How the HTV Cargo Vehicle Is Fully Stuffed–Cargo Loading Capability Enhancement and Related Issues

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The H-II Transfer Vehicle (HTV) is Japan's first cargo transfer spacecraft to deliver supplies to the International Space Station (ISS), and its maiden flight (HTV-1) was successfully completed on November 2, 2009. After HTV-1 design completion, enhancement of cargo carrying capability was required for HTV-2 and subsequent flights. A major update was introduced to obtain additional cargo loading volume in its pressurized section. In this paper, details of the design modification process are described, which include relocation of the cabin air ventilation system and general illumination devices, elimination of support structures, and modification of cargo loading shelves. Associated considerations with design modifications are also discussed, such as the completely different pattern of ventilating air flow and major changes in visual cues for module local orientation.

Nomenclature

AFT	=	*After*
AM	=	*Avionics Module*
ASI	=	*Italian Space Agency*
CG	=	*Center of Gravity*
COF	=	*Columbus Orbiting Facility*
CTB	=	*Cargo Transfer Bag*
CTBE	=	*Cargo Transfer Bag Equivalent: approximately 0.053 m3*
ELM-PS	=	*Experiment Logistic Module-Pressurized Section*
ESA	=	*European Space Agency*
FWD	=	*Forward*
GLA	=	*General Luminair Assembly*
GPS	=	*Global Positioning System*
HRR	=	*HTV Resupply Racks*
HTV	=	*H-II Transfer Vehicle*
ISPR	=	*International Standard Payload Rack*
ISS	=	*International Space Station*
JAXA	=	*Japan Aerospace Exploration Agency*
JEM	=	*Japanese Experiment Module*
JST	=	*Japan Standard Time*
LAB	=	*Laboratory module*
MPLM	=	*Mini Pressurized Logistic Module*
NASA	=	*National Aeronautics and Space Administration*
OSE	=	*On-orbit Support Equipment*
PBA	=	*Portable Breathing Apparatus*
PFE	=	*Portable Fire Extinguisher*
PLC	=	*Pressurized Logistics Carrier*

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PM	=	*JEM Pressurized Module, HTV Propulsion Module*
PMM	=	*Permanent Multi-purpose Module*
PSL	=	*Permanent Solid-state Light*
SSRMS	=	*Space Station Remote Manipulator System*
TNSC	=	*Tanegashima Space Center*
ULC	=	*Unpressurized Logistic Carrier*
VFU	=	*Ventilation Fan Unit*

I. Introduction

THE HTV is a Japanese unmanned spacecraft and a member of the logistics fleet to the ISS. Its 53 days of maiden flight were perfectly completed on November 2, 2009.

A. HTV Mission Profile

The HTV is launched by the H-IIB launch vehicle from TNSC of JAXA. The H-IIB is the latest member of the H-II launch vehicle family and was upgraded specifically to launch the HTV. Fig. 1 shows liftoff of the H-IIB TF#1, maiden flight for both H-IIB and HTV, from JAXA's Tanegashima Space Center at 2:01am(JST) in September 2009. After separation from the H-IIB, the HTV flies with its guidance and navigation system, supported by the GPS, toward the ISS and then locates its position of 10 meters from the ISS with almost no relative motion. The SSRMS, or robotics arm, then captures the HTV and berths it to the nadir side of the ISS Node 2 module(Fig. 2). Fig.

Figure 1. Lift off of HTV-1/H-IIB TF#1.

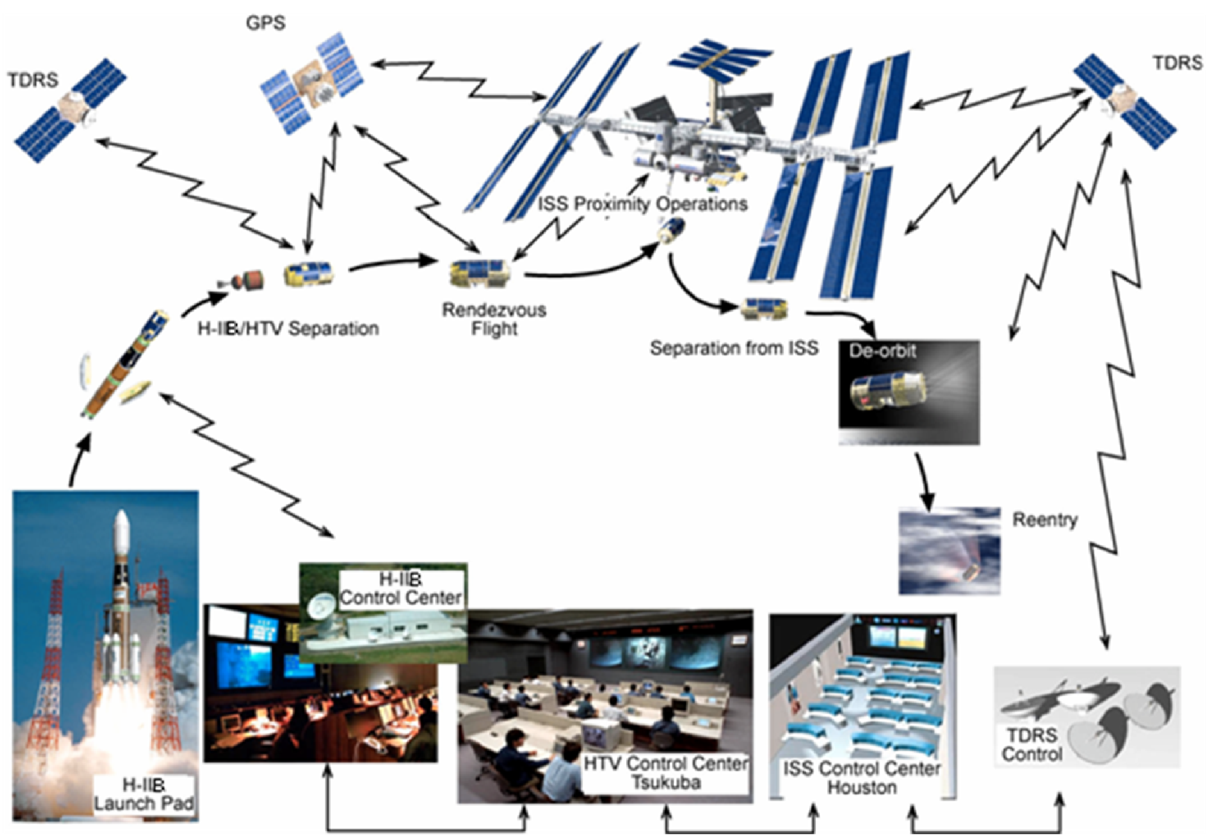


Figure 2. Mission profile of HTV

3 shows HTV-1 (maiden flight) is in final approach to the ISS. Berthing to the ISS is completed in 19:26pm(JST) September 17, 2009. After being berthed, the PLC portion of the HTV becomes a continuation of the ISS habitable cabin. ISS crew members transfer logistics supplies out of the HTV PLC and stow trash in their places. The HTV departs from the ISS and performs its destructive re-entry.

Figure 3. HTV-1 approaching to ISS.

