Concept Study of HTV-R (HTV-Return)

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Japan contributes essential services to space experiments and enables human activities included as part of the international partnership of the ISS program by utilizing the HTVs (Kounotori). As the next step toword on-orbit service, JAXA has commenced technical research into cargo return from orbit. The HTV was used in research as the base design and a return vehicle was added to enhance performance. The combined vehicle is called the "HTV-R". HTV-R enables JAXA to recover various samples of experiments conducted on the ISS and equips a new re-entry vehicle called as "HRV (HTV Return Vehicle)" for the enhanced function. The HRV will fly autonomously and conduct lifting re-entry into the atmosphere by controlling the attitude and trajectory to a predefined splashdown point. Now two types of vehicle concepts are being investigated. One uses an HTV as the base system for orbital flight and minimizes the initial cost of HTV-R program, and the other integrates the HTV components into a new vehicle, optimizing the on-orbit functions to minimize the recurring cost.

Key Words: HTV, Re-entry, ISS

Acronyms

ECLSS	:Environmental Control and Life Support System
FRGF	: Flight Releasable Grapple Fixture
HTV	: H-II Transfer Vehicle
HTV-R	: HTV - Return
HRV	: HTV Return Vehicle
ISS	: International Space Station
LEO	: Low Earth Orbit
PCBM	: Passive Common Berthing Mechanism
PLC	: Pressurized Logistics Carrier
UPLC	: Un-pressurized Logistics Carrier

1. Introduction

Until 2012, three HTVs completed the operations to the ISS and they have encouraged JAXA to start researching upcoming programs as a part of Japan's future space activity plan. HTV-R, which is likely to be one of the most attractive for system engineers who are studying the feasibility of Japanese manned space flight.

In the last ISTS in 2011[1], JAXA reported an HTV-R plan which would reduce the development cost by minimizing the items to be modified from the original HTV (fig. 1).

Now, JAXA has started researching an alternative HTV-R concept with consideration of future human activities after all planned HTV flights have been completed. The plan needs many modifications but operational costs can be minimized by frequent flights and partial re-use of hardware. This paper reports the alternative HTV-R (fig. 2), comparing it to the former HTV-R plan.

Fig. 1. The Former HTV-R (Initial Cost Minimum)

Fig. 2. The Alternative HTV-R (Recurring Cost Minimum)

2. HTV-R Concept and Target

The HTV-R (H-II Transfer Vehicle - Return) vehicle concept study commenced as an enhanced type of HTV. It uses HTVs operational heritage, resource, and interfaces (such as to the ISS, ground system, and launch vehicle). Figure 3 shows the overall

mission concept HTV-R support system. The HTV-R is launched from Tanegashima Space Center by a H-IIB launch vehicle (in the former plan) or H-IIA (in the alternative plan). Like the original HTV, it can carry cargo to the ISS but also has new cargo recovery ability (down mass up to 1.6 metric tons). For this purpose, a re-entry vehicle called HRV (HTV Return Vehicle) is installed in the HTV-R, which will conduct controlled a re-entry flight and be recovered in the Pacific Ocean. Both the former and alternative HTV-R plan use the same operation procedure but the cost per flight will be reduced in the alternative HTV-R because of the lower launch cost.

Before separating the HRV, the HTV-R will use all the flight operations developed for the HTV. The trajectories toward the ISS are the same as those of the HTV and their safety has been verified in previous HTV flights. Ensuring safety on the ISS requires considerable effort. JAXA want to minimize the task in the development even in the alternative HTV-R plan by using the trajectories as much as possible.

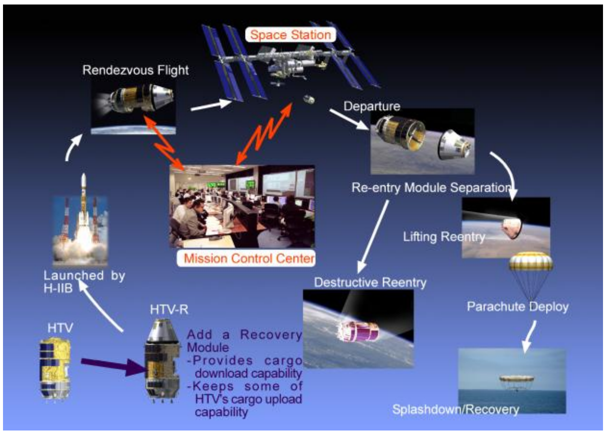

Fig. 3. Overall operation profile of HTV-R

Two major program targets identified in the 2011 report have not been changed.

- To establish safe and confident return technology as a pathfinder for a Japanese manned spaceship
- To realize an infrastructure for returning utilization specimens and on-orbit replaceable units from the ISS

But the schedule was updated and the first HTV-R flight is not expected to be earlier than the Japanese financial year 2018.

2.1 Target (1) : Pathfinder for a Manned Spaceship

Numerous technological challenges must be overcome to develop a manned transportation system between ground and orbit. The need to ensure safe and gentle re-entry technology is a key area and a major milestone in the development of the transportation system. HRV in the HTV-R simulates a manned re-entry vehicle and the demonstration of its re-entry is part of two major targets of the HTV-R program.

