2008-k-64

# Development Plan for Future Mission from HTV System

By Hiroshi SASAKI, Takane IMADA, and Shinichi TAKATA

*Japan Aerospace Exploration Agency, Tsukuba, Japan*
*E-mail: takata.shinichi@jaxa.jp*

The H-II Transfer Vehicle (HTV) is an unmanned transfer vehicle that will rendezvous with manned facilities and deliver up to six tons of cargo. HTV is a key space transportation system technology in Japan together with the H-IIA/H-IIB launch vehicle and is designed to fully satisfy the manned safety requirements of the International Space Station (ISS) program. Therefore, the technology and its system acquired through HTV development and operation will be widely utilized in future manned transportation and lunar, planetary and asteroid exploration missions.

**Key words:** HTV, Development Plan, Manned transportation, Lunar and Planetary and Asteroid exploration

## 1. Introduction

HTV is the culmination of what JAXA has been developing for many years in the area of launch vehicle, satellite and ISS/JEM program and is composed of the following systems.

- Safety and control system (rendezvous with ISS).
- Large main body system.
- Multiply redundant avionics and propulsion systems.
- Pressurized section that crew members can enter directly.
- Exposed cargo handling system with robotics arms.

HTV is one of the ISS resupply vehicles. JAXA is proceeding with the development, and the first flight is scheduled in 2009. Each module test of the first HTV has been completed, and system level verification tasks at Tsukuba Space Center (TKSC) are reaching a peak.

It is also expected that the practical operation of HTV will enable Japan to accumulate know-how that can serve as basic technology for its future projects on orbital transfer vehicles, free flyer units and manned transportation systems listed in JAXA Vision 2025.

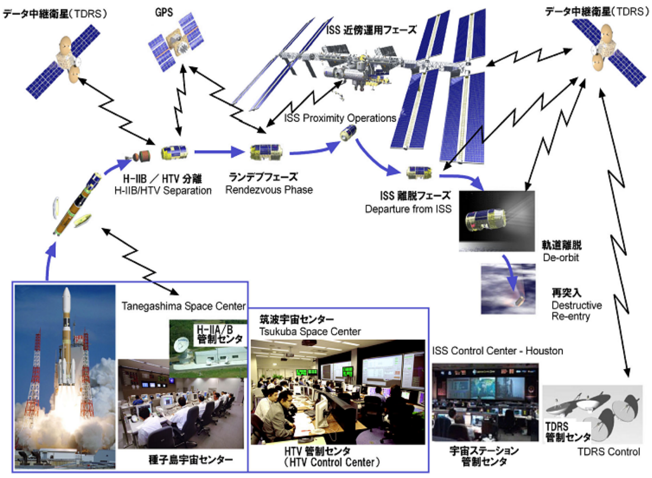


Fig. 1. HTV operation outline

## 2. HTV System unique characteristic

### 2.1 Wide variety of cargo transfer

HTV is the largest space transfer vehicle in Japan and can carry a wide variety of cargo up to 6 tons including food, clothes, water, payload racks and un-pressurized Orbital Replacement Units (ORUs). Cargo handling operations are based on ISS crew support. The crew members can enter the pressurized section directly or access the exposed cargo with the ISS robotics arm.

After shuttle retirement, HTV will be the only vehicle that can carry large pressurized cargo items or exposed cargo to ISS.

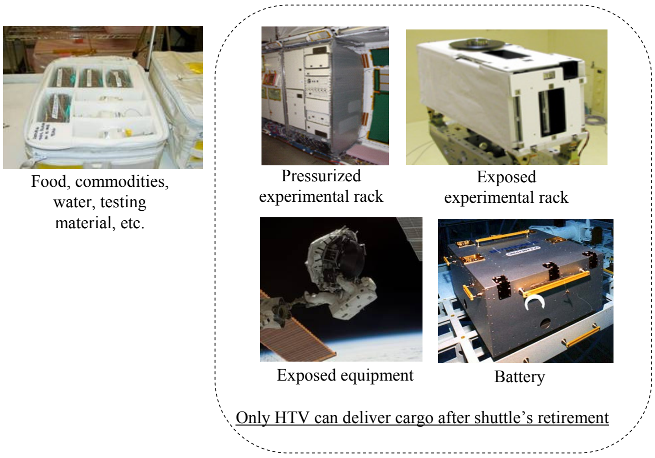


Fig. 2. Wide variety of cargo transfer to ISS

### 2.2 Unmanned space transfer vehicle to ISS

HTV is an unmanned transfer vehicle but is designed to fully satisfy the manned safety requirements of the ISS program and will rendezvous with manned facilities. It has a high-level GN&C system, automatic Fault detection isolation and recovery system, and a multiply redundant and powerful thrust propulsion system. HTV is a key space transportation system technology in Japan together with the H-IIA and H-IIB launch vehicle and will be expanded for future cargo and manned transfer missions or exploration missions.