B. Outline of the HTV

The HTV consists of five major parts: the PLC, ULC, AM, PM, and EP, which carries exposed cargo and is stowed in the ULC. Fig. 4 shows construction of the HTV. The HTV is approx. 10 meters long and approx. 4.4 meters in diameter. It carries 6 metric tons of cargo in total, i.e., 4.5 tons of cargo stowed in the PLC (namely pressurized cargo, although it is not necessarily "pressurized") and 1.5 tons on EP (namely unpressurized cargo). Table 1. compares cargo carrying capability of ISS logistic fleet, and shows the features of HTV;

1) Carrying unpressurized cargo.
2) ISPR(described later) transfer with large hatch opening
3) Flexibly carrying water as pressurized cargo, instead of using fixed tank system

The PLC carries pressurized cargo and is capable of ISS crew habitation while berthed to the ISS. The PLC primary structure design is borrowed from one of the Japanese ISS modules, the JEM ELM-PS, with modifications to the primary external load path and panel at the end of the cylinder section aiming to reduce mass and manufacturing cost, i.e. the cone and flat plate for the JEM ELM PS versus the dome structure of the HTV PLC. Fig. 5 depicts the primary structure of the HTV PLC end section where spherical surface of the pressure dome structure covers full of radius of the PLC end section. A hole in center of the dome is for tool fixture and technician's access while manufacturing. The PLC is equipped with a cabin air ventilation fan and associated ducting, smoke detector for he fire alarm, general illumination devices, and a standoff frame structure supporting cabin air ducts and illumination devices. It also provides base points for the pivot bracket for removal/installation of the ISPR, a typical pressurized cargo. Fig.6 shows an example of ISPR installation operation, in which Japanese astronaut Aki Hoshide installs the JEM robotics console rack in place of JEM PM. The bottom portion of this rack is supported by pivots

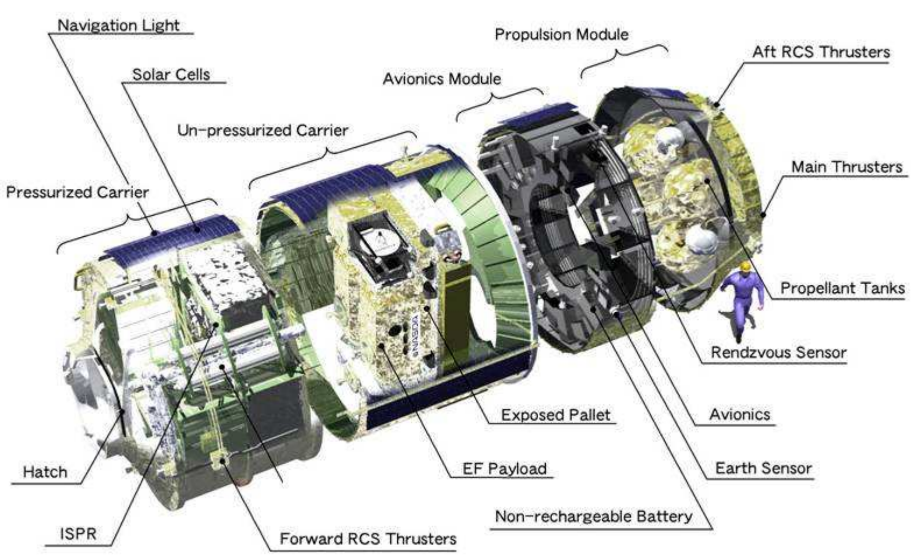


Figure 4. Construction of HTV.

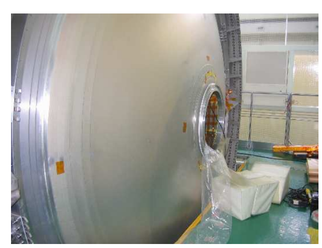
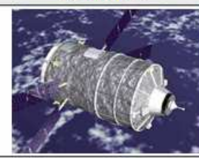


Figure 5. Primary structure of HTV PLC end section (End dome structure).

Table 1. Capability of ISS Logistic Fleet

	HTV (Japan)	ATV (Europe)	Progress (Russia)
			
Launch Vehicle	H-IIB	Arian5-ES	Soyuz-U
Length	10.0 m	10.3 m	7.23 m
Launch Weight	16.5 ton	20.7 ton	7.27 ton
Cargo (total)	6 ton	7.67 ton	2.75 ton
Pressurized Cargo	4.5 ton (max 6 ton) Water: max 2.9 ton (part of press. cargo)	max 5.5 ton Water: 840 kg	2.75 ton Water: 300 kg
Unpressurised Cargo	max 1.5 ton	Not capable	Not capable
Re-fuel/ Re-boost	Not capable	max 4.7 ton/Capable	max 1.7 ton/Capable
Hatch Opening	1.27 X 1.27 m	Φ 0.8 m	Φ 0.8 m

To accommodate cargo, the PLC provides HRRs. The HRR launched in HTV-1 is called Type 2, and is capable of stowing 26 CTBE volume of pressurized cargo. HRR Type 2 consists of metal (Aluminum) rigid box shelf structure and front panel with cargo fence With the front panel loading, HRR Type 2 carries additional 8 CTBEs than HRR type 1(Fig. 7). All of cargos are tied down to either shelf or front panel by straps. The attachment mechanism of the HRR to the PLC is compatible with the ISPR allowing the PLC to carry a combination of eight HRRs/ISPRs.

Figure 6. Installation of ISPR.

Note that HRR Type 1 was designed but not manufactured because of less cargo loading capability. The Type 2 was previously upgraded from Type 1 by adding cargo fence and strap on front panel to accept additional 8CTBEs of cargo.

The majority of pressurized cargo is packed into standard fabric bags, i.e. CTB and M-size bags, both in various sizes, which are then stowed in and on the HRRs. Table 2 shows the various types of CTBs.

II. Configuration Assessment for Additional Cargo Volume Accommodation

It was 2007 when HTV-1 PLC design had almost been completed, after years of discussion, JAXA and NASA management agreed that pressurized cargo is not as dense as assumed in the HTV-1 design baseline, and decided to enhance the PLC cargo volume accommodation capability for HTV-2 and subsequent flights to fully utilize the total cargo carrying capability of 6 toms. To break up the bottle neck in volume rather than weight, the derived requirement was to increase the PLC cargo volume accommodation capability from 208 CTBEs to 254 CTBEs. In other words, 27.8 percent of the HTV-1 PLC's internal volume was cargo (11.0 m^3 vs. 39.6 m^3), and 34.0 percent is newly required for HTV-2 and subsequent flights.

Considering project constraints, a concept study attempted to gain additional capabilities for HTV-2 to be launched in winter season of 2010/2011. Assessments assumed minimal design modification, especially to the primary structure, i.e., the pressure shell and HRR, to avoid a series of re-certification tests. Observing internal volume of HTV-1 PLC, it appeared that only 27.8 percent is occupied by cargo, however the remaining is fragmented in pieces or already occupied by system items such as ventilation fan/duct and secondary structures as shown in Fig. 8, and candidate locations are identified in:

- Vestibule
- FWD end cone section
- Cabin aisle
- Standoff areas (four corner areas surrounded by two neighboring racks)
- AFT end dome area

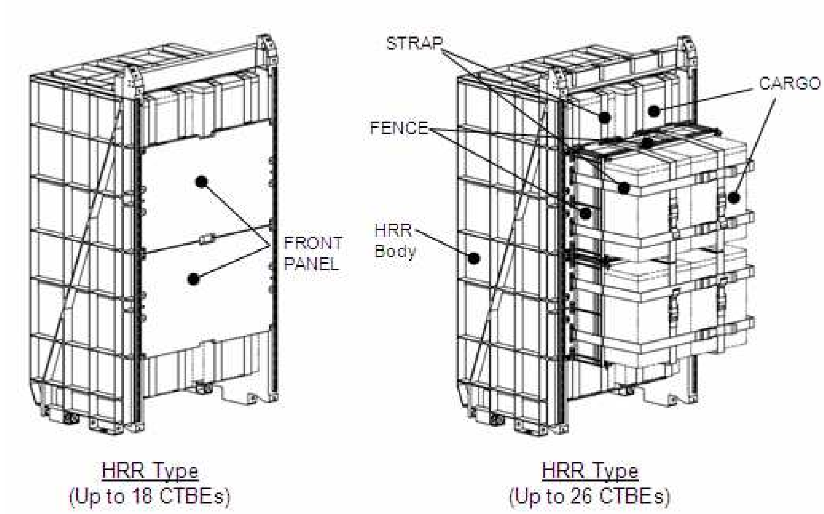
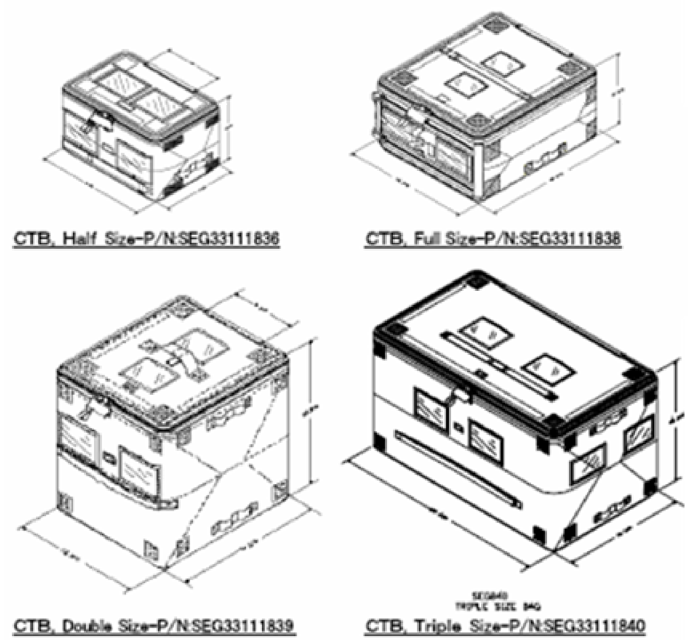


Figure 7. HRR Type1 and Type2.