JAXA has completed the first step toward a manned spaceship by HTV, and the HTV-R program will be the second. The latter requires HRV development and the HRV will demonstrate the re-entry flight. HRV has the following characteristics as a bridge to a manned spaceship.

(1) Re-entry vehicle size is equivalent to manned system

HRV design has a reasonable shape and size for a manned vehicle. The size (diameter: 4.2m) is sufficient to transport 4 crew members to a LEO station and bring them back to Earth.

(2) Similar configuration

The baseline rocket for the human launch system has yet to be determined. However the vehicle configuration of HTV-R which consists of a pressurized section at the top and a service module at the bottom is a conventional configuration in human launch systems. The experience of HTV-R development will become a useful reference for designing the human launch system especially for structure and separation mechanics.

(3) Lift control during re-entry

A modern manned re-entry vehicle should control its lift during the re-entry flight, both to relieve G-force acting on the crew and to minimize the dispersion of the splashdown area to facilitate quick recovery. It is not mandatory technology as an unmanned re-entry vehicle for sample return but needed as a means of demonstrating technology for manned re-entry.

(4) Partially redundant system

Manned vehicles should have complete redundancies in important subsystems to manage all possible failures and to eliminate any possibility to cause a catastrophic situation. However, conventional unmanned vehicles have limited redundancies in systems reflecting the need to balance mission success against weight/cost efficiency aspects. HTV-R, like other unmanned vehicles, includes partially redundant systems but must have the potential to become the base design for a manned system via functionally enhancement of each subsystem.

2.2 Target (2): Sample Return from the ISS

To utilize the ISS as a space factory as much as possible, users always want to obtain their samples from the experimental instruments in the ISS. Based on our interviews with users of experimental equipment, they wish to obtain samples as quickly, frequently and in as raw a state as possible. Smaller sample packaging is time-consuming, more troublesome, and reduces the value of the raw sample. The HTV-R program will be able to cooperate with other international partners to realize a frequent and quick sample return infrastructure from the ISS.

Also, HTV-R will realize a complete cycle of JAXA's on-orbit access. JAXA is already capable of transporting units to the ISS by HTV, but lacks the ability to return to Earth now. The second purpose of HTV-R is to return units for service from the ISS. Figure 4 shows a cycle of repair and re-use of failed component on the ISS. HTV-R flights will enable JAXA and Japanese space scientists to utilize the Japanese module "Kibo" and the experimental equipment in it more efficiently.

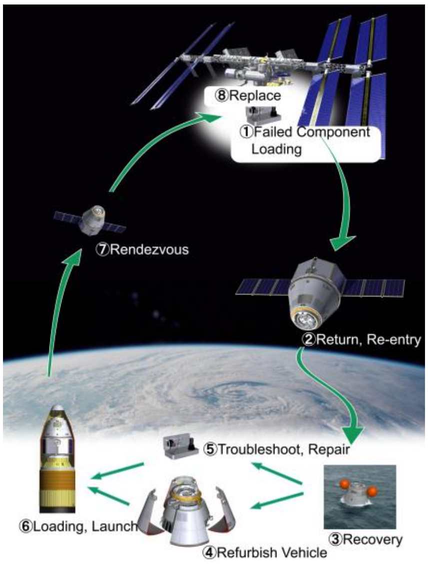

Fig. 4. Repair & Re-use Cycle

3. Vehicle Design Study

3.1 HTV-R Design

The former and the alternative HTV-R have different modules in stead of the common shape of the re-entry vehicle.

(1) Construction

Figure 5 is a cutaway image of the former HTV-R. The un-pressurized section will be retained and it will have the capability to transport the exposed pallet with cargo as HTV does now.

The interfaces between HTV-R and H-IIB will be the same as HTV. HTV-R will also retain its weight, inertia, and mass offset from the original HTV and use the avionics/propulsion module unmodified in their structure.

Figure 6 shows an image of the alternative HTV-R. All of the major functions for the flight are installed into the HRV and the following section has only functions as power source and un-pressurized cargo carrier. The main avionics boxes are installed in the pressurized section and hopefully will be re-used.

In the alternative plan, the interface between HTV-R and H-IIA will be different form the original HTV. The length of HTV-R is far shorter than the former plan, and smaller and shorter fairing will be selected for the launch vehicle.