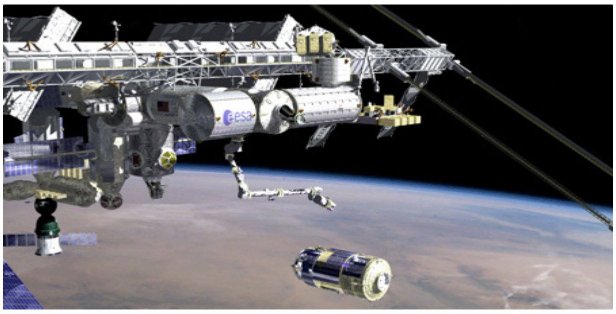


Fig. 3. Rendezvous with ISS

### 2.3 Module independency

HTV consists of four modules and exposed pallet. They are the pressurized and unpressurized carrier sections (carrier system) and the avionics and propulsion module (bus system). All modules are assembled, tested and launched at the launch site. This module independency is one of the unique characteristics of the HTV system. Only an individual module or modules will be modified and upgraded as new missions demand and will be combined with existing modules, enabling the HTV system to flexibly respond to new missions with minimum cost and time.

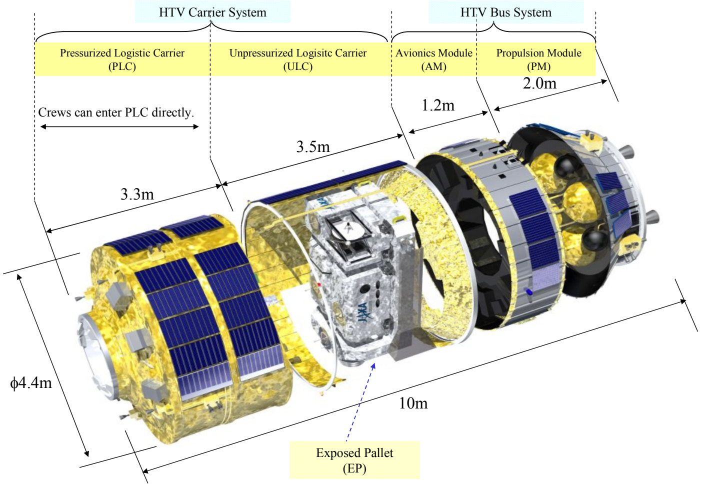


Fig. 4. Module independency

### 2.4. Efficient prelaunch analysis

As noted in 2.1, HTV can deliver a wide variety of cargo. However that results in some disadvantages like cargo cancellation risk or some special cargo mass requirement. Therefore, the mass properties of the HTV flight segment or final volume of necessary resources cannot be fixed until just before the launch. Such information is necessary for GN&C analysis, resource and mission analysis, etc. In order to overcome this problem, all preliminary analysis items and verification items were clarified, and flowcharts were created as the HTV analysis scheme. This scheme was verified in the design phase, which will increase HTV's configuration capability. Of course, it was also verified that the H-IIB launch vehicle has the capability to adjust to some range of HTV mass properties.

## 3. HTV Subsystem unique characteristic

### 3.1 Avionics System

The HTV avionics system is composed of the Command and Data Handling Subsystem (C&DH), Electrical Power Subsystem (EPS), Communication Subsystem (COM), and Guidance Navigation and Control Subsystem (GN&C). Because it must meet the two-fault tolerant requirement for ISS and crew safety and one-fault tolerant for mission success, there are two or more strings of all subsystems with various sensors for navigation data. Since the avionics system must control all HTV systems and has an automatic failure detection, isolation and recovery (FDIR) function, JAXA has conducted numerous development tests for the avionics system, software tests, subsystem tests, interface tests, etc.

As a result of HTV design, this avionics system facilitates rendezvous with manned facilities. It is equivalent to a manned spacecraft system and is expected to contribute to future missions.