Table 2. Standard cargo bags. .



Item	P/N	External Dimensions [mm](LxWxH)	Maximum Load [kg]
Half Size	SEG33111836	235x426x248	13.62
Full Size	SEG33111838	248x426x502	27.24
Double Size	SEG33111839	502x426x502	54.48
Triple Size	SEG33111840	502x426x749	81.72

A. AFT End Dome Area

The first idea is to add cargo accommodation structures at the AFT end dome area. Cargo volume analysis resulted in eighteen additional CTBEs as shown in Fig. 9. Although this area includes large vacant volume, supplemental structure is required to support launch load in X direction (axial direction of cylindrical pressure shell) that leads to less effectiveness in mass. Very limited cargo mass is allowed with the practical mass of the cargo support structure and thus was not adopted. One assessment shows approximately 160 kg of additional cargo support structure can carry 130 kg for launch loads that is less than 30 percent of the CTB maximum allowable mass of 18 CTBEs. The main reason of inefficiency is that there is very limited space in the dome to support cargo loads, mainly in the X direction and only at the center of the dome: Even with this limited area for "hard points," the dome structure is optimized to the internal pressure load and has a lower margin of safety to accept an additional cargo load.

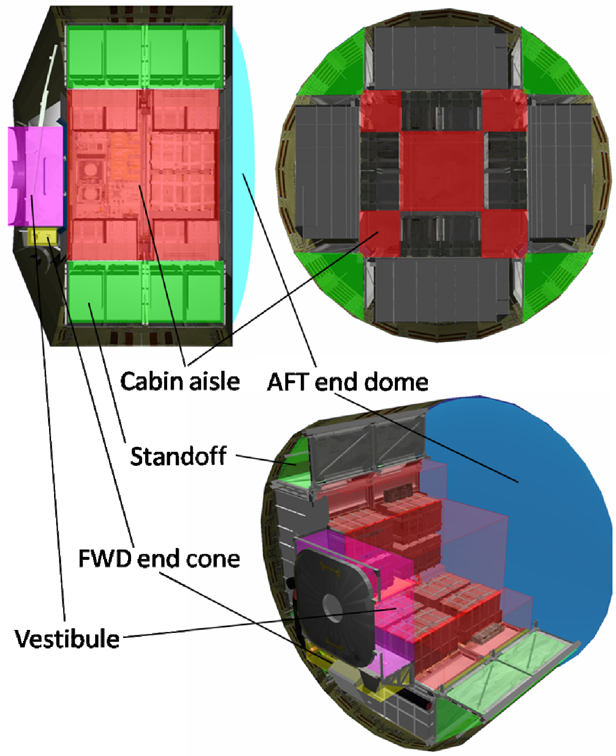


Figure 8. Vacant volume in HTV-1 PLC.

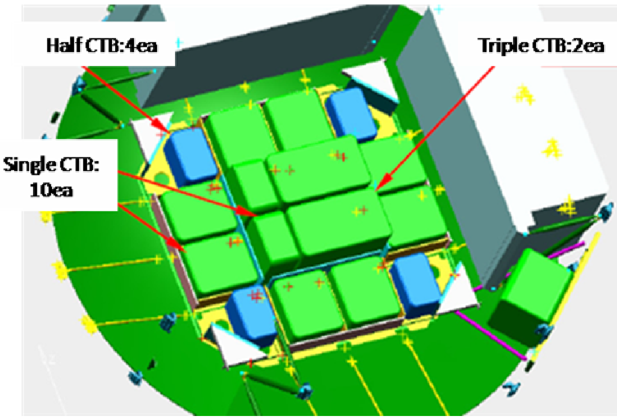


Figure 9. Cargo layout analysis in AFT end dome area.

Fig. 10 shows the similar cases of loading cargo in the other modules, such as the JEM ELM-PS and ASI's MPLM, (a)AFT end cone stowage found in MPLM, and (b) in JEM ELM-PS. Note that the stowage structures are attached to the hard point for attaching cargo support structures that is at intermediate of radius of end section unlike HTV PLC. The JEM ELM-PS carried eight of cargo bags on the end cone whereas the MPLM carries 12 CTBs.

B. Standoff Areas

Utility lines run through this area of the ISS modules, such as electric power, communication lines, cabin air ventilation ducts, avionics cooling water, and vacuum access. There are standoff frame structures in this area to support those lines and the frames provide attach points for cabin illumination devices and pivot brackets for ISPR removal/installation. The HTV-1 PLC introduced an identical design concept to maintain the commonality of interior architecture with other modules, but its standoff frames only support cabin air ventilation ducts, illumination

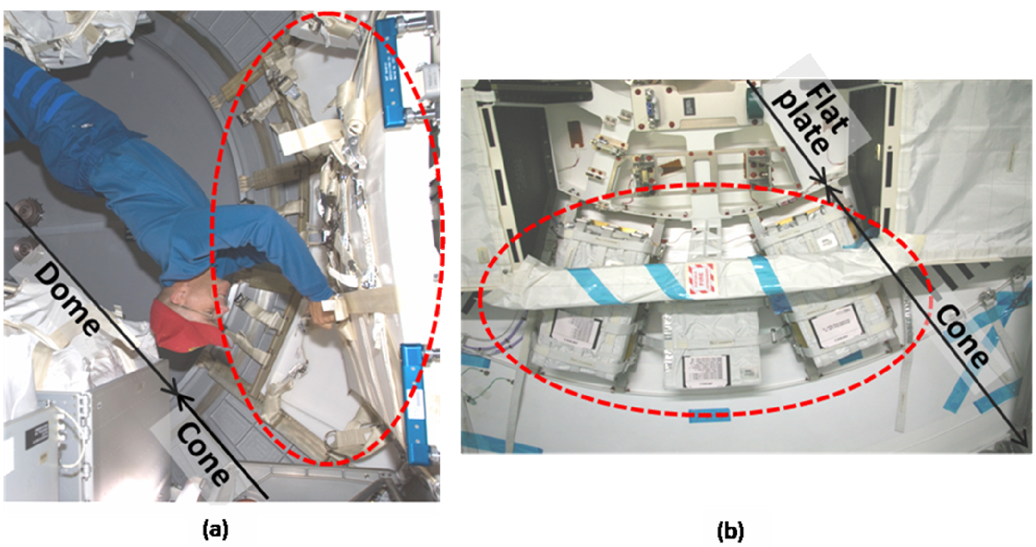


Figure 10. AFT end cone stowage in (a) MPLM and (b) JEM ELM-PS.