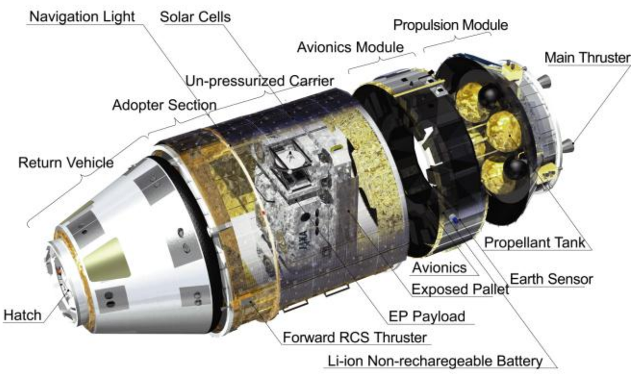

Fig. 5. Modules in the Former HTV-R vehicle

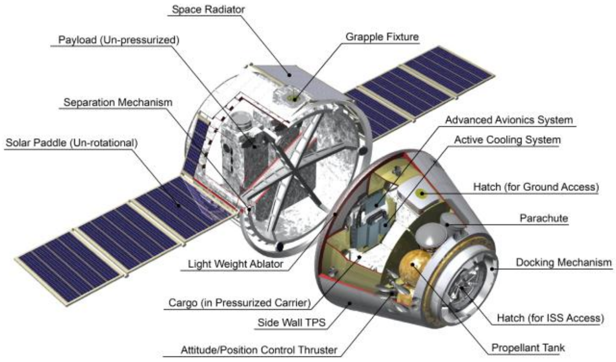

Fig. 6. Modules in the Alternative HTV-R Concept

3.2 HRV Design

(1) Functions for Re-entry flight

Some experimental re-entry vehicles have been developed and flights conducted in Japan. However differences in vehicle configuration, size, and flight pattern should be taken into account when designing the re-entry module of HTV-R (HRV). As for the similarity with manned vehicles, only Hyflex (Hypersonic Flight Experiment, flight in 1996) had guidance, navigation, and an actuator system to control the re-entry flight path, with other vehicles lacking any methods to control attitude. Since Hyflex used two moving surfaces for its Pitch/Roll control, the algorithm differs from that of manned re-entry vehicles and HRV. JAXA must therefore develop an algorithm for HRV control and the first HRV will demonstrate human re-entry flight.

(2) Volume

HRV in the alternative HTV-R plan has a slightly smaller pressurized section than the former plan but will have a volume up to 15 m^3 (excluding internal components) and probably prepare a volume exceeding 10 m^3 for return sample loading. This size is sufficient as a baseline design for the manned vehicle.

(3) Cargo Service

There are plans to incorporate new cargo services in the HRV, such as electrical power and a coolant loop, which will enable samples to be returned in temperature-controlled refrigerators. These services will also be extendable to the thermal control systems for manned vehicles in future.

4. Subsystems

The former HTV-R did not need a new system for on-orbit flight, but the alternative HTV-R plan needs a new system for all operations including rendezvous flights. The new functions and components are identified and estimated the design in the following section.

4.1 Solar Panel Optimization

The original HTV has many solar panels around the body as shown in fig. 7. Basically, the former HTV-R uses them as it's sole power source during the flight. But the design has not been

optimized as a rendezvous vehicle in LEO and should be reconsidered for the alternative plan.

The solar panels on the original HTV were added after all geometries of the body structure had been fixed. So, there is a slight clearance between the HTV body and the fairing of the launch vehicle and there was no space for HTV to equip a solar paddle extended from the body. As the result, the average solar power generation changes significantly in the variation in Sun to orbit angle as shown in fig. 8, and HTV needs frequent yaw rotation operations to increase solar power to meet requirements during flight. The same operation will be required for the former HTV-R plan.

The alternative HTV-R does not have the limitation of clearance. The extendable solar paddles will be suitable to equalize the solar power generation for the plan. JAXA conducted an efficiency analysis of four configurations of solar paddle shown in fig. 9.

Model A has two extended but un-rotatable solar paddles like the Russian Soyuz and Progress space vehicles.

Model B has two extended and rotatable paddles like SpaceX's Dragon.

Model C has a combination of two un-rotatable solar paddles and body mounted panels to increase the power generation around very low and very high Sun to orbit angle.

Model D has been modified from Model C by glowering the inclination angle by 30 degrees.

All models have the same solar panels and figure 10 shows the panels in Model A.

The analysis result is shown in fig. 11. Model B has the maximum power resource especially in case of low Sun to orbit angle but the power significantly drops at high angles because the Sun rotates around the direction of solar paddle extension. Model B to D have similar performance in the low Sun angle but Model B has less power generation capability at high angles. The tendency is improved in Model C by moving two panels to the side of the body and Model D shows nearly the same performance in all Sun angle. It suggests that Model D does not require any operational restriction for attitude to keep solar power and has the ideal characteristics as a rendezvous and docking vehicle which require it to maintain at a predetermined attitude.