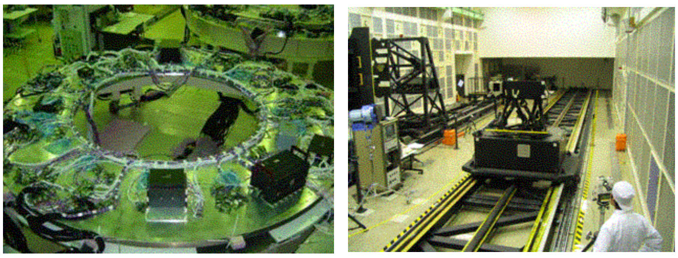


Fig. 5. Left: Avionics Test. Right: Rendezvous Test.

### 3.2 Propulsion System

The HTV propulsion system has three strings (two reaction control system branches and one main thruster branch) for safety to avoid collision with ISS avoidance maneuver (CAM). The main thruster branch is the last string and will be used when both Reaction Control System (RCS) branches have failed. To satisfy additional safety requirements, the HTV propulsion system is designed to prevent hazardous consequences of inadvertent engine firings. To satisfy the mission success requirements, the HTV Propulsion system is designed to be able to continue nominal operations if any one of its devices fails.

The thrusters are required to operate in very short pulse mode in order to rendezvous with manned facilities, which impose very stringent thermal conditions on the RCS thrusters and Main Engine thrusters. JAXA confirmed the operability and all pressure and temperature responses of each critical point in the propulsion system using firing patterns that simulated the HTV flight in the worst case scenario. Considering the safety criticality and reflecting the ETS-7 (Orihime and Hikoboshi) experience, numerous tests were conducted and new knowledge of the propulsion system was acquired. JAXA modified operations to reflect the test results.

As a result of HTV design, this propulsion system is expected to contribute to future missions with rendezvous, lunar and planetary and asteroid landings, reentry phases.

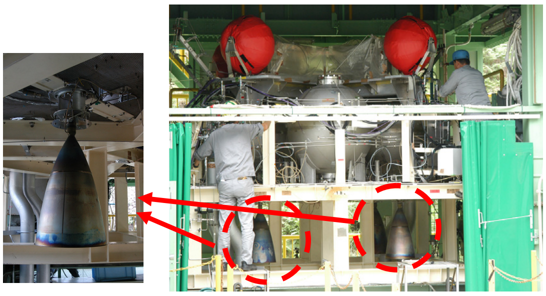


Fig. 6. Propulsion System Firing Test (Left: Main Engine thruster)

### 3.3 Carrier System based on crew member support

HTV has pressurized and unpressurized carriers. After the HTV is attached to the ISS, ISS crew enter the pressurized section and transfer cargo between the HTV and ISS. Figure 7-1 depicts the configuration of the logistics carrier with cargo. Cargo in the pressurized carrier is transferred by Inter Vehicular Activity (IVA). Also, the Exposed Pallet (EP) is removed from the HTV unpressurized carrier, and all Exposed Facility (EF) payloads are transported to their position on ISS. Figure 7-2 illustrates the operation concept of EP transfer by robotics arm.

Fig. 7-1. Cargo handling by crew member in HTV PLC

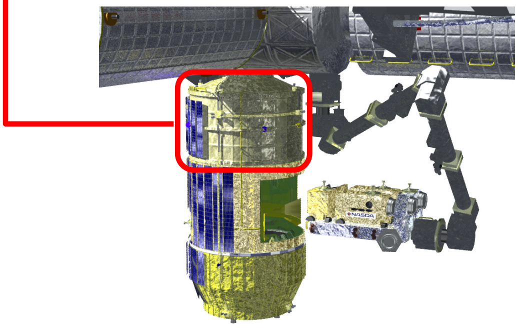


Fig. 7-2. EP handling by ISS robotics arm

## 4. Short-term HTV Development Plan

HTV's unique design technologies are summarized below.

- Rendezvous with manned facilities
- A wide variety of cargo transfer
- HTV Capture and Release
- Assembly of large-scale space structures
- Simulation and operation technology

These technologies are realized by the HTV bus system, carrier system, and operation system.

For short-term development, these technologies must be effectively utilized as the baseline. For efficiency, the following items must also be emphasized.