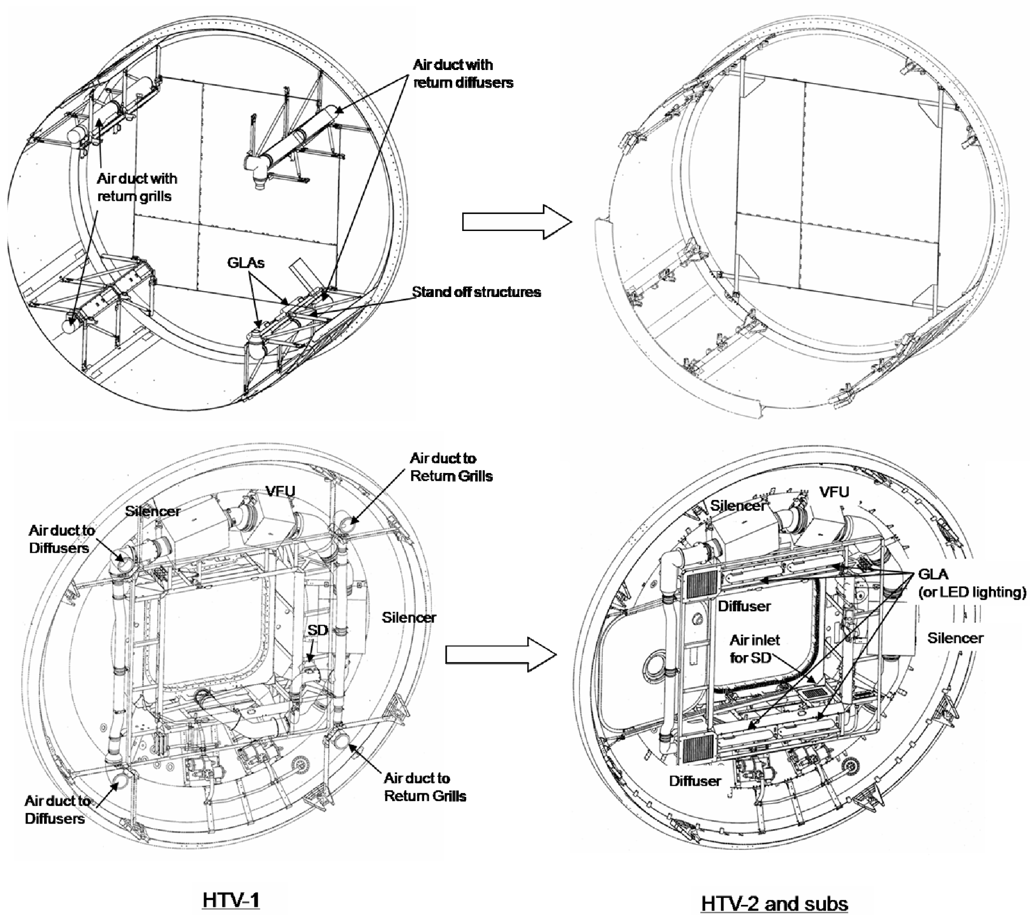


Figure 11. Removal/relocation of items from stand off area.

devices, and pivot brackets.

To utilize these areas, hardware needs to be removed and/or relocated, and physical access needs to be secured to avoid blockage by HRRs, which are not designed to be removed on orbit. Fig. 11 illustrates the removal/relocation concept. The standoff frame structure is eliminated, cabin air ducts and air inlets (return grills) in this area are removed, and cabin air diffusers and illumination devices are relocated around the FWD end cone section at the surrounding module hatch opening. The bottom plate of the HRR is modified to be retractable for ensuring access to this area as shown in Fig. 12. Even with this modification of the HRR, there remains one standoff area surrounded by the top portions of the HRRs that is not accessible. If modified to make two of the eight rack attachments upside down, all four standoff areas are accessible. This, however, requires modification of the primary structure of the PLC and introduces complications in cargo installation operation on ground.

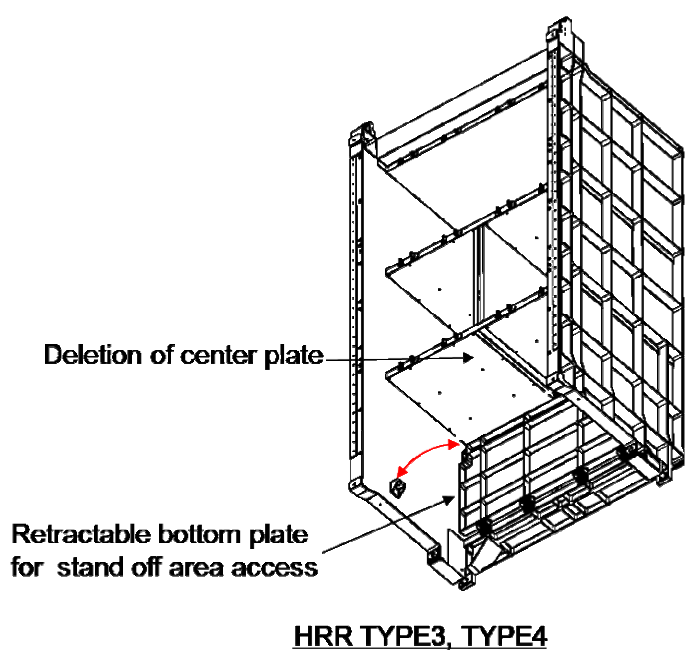


Figure 12. Retractable bottom plate of HRR and cargo access to stand off area.

Taking account the benefit of mass reduction by removal of items from stand off area, additional cargo stow in this area is considered as one of feasible candidate locations.

C. Cabin Aisle

The biggest concern when loading additional cargo on the front panel is the interface load between the HRR and the PLC. Additional mass on the front panel will move the CG further from interface points located on the back side of the HRR, and will make the moment arm longer. To maintain CG location near side of the interface points, cargo mass distribution needs to be controlled.

Instead of modifying the HRR, other concepts are briefly assessed, such as one of the idea sketch from concept study(Fig. 13). In this layout, the cargo accommodation structure is built into the PLC, and looks quite effective from a cargo volume viewpoint. These built-in shelves increase module wise capability up to 264 CTBEs, whereas the HRR and standoff area accept up to 232 CTBEs. Yet, many concerns were identified such as the excessive mass of the structure, complex outfitting process, and ground cargo loading process inside the module, and assessment was terminated in the early phases.

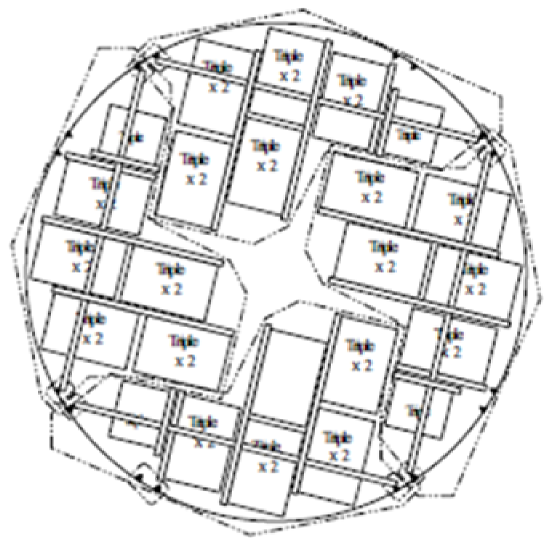


Figure 13. Preliminary idea of cargo layout in cabin.

For ISS permanent habitable modules such as JEM PM, ESA's COF and US LAB, organizing module internal volume, especially in the cabin aisle, is critical not only to contribute to crew comfort and work performance, but also resolve physical/operational conflict of volume and ensure emergency egress pass. Considerable efforts were made to establish and maintain internal volume configuration function and process.1 Nevertheless, because HTV is transporter, her design priority is in carrying more cargo. Also she is considered as visiting vehicle to the ISS, internal volume configuration is not severely controlled for above purpose, however it is obvious that crew can not access to cargo located fur side before removing near ones. Crew is advised not to dig a deep hole when retrieving cargo, as discussed in later section.

D. Other Candidates

Other candidate locations are the vestibule and FWD end cone section. Fig. 14 shows the stowage concept. 3 CTBEs can be located in vestibule area with avoiding interference with the Hatch kinematic envelope that is indicated as violet colored area in the center of the drawing, however they interfere with late cargo stowage access in the PLC when conducted in a vertical position on the ground (briefly discussed in later section and indicated in Fig. 27). PFE and PBA stowage in FWD end cone section that is vacant during launch, is capable of the one Half CTB each in terms of volume. Cargo to be stowed in this area needs to be retrieved immediately after Hatch open to allow stowage of PBA/PFE that are transferred from the ISS for HTV use.