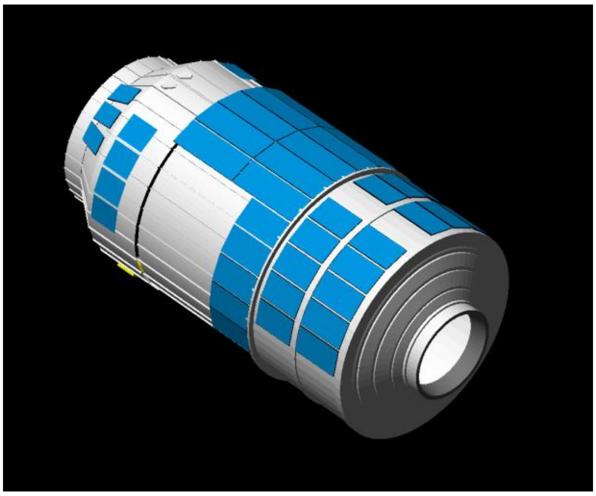

Fig. 7. Solar Panels on the Original HTV

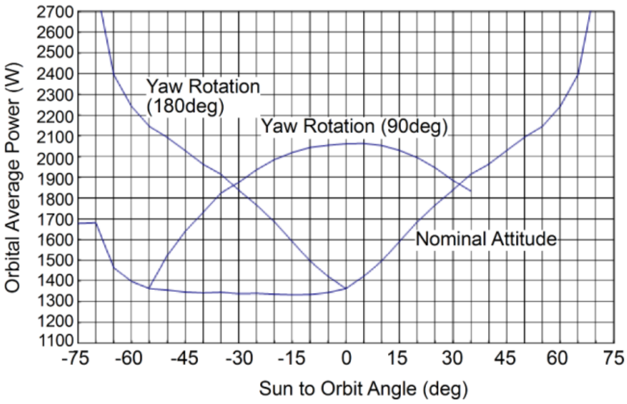

Fig. 8. Solar Power Generation in Sun Angles

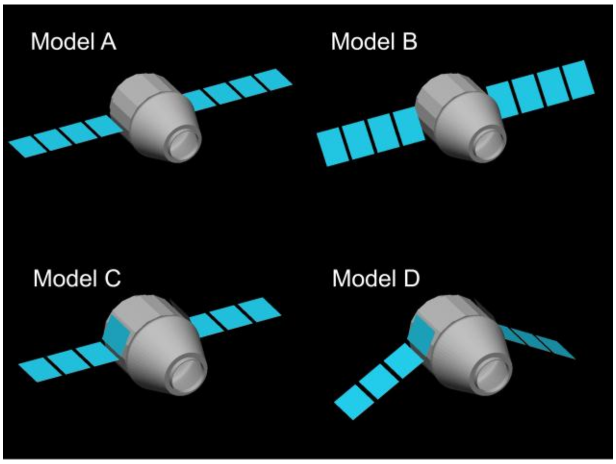

Fig. 9. Solar Paddle Configuration Models

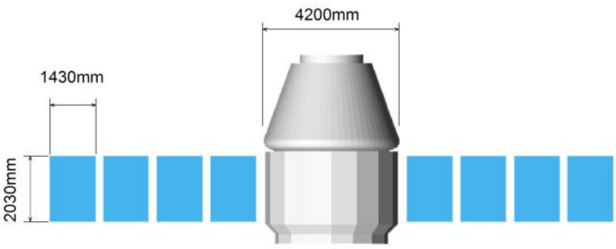

Fig. 10. Geometries in Model A

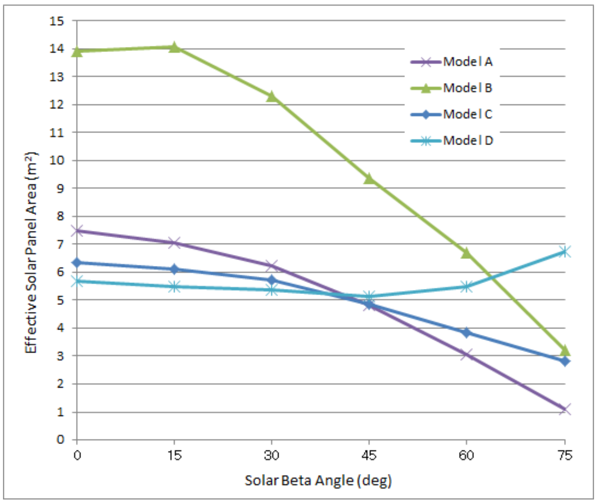

Fig. 11. Effective Solar Panel Area in each Model

4.2 Power Requirement

In parallel with the analysis of power generation, the requirement for electrical power consumption should be estimated. It determines not only the area of the solar panel but also the size of radiator and affects the vehicle configuration.

The power consumption data from HTV is applicable to HTV-R since they take almost the same orbital trajectory. From the experience of HTV, the heaters in the cargo transport vehicle consume large amount of the total power since the carrier has a large surface and radiates a lot of heat. The heater power consumption was estimated from HTV's by comparing their surface areas. Figure 12 shows the result. The HTV-R has a surface area of 35.6 m^2 and will consume nearly half of that of the HTV which has a surface of 60.6m^2.

The estimated summary of the power consumption is shown in table 1. The reasons for the estimation are shown in the following sentence.

Table 1. Power Consumption Estimation

	HTV	HTV-R	note
Heater (in PLC)	778.3	258.8	relative to surface
Component (in PLC)	153.5	153.5	
Heater (in UPLC)	53.1	26.6	
Component (in UPLC)	29.5	14.8	relative to volume
Heater (in Avio. Module)	234.7	0	installed in PLC
Avionics	793.8	396.9	power saving
Heater (in Prop. Module)	289.8	144.9	relative to surface
Component (in Prop. Module)	94.9	94.9	
Total	2,427.6	1,090.4	

