufacturing, disposition for non-conformances and incorporating the flight results. Among these, it has been experienced many times that slight changes or changes that are supposed to be improvements have an adverse effect on the overall system. Configuration management and change management, which are described in the following, are the important factors to avoid the aforementioned situation.

An important aspect for configuration management is where to set the baseline of configuration. For "Kounotori," the baseline of each vehicle is confirmed by a review meeting. Each module, the primary subsystems and primary components are subjected to Manufacturing Readiness Review (MRR) to indicate the baseline of configuration. The baseline includes drawings, specifications and procedure for manufacturing. Based on these documents, we identified changes from previous vehicles and confirmed the applicability of said changes in the review process.

(b) Change management

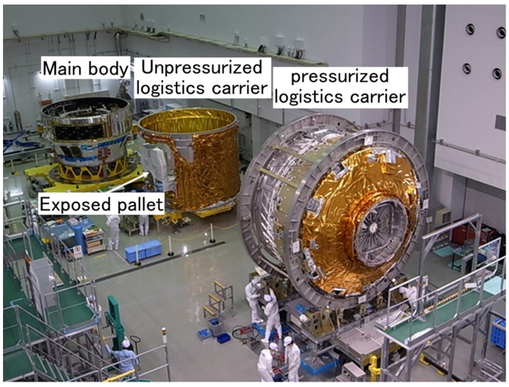
For space equipment, changes should be submitted to customers for approval when they deviate from the customers' requirements, or when changing a manufacturing process that has been approved by the customer. It is commonly believed that changes other than those can be made in-house. However, it is desirable to carefully confirm any changes in order to prevent significant failures from occurring in the future. Accordingly, it was decided to regard any changes as "significant changes" except when their effects are obvious, and submit them and their applicability up the chain for approval. Based on this, the partner companies, Mitsubishi Electric Corporation and IA, make applications for significant changes to MHI, which MHI evaluates. When MHI determines that the submitted changes are significant, they are then submitted to JAXA. In addition, any significant changes in MHI are also submitted to JAXA. Configuration changes that emerge after the MRR are subjected to change management one by one, and are also reviewed whole in a Pre-Shipment Review (PSR), just like MRR, providing a two-step check process to prevent omissions.

(c) Quality management

Non-conformance management is significant for quality management. Critical non-conformances are discussed together with JAXA. Minor issues are not reviewed one by one, but are reported in the regular monthly meetings and in the MRR and PSR to confirm the adequateness of disposition. MHI took over the inspections that JAXA performed during and after the completion of the manufacturing. However, MHI was not involved in the development of the Avionics Module, for which Mitsubishi Electric Corporation was responsible. Accordingly, the quality management of the Avionics Modules is carried out under the cooperation and advices of JAXA.

(4) Providing more reliability and efficiency to launch-site operation

Each Kounotori Module is manufactured by the responsible company in their plants and brought to the JAXA's Tanegashima Space Center. Once each module is unpacked on-site, it is functionally tested and completed for launch configuration. (Working overviews are shown in **Figure 7** to **Figure 11**)



Provided by JAXA

Figure 7　Overview of launch-site operation

Provided by JAXA

Figure 8　Overview of pressurized cargo loading inside pressurized logistics carrier

Provided by JAXA

Figure 9　Overview of exposed pallet with loading unpressurized cargo inserted in unpressurized logistics carrier

Provided by JAXA

Figure 10　Overview of assembled “Kounotori”

Provided by JAXA

Figure 11　Overview of “Kounotori” before delivery to launch vehicle

One of the characteristics of the manufacturing of "Kounotori" is that the work period at the launch site is long, takes about half a year. This is because the spacecraft is assembled while loading cargos for the ISS. MHI implements the following measures in order to make the long-term launch-site operation safer, more reliable and more efficient.

(a)　Organizing launch-site operation team

MHI selects specialists from each department and section in several factories and dispatches them for launch-site operation. In a word, the operation is performed by a mixed team with an unusual organizational structure. In response to this, MHI organized a Successive HTV Launch-site Operation Team (SHOT) for the purpose of providing an explicit chain-of-command at the launch site and integrate the safety management, enabling operations to be carried out with a sense of unity. Other companies also organize similar teams, and we share safety awareness and other information with them toward the fostering of camaraderie.

(b) Efficiency

The operational learning level improved over the operations on the HTVs, and streamlining is being attempted by optimizing schedules and removing omissible processes. As a result, whereas the launch-site operation for No. 2 took more than six months, the operation for No. 3 could be completed in five and half months (five months in actual worked hours).

(c) Launch-site Review meeting

Launch-site Review meetings were held at three turning points after the separate operations for each module are completed, when the vehicle is assembled and when the propellants were loaded (before delivery to the launch vehicle). In the meetings, the adequateness of completed operations and the preparation status for subsequent operations are checked in order to confirm that nothing has been overlooked before proceeding to the next step. The effective procedures performed by the review board for the H-IIA launch vehicle are utilized for "Kounotori." Responsible quality evaluation was performed by designating dedicated persons in charge of evaluation with respect to the propulsion, avionics and mechanical systems (evaluation by system), and quality confirmation supervised by a coordinator was performed by designating dedicated a evaluator for each module (evaluation by module)

5. Conclusion

HTV No. 3 was launched on July 21, 2012, completing its mission on September 18. This resulted in three consecutive successes for Kounotori, two of which were under the management of MHI. The modules for vehicle No. 4 are now being manufactured at a good pace in various factories, toward a launch sometime in the next fiscal year.

Such satisfactory manufacturing progress is considered to have been realized by virtue of the following factors:

- Prompt transition to operational flight vehicles production framework: Transition is executed smoothly by early award of the production prime contractor and start of transition even the Demonstration Flight Vehicle is under development.
- Consolidated procurement of parts and materials for six HTVs: Consolidated procurements are enabled early at the execution of the production contact since the launch of six HTVs was agreed early between JAXA and NASA.
- Information sharing and cross-checking between companies: The framework was open as prime manufacturer and partner companies attended each others' review meetings
- Utilization of experience in continued production of the H-IIA: Effective quality management techniques were incorporated

Lastly, HTV No. 3 urgently carried a catalytic reactor as an alternative for faulty equipment on the ISS in response to an urgent request from NASA. MHI has been known later that NASA was considering transporting the equipment either by SPACE-X's Dragon No. 1 or "Kounotori," and they decided to use "Kounotori" because of its higher reliability. As the manufacturer of "Kounotori," nothing makes us happier than receiving the appreciation of NASA. "Kounotori" can transport a broad range of cargo. From now on, we will maintain the continued success of the HTVs and transport various cargo to the ISS.

References

1. Matsuyama et al., Effort and Outcome of the Operational Flight HTV Production as a Prome Contractor, 56th Space Science and Technology Joint Conference
2. JAXA HTV3 Press Kit
3. Miki et al., Development of the H-II Transfer Vehicle (HTV), Mitsubishi Heavy Industries Technical Review Vol. 47 No. 1 (2010)