Those areas are considered secondary candidates as long as required increase is achieved by stand off area and cabin aisle.

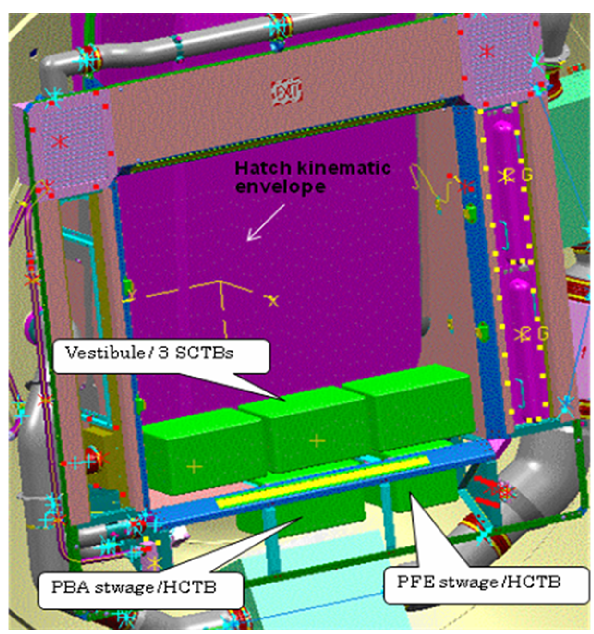


Figure 14. Other candidate locations.

E. Adopted Cargo Loading Configuration

After investigating the pros and cons of the candidates such as mentioned above, the following

configuration has been chosen to achieve the loading of 254 CTBEs.
The front panel of the HRR is modified and upgraded to Type 3 and Type 4. HRR Type 3 carries 28 CTBEs whereas Type 4 carries 34. A remarkable feature on HRR Type 4 is the "double deck" structure on its front panel. The bottom plates of Type 3 and Type 4 are also modified to retract for access to the standoff area stowage. Fig. 15 shows HRR Type 3 and Type 4. In Fig.15, solid red line in left/center indicates additional cargo volume to HRR Type2, whereas right shows relative location of HRRs in PLC with standoff stowage (broken line in black represents the hatch opening).

Allowable CG location is determined as indicated in Fig. 16, so that HRR Type3 and Type 4 can maintain interface load with PLC. Continuous effort gradually enlarged the allowable CG location even after HTV 1 by reflecting lessons learned. Even with mass distribution constraints, the total cargo mass for a HRR is maintained to ensure average cargo mass is heavier than the assumed cargo mass requirement of 254 CTBEs. For modification of the HRR, structure tests for certification updates are not conducted, but the "non test factor" is introduced to the strength analysis according to ISS structure design requirement. The additional mass of HRR Type 3 and Type 4 from Type 2 is shown in Table. 3. HRR Type 4 carries much volume, however averaged density of cargo is less than the others. Modification of HRR was further structure mass effective comparing with adding cargo accommodation structure in the AFT end dome area. Thus additional stowage in AFT dome area is not adopted.

Two new cargo accommodation structures, each can accommodate 3 CTBEs, are introduced in the standoff area to supplement the HRR Type 3 and Type 4 that carry 248 CTBEs in total, i.e. 6 CTBEs. Two of these structures are

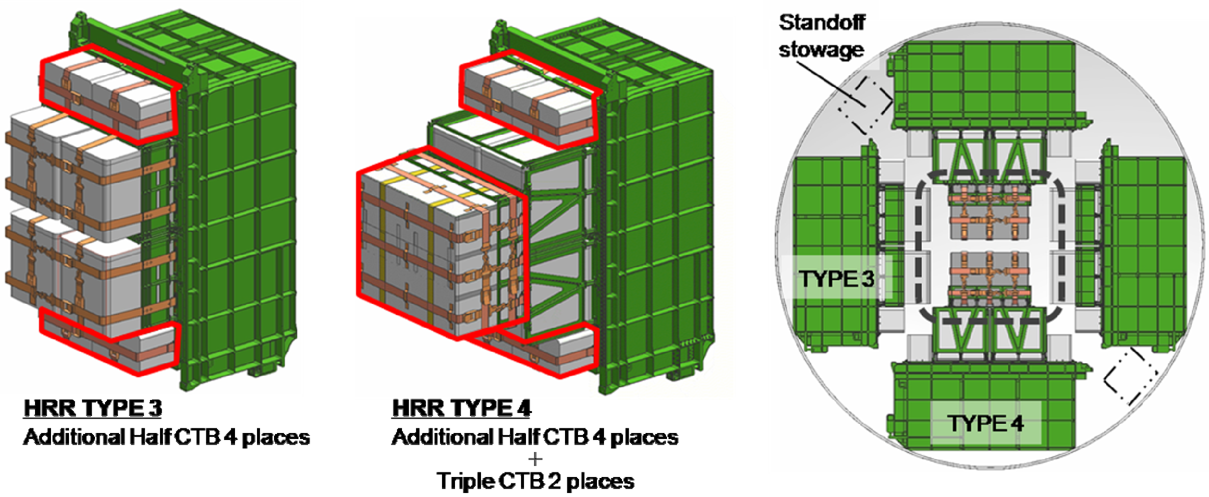


Figure 15. HRR type3 and type4.

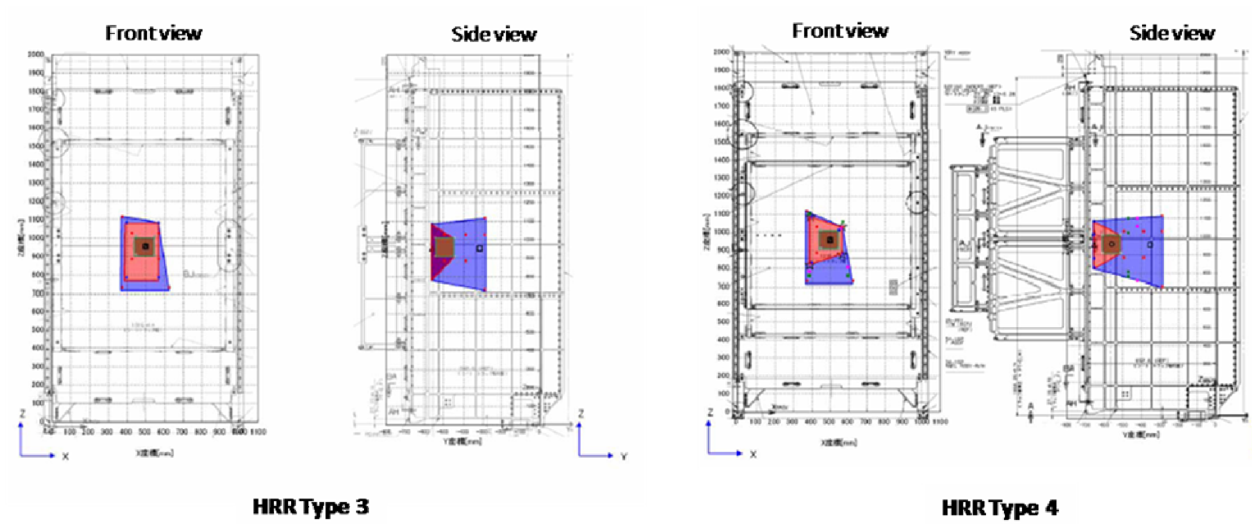


Figure 16. CG constraint for HRR Type 3 and Type 4.

Table 3. Comparison of HRR Mass.