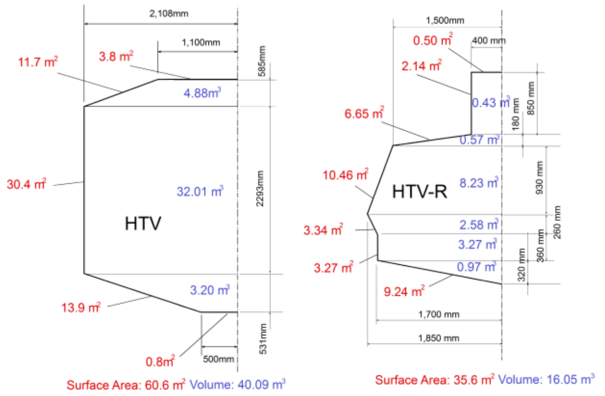

Fig. 12. Surface/Volume Comparison

(1) Heater in PLC (Pressurized Logistic Carrier)

Heater power consumption from the carrier is estimated in relation to the surface area. In the HTV-R, all avionics are installed in the PLC and they supply heat. So, a half of the power consumption is integrated into the heater power supply.

The outer most surface of HTV-R will be covered by low radiation material such as MLI to reduce heater power requirements in orbit.

(2) Components in PLC

The internal volume of HTV-R will be one third of the HTV and power consumption of environmental control components such as fan and illumination should decrease, but some components have to be added as a part of the active thermal control system. So, the power consumption by components in PLC maintain the same value of the HTV.

(3) Heater in UPLC (Un-pressurized Logistic Carrier)

The HTV-R service module has almost a half volume of the HTV UPLC and should consume a half power of HTV.

(4) Components in UPLC

HTV has many mechanisms to fix and release the exposed pallet and cargos. HTV-R will be equipped with similar mechanisms but the exposed pallet is not required to bind cargos and the number of them is reduced compared to HTV.

(5) Heater in Avionics Module

All of the avionics are installed into the pressurized section and require no heater to maintain their temperature. HTV used passive radiation to remove the heat from components and required heaters in the cold environment, but HTV-R uses an active cooling system to control the temperature and requires no heater even in such an extremely cold environment.

(6) Components in Avionics Module

The avionics design has improved compared to the 1990's when HTV was designed. The size, weight, and power consumption of components in HTV-R are estimated to be less than a half of HTV.

(7) Heater in Propulsion Module

Heater power consumption in the Propulsion Module is

divided into the heater for thrusters and the heater for propellant lines and storage. Because HTV-R and HTV have a similar number of thrusters, they will consume a similar amount of power, but the installation volume of HTV-R propulsion system is drastically reduced compared to HTV. So, the total heater power in HTV-R is roughly estimated to be half of HTV.

(8) Components in Propulsion Module

The number of components in HTV-R and HTV propulsion are nearly the same. Necessary power for each propulsion component has not been considerably reduced from 15 years ago since they consume the power for magnetic movement. So, the power consumption in HTV-R Propulsion Module is estimated as the same value of HTV's.

4.3 Radiator Requirements

HTV-R needs radiators to discharge the heat generated by components in the Avionics Module and Pressurized Logistic Carrier by transforming electrical power. In addition, heat from the human body has to be taken into account to determine the potential of the radiation system with consideration the future expansion toward it's use as a human spaceship.

The heat from a human body was calculated as follows.

(1) Heat from Crew

132W per a human is used as the reference value to design air conditioners. Four crew has been counted as the maximum number for a spaceship equivalent to the HTV-R. So, a total of 528W is used as the heat from crew.

(2) Heat from Components

All of the electrical power consumed by the components in the pressurized section such as thermal control, illumination, and air circulation shall be removed from the vehicle as heat by radiation. But, the electrical power consumed in the Propulsion Module and UPLC move to the surface of the un-pressurized body as heat and radiate independently from the active thermal radiation system.

The necessary value to be taken into account as the requirement to the thermal radiation system is the summed value of the component in PLC (153.5W in table 1), the avionics (396.4W in table 1), and the heat from crew (528W in (1)).

(3) Radiator Design

1,078.4W is estimated as the total heat to be discharged by the radiation system as a result of (2). The necessary surface area for radiation is affected by solar absorptance, albedo/infrared radiation from the Earth, and reflection/radiation from the other part of the vehicle. The most suitable location of the radiator is the zenith side of body as shown in figure 13. The effect from the Earth and other parts of the vehicle can be mitigated in the location because the radiator panels do not face to them.

Under this assumption, 250W to 330W/m^2 can be used as the averaged value of the radiator performance even though it relates to the fluid temperature. 1,078W can be radiated to space by 3 to 4m^2 and the configuration shown in figure 13 (it has 6m^2 as total) has enough margin.

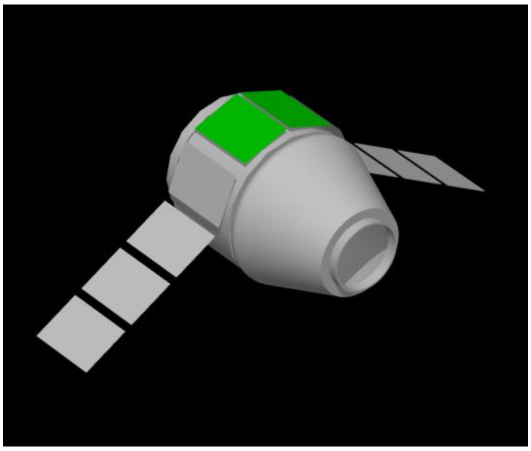

Fig. 13. Radiator Layout (Shown as Green Area)

4.4 Propulsion System

(1) Schematic and Layout

HTV-R new concept needs to equip all thrusters in the Re-entry module. Thrusters are divided into two strings and four blocks to enhance redundancies from the original HTV as shown in fig.14. Thrusters are located at the proper position and direction on the body (shown in fig. 15) and they do not spoil all functions for attitude and de-orbit control even thought the worst two failures have occurred in any thruster blocks.