- Minimum design change
- Minimum cost and time
- Configuration with H-IIB launch vehicle

Design change of the bus system could significantly impact the HTV system. Therefore for short-term development, the first approach is to modify only the carrier system without changing the bus system design. The second approach is to modify the original HTV bus system for future mission.

### 4.1 ISS re-supply with developed carrier system

As illustrated in Figure 8, the HTV has a large hatch in the pressurized section and a large opening mouth in the unpressurized section. After the space shuttle retires, HTV will be the only vehicle that has the unique capability of carrying whole racks and unpressurized ORUs. The capability to recover cargo from the ISS will also be reduced after the shuttle retires. Therefore, in the short term, HTV is expected to develop its carrier system to meet a wide variety of cargo needs.

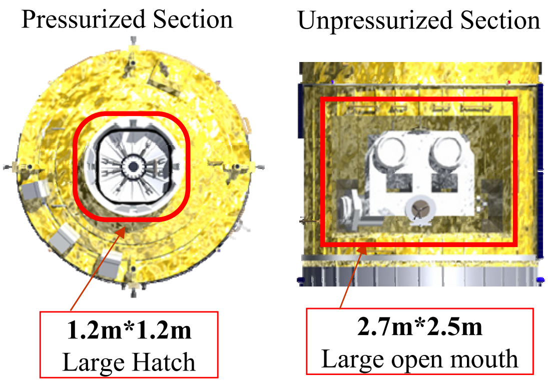


Fig. 8. HTV's unique carrier system

### (1) Pressurized carrier system

In this configuration, HTV has no unpressurized section. A large pressurized carrier will be developed and assembled with the avionics and propulsion module. In this configuration, about seven tons of pressurized cargo can be delivered to the ISS. The total mass of the modified HTV will be the same as that of the original HTV, so there will be no impact on the H-IIB or HTV bus system.

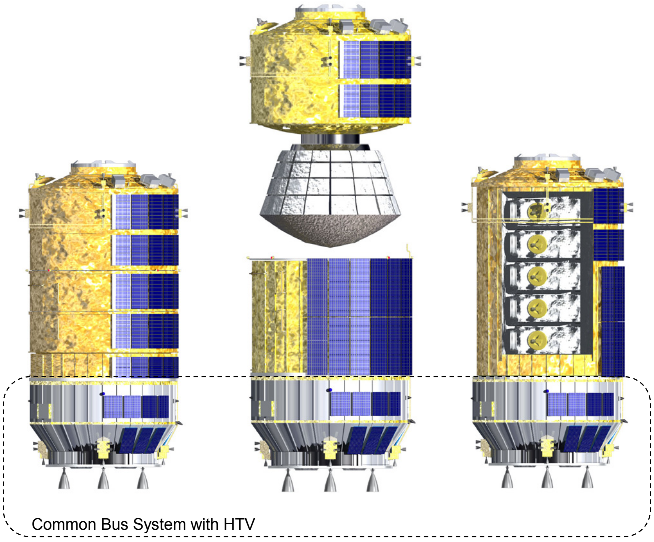
### (2) Re-entry capsule system

After space shuttle retirement, the capability to recover test samples from the ISS will be reduced, so HTV is expected to carry a return capsule.

One concept for this case is to convert the unpressurized section into a capsule container that can deliver about 2.5 tons of capsule system to the ISS. The capsule container and pressurized carrier will be finally attached to the avionics and propulsion module. The total mass of the modified HTV will be the same as that of the original HTV, so there will be no impact on the H-IIB or HTV bus system.

### (3) Unpressurized carrier system

In this configuration, HTV has no pressurized section. A large unpressurized carrier will be developed and finally attached to the avionics and propulsion module. In this configuration, about seven tons of unpressurized cargo can be delivered to the ISS. The total mass of the modified HTV will be the same as that of the original HTV, so there will be no impact on the H-IIB or HTV bus system.



(1) Only pressurized carrier (2) Re-entry capsule (3) Only unpressurized carrier

Fig. 9. Modified carrier system lineup with common HTV bus system

Table 1 Cargo Mass to ISS

| Carrier Type | Cargo Mass to ISS |
|---|---|
| (1) Only PLC | 7.0 tons of Pressurized Cargo |
| (2) PLC & Capsule | 4.5 tons of Pressurized Cargo<br>2.5-ton Capsule System |
| (3) Only ULC | 7.0 tons of Unpressurized Cargo |
| Original HTV | 4.5 tons of Pressurized Cargo<br>1.5 tons of Unpressurized Cargo |

### 4.2 Construction of Low-orbit transfer system

JAXA is also studying enhancement of the HTV system and will provide a large inter-orbit transfer system in the near future for additional utilization opportunities. This enhancement will also be possible with combinations of the H-IIB and HTV bus system.