Type of HRR	Rack mass (kg)	Max. cargo capability	
		Mass(kg)	Volume(CTBE)
Type 1	116	297	18
Type 2	134	429	26
Type 3	135.8	462	28
Type 4	153.2	465	34

Figure 17. Cargo accommodation structure in standoff area.

nominally installed for each flight, whereas two more attach points are manufactured for optional purpose. Fig. 17 shows the cargo accommodation structure that is capable of 65.4 kg of cargo loading with 23.8 kg of structure mass. Structure mass efficiency is constrained by asymmetry of the structure to maintain cargo handling corridor, and limit load is compromised down to 80 % of allowable Triple Size CTB. Re-orientation of the HRR, as briefly discussed in the previous section, is not needed because the required number of cargo to be stowed in the standoff areas is small. However, removal/relocation of items, as also discussed previously, is introduced. HTV system hardware, e.g. cabin air duct and stand off frame structure , was removed/relocated accordingly.

III. Engineering Considerations in Adopted Configuration

The adopted configuration has its own unique features, and they are assessed from the view of habitability, usability, and safety.

A. Cabin Air Ventilation

Regarding habitability, change in cabin air ventilation is the biggest concern, i.e. the air flow pattern is completely different in accordance with the relocation of cabin air diffusers and elimination of the cabin air inlet (return grill), because prevention of contaminant accumulation for crew health and fire detection by smoke is relying on it. Cabin air ventilation consists of two parts, that is, intra-module ventilation and inter-module ventilation, which are supported by the VFU in the PLC. In the HTV-1 PLC, similar to JEM ELM-PS, the VFU sucks fresh air from the Node 2 element of the ISS where the HTV berths to, and supplies to the PLC cabin aisle from diffusers located at the corner area of the HRRs. 53.0 % of supplied air goes back to the Node 2 module through hatch opening, and the rest returns to the VFU through the return grill and ducting. On the way back to the VFU, the smoke detector monitors for smoke. In the updated configuration, cabin air diffusers are relocated to the FWD end cone area at the surrounding hatch opening. The return grill is also relocated to the vestibule, and is optimized for fire detection (5 percent of total flow rate) instead of inter-module ventilation purpose.

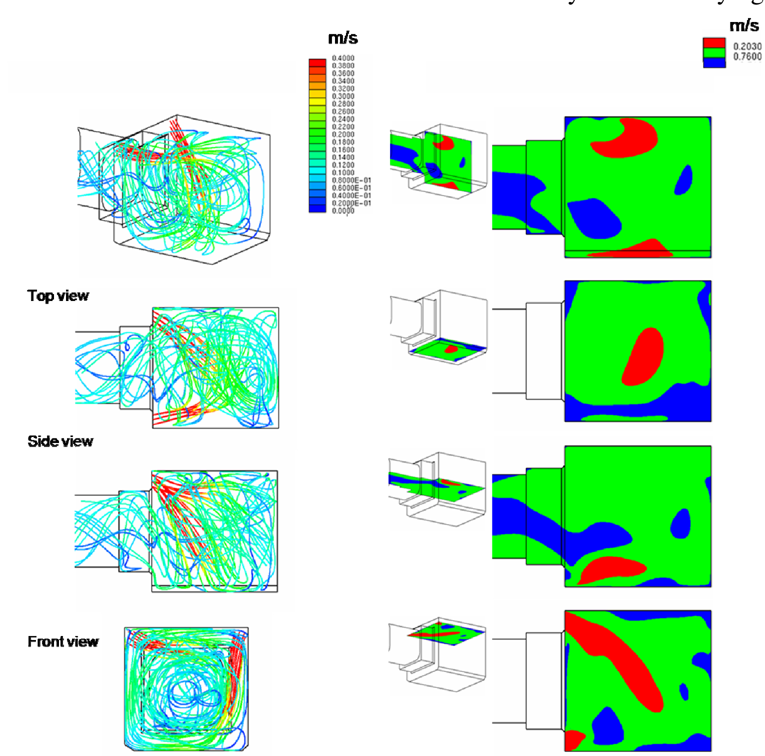


Figure 18. Cabin air flow pattern.

The cabin air flow of updated design agrees with the following ISS common criteria:

1)Air Circulation performance at more

than 0.15m distant from cabin area wall of HTV PLC should be as following.

- Local maximum flow velocity : 1.02 m/sec
- Local minimum flow velocity : 0.035 m/sec

2)The flow velocity should me within following range in more than 2/3 of analyzed volume

- Time averaged flow velocity : 0.076 - 0.203 m/sec

and

3)Assume no bump at rack front surface

In case of front loading cargo, crew members are advised through operation procedures to retrieve front cargo from hatch side where cabin air diffuses are locating and not to dig the “deep hole”, to prevent air stagnation. Several iterations with trimming the air injection direction resulted in a swirling flow pattern[2] which effectively maintains velocity potential and contributes to satisfy the ventilation requirement (Fig. 18).

B. Removal and Installation of the ISPR

The pivots are useful for tilting the ISPR, the biggest piece of pressurized cargo, up and down during installation/removal; however, they will not be available after elimination of the standoff frame structure, which provides the attachment points of the pivot brackets. I made interview with several crew members if they could install/remove an ISPR without the support of the pivots. They all answered that they could. In spite of their answers, a removable standoff frame with pivots has been prepared as OSE considering the difficulties in on-orbit operation especially in installation. Fig. 19 illustrates the standoff frame OSE. Standoff frame OSE provides base point of the pivot bracket, as indicated in violet, to support ISPR tilting. It is disassembled as shown in the right for launch and on-orbit stowage. It is still a question of crew preference whether they should attempt difficult tasks without the OSE or take the additional time needed to assemble the OSE (currently predicted in 40 minutes). There are also no plans to order crews to use the OSE in on-orbit operation procedures.

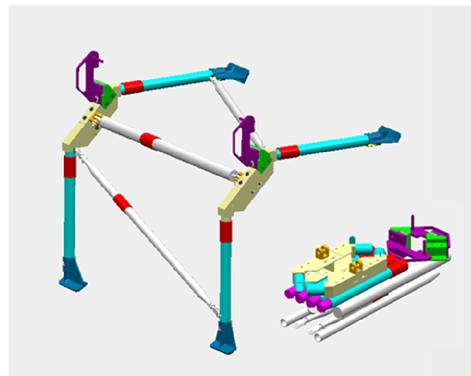


Figure 19.   Standoff frame OSE.

C. Illumination Level

It is fortunate, in a sense of illumination level, that the shape of the cabin aisle is roughly cubical, and the distance between the illumination devices and principal “floor” remained same even after relocation of the lighting. The effects of changing the illumination devices, an issue separate from cargo capability enhancement activities, were analyzed (Fig.20). Illumination level is evaluated 30 in. apart from opposite surface of the illumination devices. Result shows well above the minimum required level of 108 lx. Analysis is assuming flush surface of racks

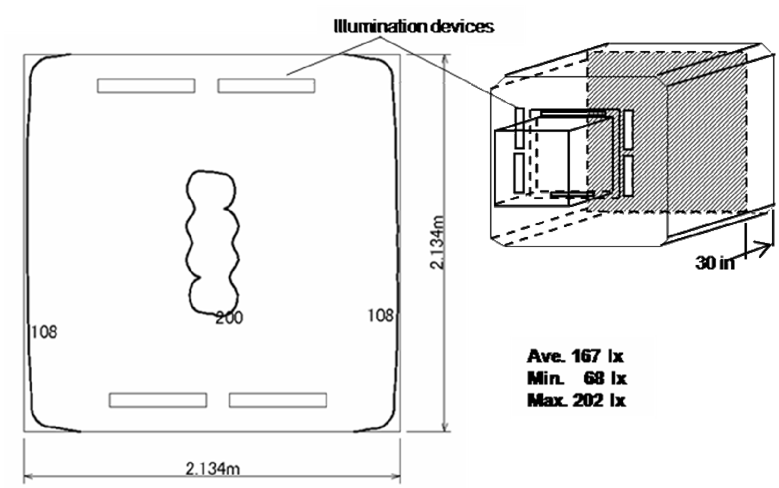


Figure 20.   Analysis result of cabin illumination level.