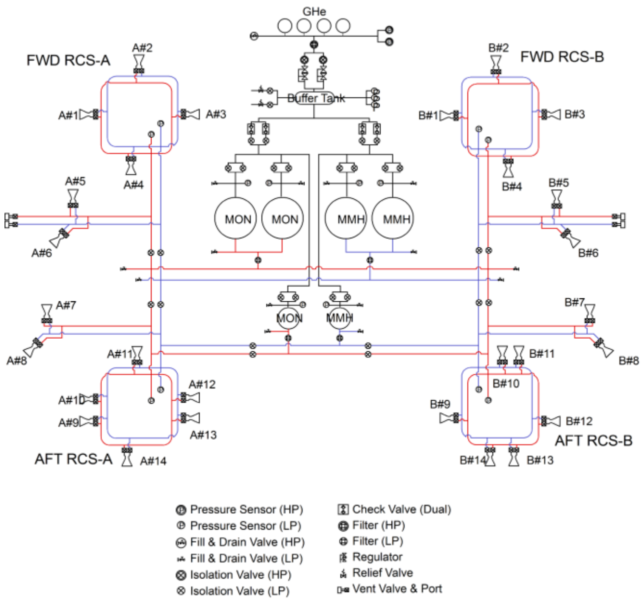

Fig. 14. Propulsion System Schematic Diagram

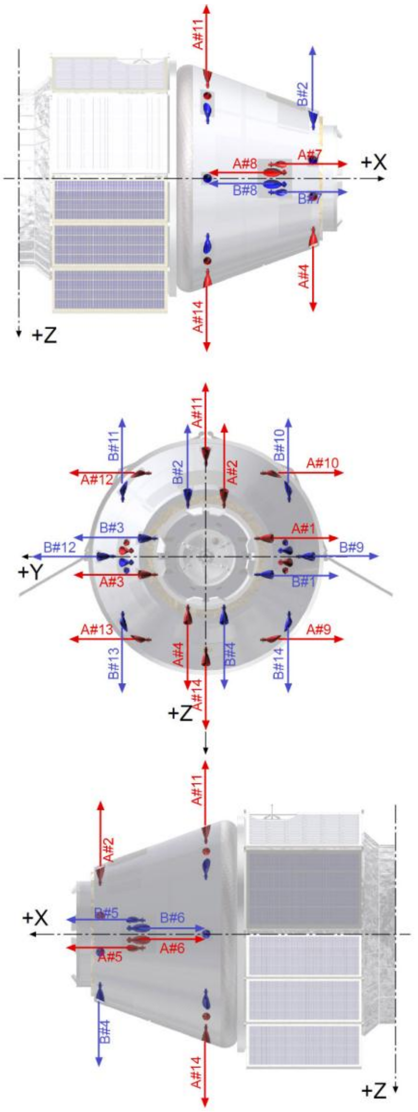

Fig. 15. Thruster Assignment

(2) I/F with GN&C Subsystem

Figure 16 shows the interface between propulsion and GN&C subsystem. It has four driver blocks and the HTV-R uses a combination of them. The original HTV has an abort string in addition to the main/backup string, but HTV-R can enhance it's survivability by dividing the system into four and isolating failed block(s).

The design also enables the use of the same configuration in all four strings and relieves the task of verification. Thruster #5 to #8 are used for de-orbiting and have electrical redundancies by cross strapping from two drivers. The configuration enables it to conduct emergency de-orbit maneuvers under the worst two failure scenarios and will be one of the important factors as a human spaceship in future.

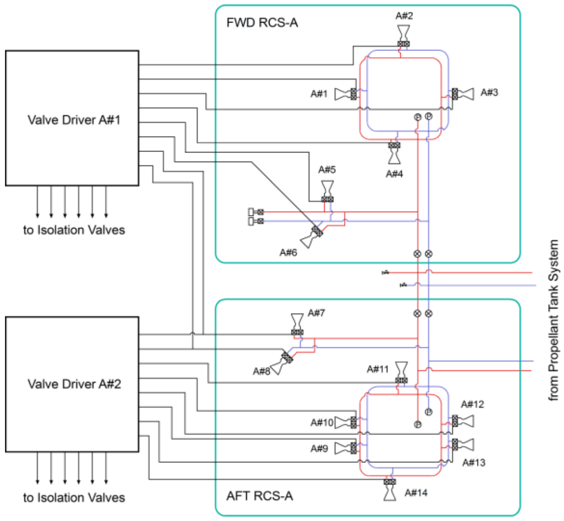

Fig. 16. Valve Driver System (same as in RCS-B)

(3) Failure Control

i) Nominal

Table 2 shows one of the thruster assignments in nominal use. Because the new HTV-R concept has thrusters around the center of mass, only thrusters #9 to #14 take control of the position in stead of original HTV controlled by two thruster combinations.