- Unmanned free flyer
- Earth observation from low earth orbit
- Data during atmospheric re-entry

### 4.3 Modification of bus system for future multi-mission

In order to respond to multiple missions in the long-term development plan, the mass of the bus system is expected to be reduced based on HTV development and operation results by the following methods.

- Mass optimization of sub-structure
- Optimization of thermal control or harness
- Development of new components

The methods above will help reduce the mass of the new bus system (new avionics module and new propulsion module) to about two tons. Additional mass reduction of resources will be possible by

- Reducing primary battery units,
- Paddle of Solar Array Panel (SAP), and
- Modifying system design based on the new mission.

Figure 10 presents examples of this light new bus system. Consecutive HTV operation and development, new recovery capsules systems and other subsystem studies including the new bus system may yield a new inter-orbit transfer system in the future.

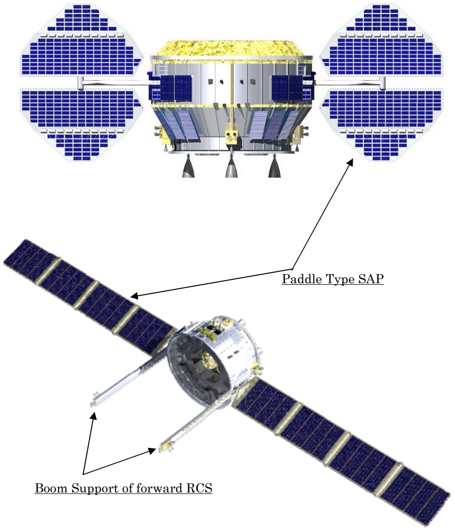


Fig. 10. Two examples of light new bus system of the future

## 5. Long-term HTV Development Plan (Beyond the ISS)

Through the HTV and ISS development and operation, including the short-term step-by-step modification of HTV, accumulated know-how and continual subsystem study may lead to a new future inter-orbit transfer system for space platforms, lunar, planetary or asteroid exploration missions, or manned vehicles.

### 5.1 Lunar, planetary, asteroid exploration support

One application example of this new bus system is a cargo transfer mission to the lunar (or other planetary, asteroid) surface. The lunar case was studied this time. A lunar transfer vehicle and lunar module are expected to have subsystems or functions based on the HTV such as

- Safety and control system,
- Large main body structure system,
- Multiply redundant system of avionics and propulsion including thruster pulse operation while landing, and
- Cargo handling by crew members or robotics arm on the Moon.

From the viewpoint of cargo carrying capacity, it’s better to separate the HTV bus system before entering LLO (lunar low orbit) (CASE 1). However, the lunar module will grow in size, and the HTV bus system will be used only to enter the lunar transfer orbit (LTO), which will bring few benefits to the HTV bus system. Moreover if lunar landing will be done using the HTV bus system (CASE 3), the HTV has to carry more than three tons of propellant. This means that the propellant tank design has to be changed (the maximum propellant mass of the original HTV is 2.4 tons) and will result in serious design changes to the propulsion module.

However, if the HTV bus system remains in LLO (CASE 2), it will be very useful because it will provide support such as tracking or data relay during the lunar module's landing or cargo operation on the Moon.

Therefore, case studies are being conducted in order to determine the appropriate configuration assuming that

- minimizing the design changes to the HTV bus system as well as the requirements for the lunar landing module,
- the new bus system will weigh about two tons, and its design (especially including the propellant tank or main body) is based on the HTV, and
- the lunar module is designed based on the HTV bus.