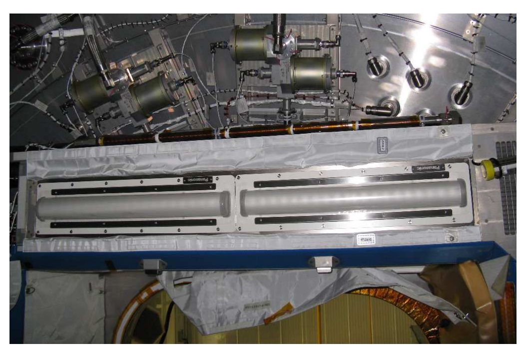


Figure 21. LED lighting (PSL) in HTV-2 PLC.

according to ISS verification requirement just as air ventilation requirement. In case of front loading cargo, crew members are advised through operation procedures to retrieve front cargo from hatch side where illumination devices are locating.

Note that HTV-2 and subsequent flights will be equipped with two of the ISS conventional illumination devices with fluorescent tubes and two of the newly developed lights using LED technology, i.e. GLA and PSL, whereas there were four GLAs on HTV-1. PSL is designed to be interchangeable with GLA. Fig.21 shows PSL outfitted in HTV-2. Hatch opening is also pictured at the bottom.

D. Accessibility

Accessibility to the standoff cargo and standoff frame OSE was checked by 3D CAD and by using physical mock up, because it needs to be installed/removed through the gap in between the adjacent racks are in place. There are indications of limited clearance of both physical and visual access, but no interference is observed.

Regarding access to the "second floor" of the HRR Type 4 front panel after the cabin aisle is mostly filled with cargo, the second floor of HRR Type 4 is accessible only from the side facing to Hatch opening, as shown in Fig. 22. The front panel of HRR Type 4 is designed to be attached to the rack's main body facing cargo accessing end to both *left* and right side of the HRR without modification.

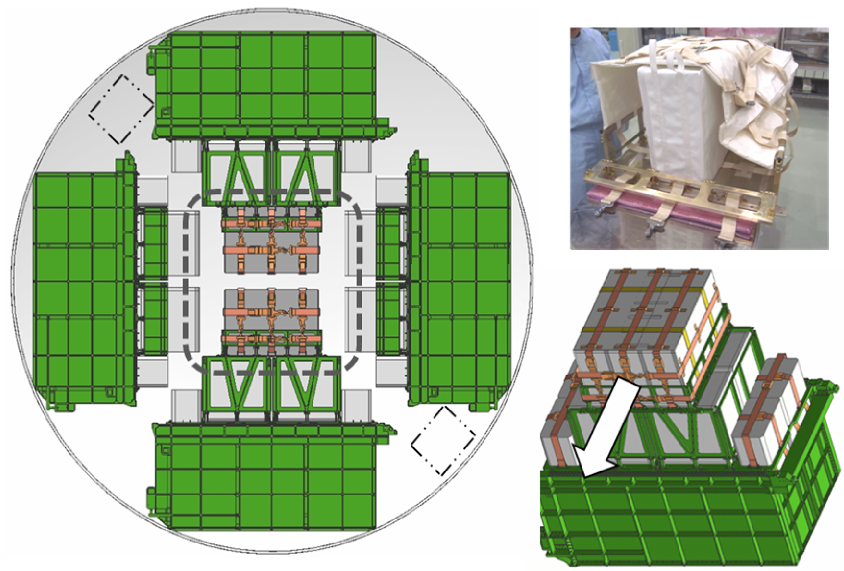


Figure 22. Access direction to the second floor of HRR type4 front panel.

E. Local Orientation

In the on-orbit weightless environment, gravitational cues such as gravireceptor information, does not help crew maintaining spatial orientation any more, and vision plays much more critical roles[3]. In particular, lighting drives human sense of physical status, e.g. time and location, and is very important in helping crew to locate him/herself in the module interior[4]. ISS modules are designed to provide illumination devices at the two corner areas of the racks to keep the local vertical common and relative to the module axes as shown in Fig. 23. Direction of characters/symbols used in labels/decals are aligned to local vertical and blue paint on bottom corner panels are also signs of "floor" to support lighting cue. By relocating the illumination devices from the HTV-1 design, this commonality is not maintained in HTV-2 and subsequent flights. Another concern is module orientation (module local vertical) relative to ISS axes. Fig. 24 shows the connection of ISS habitable modules. Blue shaded plane represents

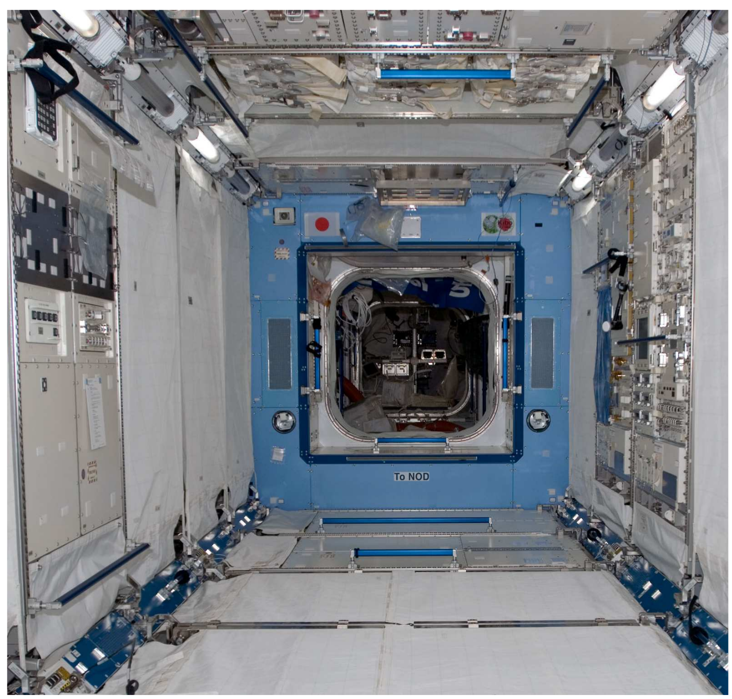


Figure 23. Definition of local orientation in a ISS habitable module.

the “Floor” of modules, whereas the arrow indicates “Up”. Most of permanent habitable modules are on the same plane and their local vertical is consistent. Exceptions are found in the JEM ELM-PS, MPLM, and HTV-1 (and the future PMM), where those modules are attached to the Zenith/Nadir port.

Concerning crew recognition and adaptation to the HTV-2 local vertical because of above “double” inconsistency to other ISS modules, observation of recorded downlinked video during the HTV-1 mission is attempted. When the crew is moving in the habitable portions of the ISS, they frequently fly like “Superman” by kicking off from the wall or crawling on their hands in a headfirst posture. In spite of this tendency, the crew enters to HTV-1 in a foot-first posture in 37.9 % out of the twenty nine cases observed. Frequency of the foot-first posture is dependent on individual crew members. On the other hand, when exiting HTV-1, the foot-first posture is not observed, and correlation is not observed between crew posture and the local vertical of the HTV-1 PLC that is crew facing “floor” of HTV-1 PLC in 46.2 % of the cases, however there may be possibility of correspondence with the next module where crew goes into. Thus it may be concluded that some crew members tend to recognize the HTV cabin volume as a continuous part of the Node 2 module with the same local vertical, like a basement or manhole, without adapting to the HTV’s own local vertical, and regardless of the location of lighting and orientation of label/decal. The shape and size of the cabin may affect this tendency, i.e. the shape of HTV cabin aisle is an approximately 2 meter cube[3]. There may be a different result when observing the MPLM, which has a cabin approximately 4 meters long and similar cross section, berthed to the same port of the Node 2 module, and crew may adapt to its own local vertical after entering.

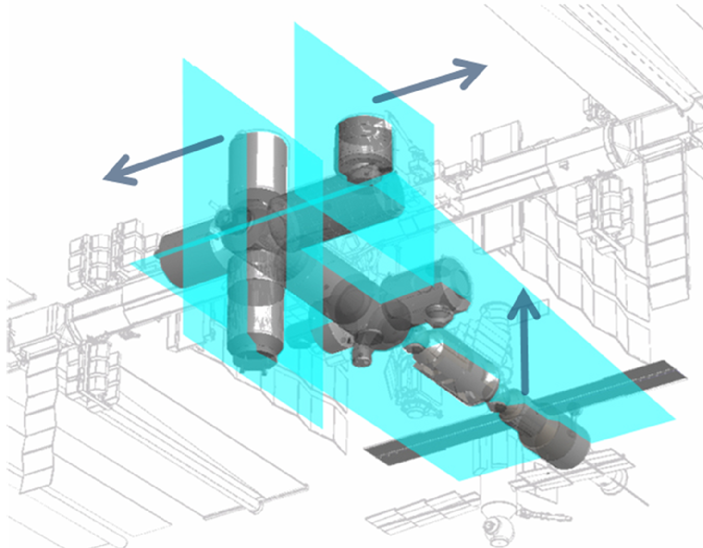


Figure 24. Definition of local orientation in ISS habitable modules.