Table 2. Thruster Assignment (Nominal, same in RCS-B)

		RCS-A													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
ϕ	+										○			○	
	-									○			○		
θ	+				○							○			
	-		○												○
ϕ	+	○											○	○	
	-			○						○	○				
X	+						○		○						
	-					○		○							
Y	+	○								○	○				
	-			○									○	○	
Z	+		○									○			
	-				○										○

ii) 1 Failure Case

Both RCS-A and RCS-B can take control for all operations by independently and one of them can be shut down when a failure occurs in the string. In addition to stop a string, the new HTV-R concept can use the combination of thruster #1 - #6 and #7 - #14 in the different string as shown in table 3.

Table 3. Thruster Assignment (1 Failure Case, sample)

		RCS-A						RCS-B							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
ϕ	+											○			○
	-										○			○	
θ	+				○						○	○			
	-		○											○	○
ψ	+	○											○		
	-			○						○					
X	+						○		○						
	-					○		○							
Y	+	○								○					
	-			○									○		
Z	+		○								○	○			
	-				○									○	○

iii) 2 Failure Case

Enhanced survivability is one of the major purposes of re-designing the propulsion system. The original HTV were required to conduct an operation for safing only but the new HTV-R concept is planned to enhance the operability and to enable it to continue flight in addition to safing. Many cases of failure should be considered to cover the all possibilities, and one of 2 failure cases is shown in table 4.

As shown in the table, all attitude control functions and X axis control are kept as nominal and HTV-R can conduct the proper re-entry maneuver for survival to Earth.

Table 4. Thruster Assignment (2 Failure Case, sample)

		RCS-B													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
ϕ	+											○			○
	-										○			○	
θ	+				○						○	○			
	-		○											○	○
ψ	+	○											○		
	-			○						○					
X	+						○		○						
	-					○		○							
Y	+	○								○					
	-			○									○		
Z	+		○								○	○			
	-				○									○	○

iv) 3 Failure Case

This concept makes it possible to survive after 3 failures that have killed three out of four thruster blocks. Every thruster is carefully assigned so as not to lose basic controllability for 3 axis control plus one direction moving. It will enable re-entry maneuvering and the vehicle might survive to Earth despite the degraded performance. Further investigations are required to show coverage and feasibility. Table 5 shows a case of 3 failures in which only an aft block, and table 6 shows it in which only a forward is working.

Table 5. Thruster Assignment (A FWD+A AFT + B FWD Failure Case)

		RCS-B													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
ϕ	+											○			○
	-										○			○	
θ	+										○	○			
	-													○	○
ψ	+												○		
	-									○					
X	+								○						
	-							○							
Y	+									○					
	-												○		
Z	+										○	○			
	-													○	○

Table 6. Thruster Assignment (A FWD+A AFT + B AFT Failure)

		RCS-B													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
ϕ	+		○		○										
	-	○		○											
θ	+				○										
	-		○												
ψ	+	○													
	-			○											
X	+						○		○						
	-					○		○							
Y	+	○													
	-			○											
Z	+		○												
	-				○										

(4) Installation

The installation plan of the propulsion system is shown in fig.17. Since the HTV-R is a re-entry vehicle, it should be designed to have the center of mass as low as possible. Propellant tanks are not heavy after most of the propellant is depleted on-orbit, so, they are installed at the top of the vehicle. Parachutes and floating bags will be installed in the same circumference as the tanks and the pressurized section has about 3.5m diameter at the it's maximum point.

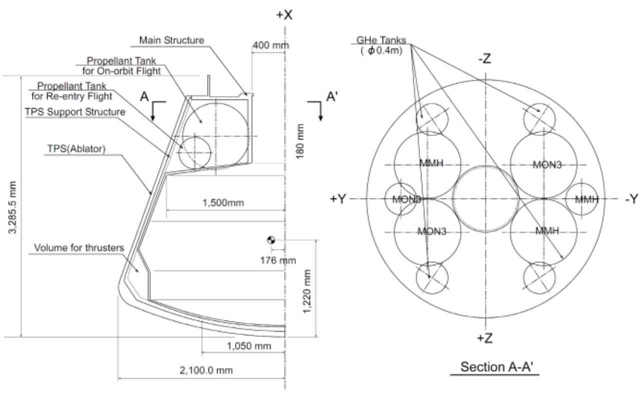

Fig. 17. Propulsion System Installation

4.5 Aerodynamic shape

Re-entry module of the alternative HTV-R has the same aerodynamic shape as the former HTV-R shown in Fig.18. Any critical problems have not been identified in the current HRV

shape through wind tunnel tests and computer coded simulations. The size was determined giving consideration to the installation onto the original HTV in the former HTV-R plan, but the weight is also suitable for launch by an H-IIA in the alternative HTV-R plan. So, the 4.2 m diameter has been kept as a reasonable size for the limited weight, which would also be reasonable for the structure.