Table 2 Configuration case study for lunar mission

| | CASE 1 | CASE 2 | CASE 3 |
|---|---|---|---|
| LTO | HTV Bus | HTV Bus | HTV Bus |
| LLO | Lander | HTV Bus | HTV Bus |
| Landing | Lander | Lander | HTV Bus |
| Merit | HTV tank can be used. | HTV bus can support landing from LLO.<br>HTV tank can be used. | New lander is not necessary. (But HTV bus has to be modified). |
| Demerit | New lander is necessary<br>HTV bus cannot support landing on LLO. | New lander is necessary | HTV tank cannot be used.<br>HTV bus cannot support landing on LLO. |

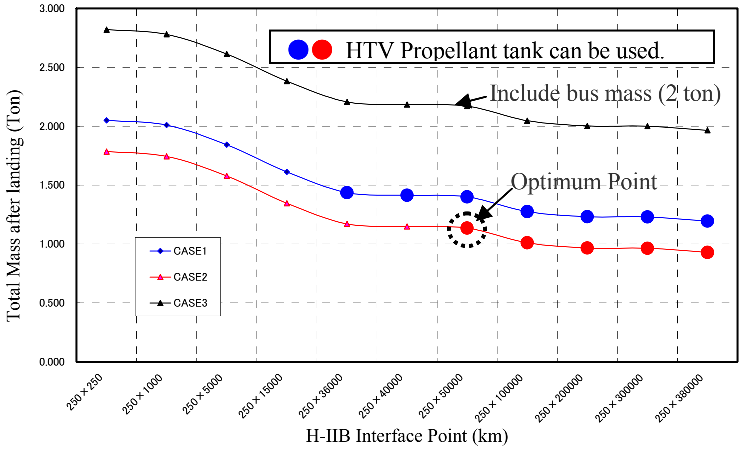


Fig. 11. Total lander and payload mass after landing with combination of HTV modified Bus System

It's necessary to change GN&C system sensors for attitude determination and to modify the software. However the HTV GN&C software already has a navigation mode that can accept commands from operators on the ground and can continue flying. Therefore, the impact of modifying the GN&C will be minimized.

From the viewpoint of application of H-IIB and HTV, one more assumption should be added to those above.

- To maintain the interface specifications between HTV and H-IIB, especially the launch capability

From the simplified calculation presented in Figure 11, "SR:250km-LR:50000km in CASE 2" will be the most suitable separation point without adding propellant to the HTV bus system and a few hundred kilograms of payload (one ton or more of payload and lander) will be delivered to the lunar surface like a lunar rover or some supplies to support activities on the Moon.

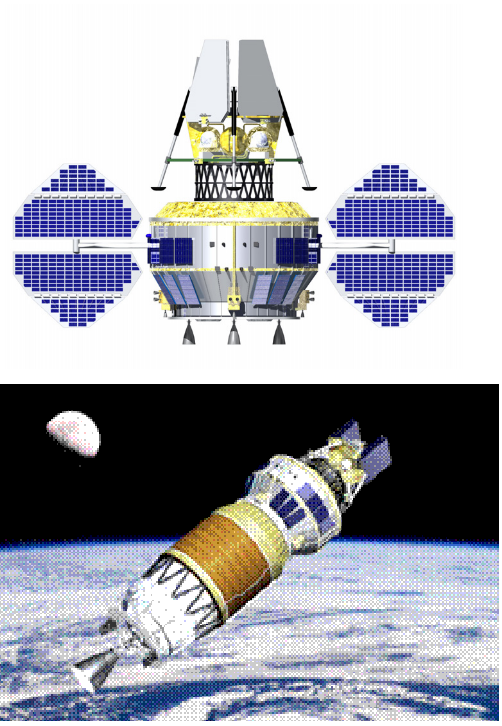


Fig. 12. Lunar module with H-IIB and new HTV bus system

## 5.2 Future Platform System

The technologies acquired through the original HTV and the modified HTV will be the baseline of future platforms, which will be the bases of multiple activities in space. Assembling of large structures that will be delivered by HTV is expected to provide a platform that can be used for

- Earth or space observation equipment,
- a space experiment laboratory, or
- a space port for assembly and improvement of Lunar or Martian orbiting satellites.

Applying the platform and cargo transfer service provided by the HTV will enable serving a wide variety of multiple needs like providing the experiments or missions in a short time.

Table 3 Platform utilization

| | |
|---|---|
| Geostationary orbit platform | -Observation<br>(Weather forecasting, Environment monitoring, disaster prevention)<br>-Solar energy generation<br>-Communication base (Data relay) |
| Low-orbit platform | -Observation<br>(Environment monitoring, disaster prevention)<br>-Space observation<br>(Subaru Telescope class)<br>-Science and engineering experiments, material science experiments |
| Other | -Arrival and departure port for inter-orbit transfer vehicle<br>-Assembly and improvement of Lunar or Martian orbiting satellite |

Figure 13 illustrates an example of a future HTV-based platform in LEO. The platform assembly and operation procedure is described below.