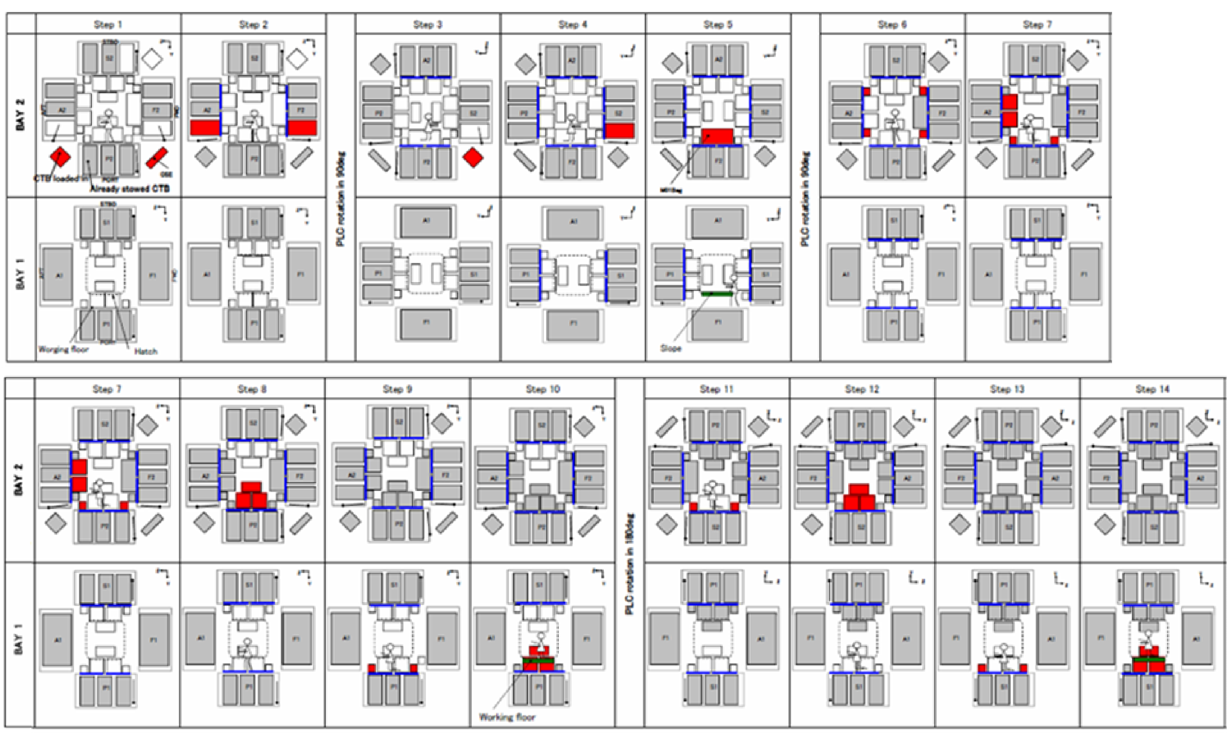


Figure 25. Ground cargo loading procedure on HRR front panels.

Assuming the above discussion, the lighting direction of HTV-2 and subsequent flights, which aligns with the Node 2 module, will be more suitable to crew spatial perception than that of HTV-1. Labels/decals are also aligned to the lighting direction in HTV-2 and subsequent flights.

F. Ground Operations

Handling cargo bags on the ground is much more difficult than on orbit, especially for larger ones such as M01-size bags with weights up to 135 kg. Cargo bags are loaded inside the HRR before it is installed in the PLC except for the locations for standoff area access. Then, HRRs with their internal cargo bags and ISPRs, if applicable, is installed into PLC, stow in stand off area, fill the vacant shelf for stand off access, and Cargo loading of the HRR front panel starts. , and s. Upgrading the HRR causes much difficulty in the front loading process because no working volume remains after it is fully stuffed. This puzzled the engineers and resulted in the complicated procedure. As shown in Fig. 25, fourteen steps are required only for front panel and stand off area loading with PLC rotation in three times. (Cargo shaded in red is the subjected cargo to the corresponding steps) Most recent study shows twenty one steps and four rotation, especially for HTV-2 to squeeze the launch site schedule and allow much later turn over of cargo from Cargo Owners.

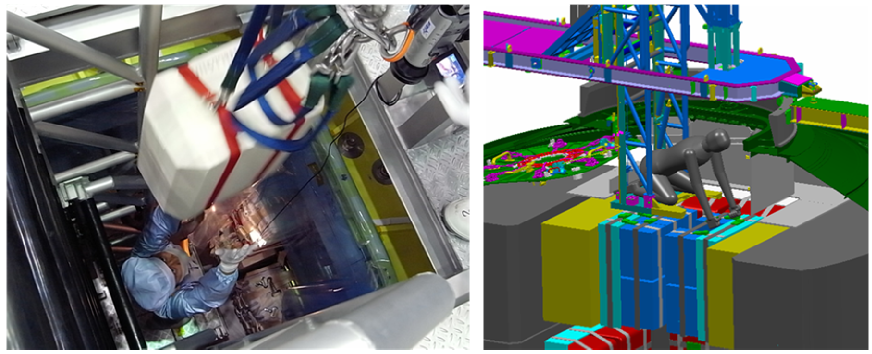


Figure 26. Cargo late stow. (Left: picture from late stow demonstration for HTV 1 using dummy cargo. Right: expected posture of late access after cabin aisle is filled with HRR Type 4 cargos.)

Cargo loading capability enhancement also affects late cargo stowage capability. The HTV is required to allow access to the pressurized cargo 4 days before launch within launch vehicle fairing. In the case of HTV-1, a technician went down to the cabin and accessed the HRR from the front side, whereas technicians operate from above the cargo for HTV-2, as shown in Fig. 26.

IV. Conclusion

The design update of the HTV PLC to accommodate an additional 46 CTBEs of pressurized cargo volume was described. Required additional accommodation of 46 CTBEs is achieved by modifying the HRR from Type 2 to Type 3 and Type 4, and additional cargo accommodation structures in the standoff area. With the additional 46 CTBEs that makes 254 CTBEs in total, JAXA can fulfill its obligation to the ISS program, however the assessments discussed above shows that HTV has much potential to accommodate pressurized cargo, at least in terms of volume. Most recent result, not discussed herein, shows possibility of additional 31 CTBEs from 254, that might HTV get much worth in ISS program considering that actual cargo density is less than the assumption of 254 CTBEs requirement, and that the potential extension of operation life of the ISS now under discussion.

Associated engineering considerations, caused by relocation of cabin air ventilation ducts, stand off frame structure, and illumination devices, were also discussed, including cabin air ventilation, removal and installation of ISPRs, illumination level, accessibility, local vertical, and ground operations. Considerations are reflected in the upgraded design and procedures to meet system requirements. Although a few minor concerns still remain, such as local orientation and usage of the standoff frame OSE, design of HTV-2 discussed herein was formally certified and the vehicle has been manufactured. Continuous observation and comparison of crew behavior will help better understanding, between HTV-1 and HTV-2. as well as a comparative study with the MPLM and PMM.

Avionics Module and Propulsion Module portion of HTV-2 is now (as of May 2010) in JAXA's Tsukuba Space Center for final system tests including thermal-vacuum test and PLC/ULC portion is already on-dock the Tanegashima launch site targeting launch in winter season of 2010/ 2011, and the other subsequent spacecraft are being manufactured.

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