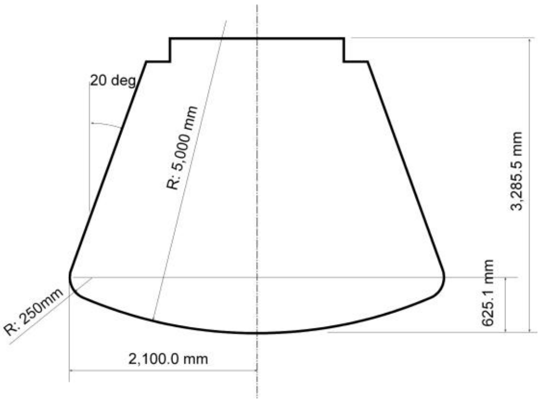

Fig. 18. HRV aerodynamic shape

4.6 Thermal Protection

When the HRV returns from LEO, it does not need a mighty thermal protection system like the Hayabusa capsule due to its relatively low re-entry speed and thermal environment. However, the HRV needs a much larger surface to be thermally protected than other capsules in past JAXA missions, hence the much greater need for lightweight (low density) material than others, the development of which will be included in that of the HTV-R development especially in the alternative plan.

4.7 Avionics

The HRV avionics should have sufficient redundancies, while it is also preferable to allow for future enhancements for the manned vehicle. Figure 19 shows a sample schematic of the avionics in the HRV. The adopter section in fig 19 is replaced by the service module in the alternative HTV-R plan and every components will be updated but the redundancy in functions to manage failures occurring in itself will be the same as the former plan. In both cases, to enhance the system toward the manned vehicle level, emergency components will be installed into the schematic to satisfy safety requirements after any two failures occur.

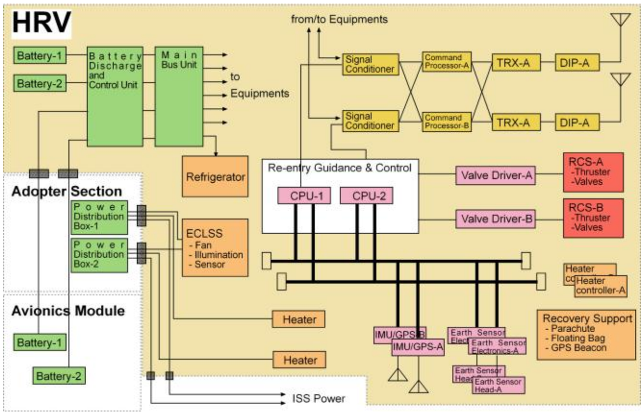

Fig. 19. Avionics system (example)

4.8 ECLSS

Basically the same ECLSS (Environmental Control and Life Support System) such as air circulation, illumination, etc.) as the HTV is planned as shown in Fig.20. HRV has a much smaller IVA volume than the original HTVs pressurized section and can be simplified.

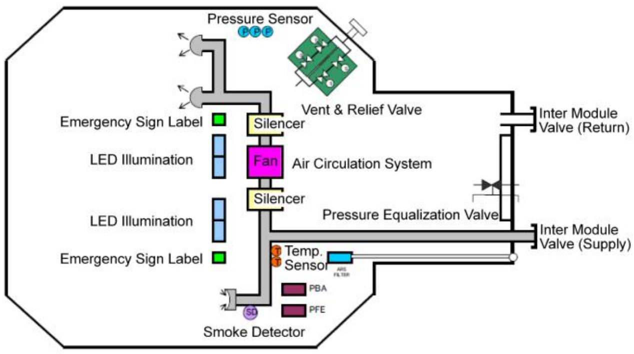

Fig. 20. ECLSS in HRV pressurized section

4.9 Active Cooling System

HTV does not need any active radiation system and uses only passive radiation. However, in both of the former and the alternative plan, the HRV surface is covered with thermal protection materials and some form of active thermal radiation system will be required to radiate all the heat. It will be used for all avionics boxes and refrigerators for cargo service in the HRV.

4.10 Recovery System

At the end of re-entry flight, the HRV deploys parachutes to decrease the velocity and splash down softly. A combination of two or three main parachutes and a redundant pilot chute is the baseline, and these are ejected by mortars, as in the case of other re-entry vehicles.

HRV is not expected to be recovered on the ground in any case, eliminating the need for contingency landing equipment. It may be a mandatory system in a manned vehicle for contingency escape at the launch pad and the need for an air bag system will be studied again in the manned vehicle development in future.

5. Conclusion

JAXA continues investigations and tradeoff studies of these HTV-R plans. A detailed development plan is necessary before starting the program in order to estimate the total budget to complete it and to determine which way JAXA should proceed.

The starting time and the first fight target date will not be made public any time soon but once JAXA has started the HTV-R development, it will be a solid step towards the development of the future manned spaceships. The first HTV-R flight and HRV re-entry will represent a major milestone in Japanese human space activities.

References

1) Suzuki, Y., Imada, I.: Concept and Technology of HTV-R: An Advanced Type of H-II Transfer Vehicle, ists28 (2011),
2) Imada, I.: Manned Spacecraft Development Plan from HTV Technical Heritage, ists27 (2009), 2009-g-02.