- The first HTV with some hatches and also robotics arm is launched.
- The second HTV is launched and rendezvous with the first HTV. It is captured by the first HTV's robotics arm and provides communication and electric power.
- A modified JEM is also delivered by a modified HTV as depicted in Figure 14.
- After that, an HTV or cargo transfer vehicle will visit this platform as the mission demands.
- In order to implement a mission on a platform, space robots will probably play an active role in the pressurized section or outside the platform. The robots will provide support such as monitoring, assembly and observations. Of course, these robots can be controlled by ground operators.
- At the end of each mission, some test samples will be recovered by the HTV recovery capsule.

It is important that the platform will be completely based on Japanese technologies obtained from the JEM and HTV programs and that Japan will be able to realize and maintain this end-to-end system (from launch, experiment and recovery) by itself. Table 4 lists the cargo transfer capability for the original and modified HTV bus. With the modified HTV bus, the mass can be reduced by two tons.

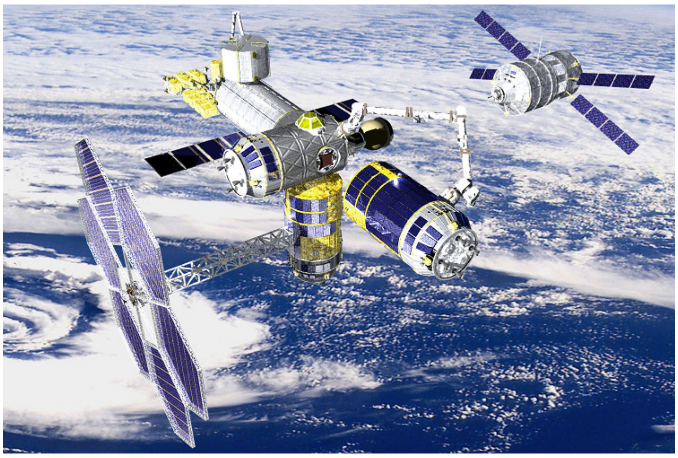


Fig. 13. Future platform based on JEM and HTV technologies ( and ATV)

Table 4 Cargo transfer capabilities

| | | H-IIB | H-IIA204 | H-IIA202 |
|---|---|---|---|---|
| Launch Capability | | 19 | 15 | 10 |
| Platform Mass | Original HTV | 13 | 9 | 4 |
| | Modified HTV | 15 | 11 | 6 |

(Ton)

If a larger H-IIB (H-IIB+) or modified propellant tank is used, the HTV will be able to carry heavier and larger cargo, which will benefit multiple missions.

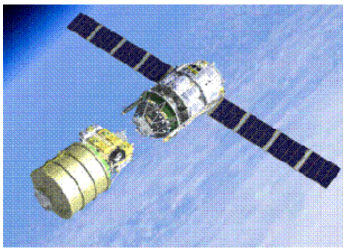


Fig. 14 Cargo Transfer to future platform

## 5.3 Manned Space Transfer Vehicle

In 2005, JAXA Headquarters announced a new and ambitious plan to develop a manned space transfer vehicle by 2025. Developing and operating the HTV will enable Japan to accumulate experience in rendezvous with manned systems and in on-orbit reliable real-time operations in preparation for developing future manned transportation systems. JAXA thus considers HTV to be a key vehicle in human space activities and space transportation. A case study is presented in the paper "Preliminary Study for Manned Spacecraft with Escape System and H-IIB Rocket" in this ISTS.

Fig. 15. Manned Space Transfer Vehicle

## 6. Conclusions

HTV has the potential to be the base of a future inter-orbit transfer vehicle at both the system and subsystem level. The HTV development process is now coming to a peak of all system level verification tasks, and know-how accumulated through HTV development and operation will contribute to future missions.

## 7. References

1) Hiroshi Sasaki: HTV Development and the Future Vision, *ISTS*., (2006), ISTS 2006-o-1

2) Takane Imada, M Ito, S Takata: Preliminary Study for Manned Spacecraft with Escape System and H-IIB Rocket, *ISTS*., (2008), 2008-g-14