Requirement and Design of Guidance & Navigation system in HTV-R Re-entry Vehicle

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JAXA is studying the feasibility of HTV-R which will enable to recover various samples from the ISS and demonstrate the re-entry technology necessary for a manned space flight in future. The guidance & navigation system in its re-entry vehicle should comply several requirements such as g-force limitation with enough reliability in addition to compensate the location & velocity errors at re-entry point toward the pre-determined splashdown area. This report will introduce the system with referring to manned design philosophy established in the HTV development.

Keywords: HTV, Re-entry, ISS

Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTV</td>
<td>H-II Transfer Vehicle</td>
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<td>HTV-R</td>
<td>HTV - Return</td>
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<td>HRV</td>
<td>HTV Return Vehicle</td>
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<td>ISS</td>
<td>International Space Station</td>
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<td>LEO</td>
<td>Low Earth Orbit</td>
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<td>PCBM</td>
<td>Passive Common Berthing Mechanism</td>
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<td>GSE</td>
<td>Ground Support Equipment</td>
</tr>
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</table>

1. Introduction

The third HTV (fig.1 is a photo during the mission) successfully completed its cargo resupply mission to the ISS on Sep. 14, 2012. HTV-3 delivered lots of cargo, including five micro satellites, two orbital replacement units, water, and the consumables necessary for the crew living in the ISS.

JAXA has started researching upcoming programs as a part of Japan's future space activity plan. This includes HTV-R (HTV-Return), which is likely to be one of the most attractive for system engineers who are studying the feasibility of Japanese manned space flight.

Fig.1  HTV-3 on Orbit (Photo) ©NASA

2. HTV-R Concept and Target

"R" in the name of HTV-R means several characteristics of the program as shown in Fig. 2. The HTV-R is the first operational return vehicle from orbit with logistics in the pressurized carrier in Japan. It also enables JAXA to recover the failed equipments from the ISS for repairing and replacing them. The HTV-R is planned to replace the pressurized cargo carrier in the HTV with keeping the operational robustness in the other section. The size and
shape of the HTV-R resembles them of a manned spaceship and will realize JAXA's hope to send Japanese astronauts by themselves in the future.

JAXA is researching the reasonable operation profile for the HTV-R. Figure 3 shows a concept of HTV-R operation and supporting system. The HTV-R is launched from Tanegashima Space Center by a H-IIB launch vehicle. Like the original HTV, it can carry cargo to the ISS but also has a 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, and HRV conducts controlled a re-entry flight and be recovered in the Pacific Ocean.

(2) Interfaces
A cutaway image of the HTV-R in shown in fig. 5. The un-pressurized section is retained and it has the capability to transport the exposed pallet with cargo as HTV does now.

The interfaces between the HTV-R and the ISS uses the same berthing system (Passive Common Berthing Mechanism: PCBM). The HTV-R has a grapple fixture (Flight Releasable Grapple Fixture: FRGF) at the same location as the HTV and the robotic system on the ISS will be capable of capturing the HTV-R with the same procedure that currently used for the HTV.

2.2 HTV-R Design Target
JAXA is designing the HTV-R vehicle with aiming the following two targets.

(1) Re-entry vehicle size is equivalent to a manned system
The re-entry vehicle (HRV) design has a reasonable shape and size for a manned vehicle. The internal volume is sufficient to transport 4 crew members to a LEO station and bring them back to the Earth. The HTV uses the same launch configuration, re-entry flight, and the similar redundancies in the system. Figure 6 suggest that HRV has a comparable internal volume with other space vehicles for human spaceflights.
Sample Return Capability from the ISS

The HTV-R is utilized for the ISS program by the up-mass and down-mass capability. The program should cooperate with other international partners to realize a frequent and quick sample return infrastructure from the ISS. Figure 7 shows that the HTV-R also realizes a complete cycle of JAXA’s in-orbit experiments by adding the ability to obtain the outcome from them.

[HRV Specification]
Concept: Replace pressurized Carrier
Total Mass: 6.5 ton
Diameter: 4.2 m
Height: 3.8 m
Downmass Capability: 1.6 ton
Volume: 16.7 m³ (gross)

Artist’s impression of the HRV is shown in fig. 8.

Fig. 7 Recovery/Repair/Re-use Cycle by HTV-R

2.3 HRV Design

The re-entry module in the HTV-R is the most important part of the program. The HRV is designed to satisfy the requirements shown in section 2.2.

2.4 HRV Operation

JAXA should build a new operation procedure for the HRV recovery. Figure 9 shows the additional operations from the original HTV. The navigation and control during re-entry and the sea recovery operation are required for HRV flight and they resemble a human spaceship’s.

Fig. 9 Operations after HRV Separation

3. Flight Control System in HRV

Figure 10 shows the necessary functions in the HRV guidance and navigation system during the re-entry flight. They are also constrained as shown in table 1 to resemble them in a manned spaceship.
Table 1  Guidance Constraints during Re-entry Flight

<table>
<thead>
<tr>
<th>Technical Challenge</th>
<th>Constraint for re-entry guidance</th>
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</thead>
<tbody>
<tr>
<td>1 Small splashdown area near from Japan for easy and quick recovery operation.</td>
<td>Less than 5km circle: Position accuracy target at the height of parachute deployment.</td>
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<tr>
<td>2 System design toward future study of Japanese manned space vehicle</td>
<td>Less than 4G: Aerodynamic acceleration during re-entry flight from low-earth orbit. Aerodynamic heating and the rate are other constraints.</td>
</tr>
<tr>
<td>3 Robustness against uncertainty of mass property due to variable cargo installation.</td>
<td>25% aerodynamics error from variable L/D. It should be acceptable by guidance algoritam.</td>
</tr>
<tr>
<td>4 Usage of the HTV as the de-orbit module because of keeping safe re-entry.</td>
<td>-1.2 to -1.5 degree of (y)flight path angle). Possible range of a initial de-orbit condition at Entry IF point(EIP point;120km altitude). 51.6 degree of Indination is another constraint to select splashdown areas.</td>
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Fig. 10 Guidance & Navigation during Re-entry Flight

3.1 Guidance and Navigation

The HRV guidance system targets a predefined splashdown point in the sea areas shown in fig. 11. The final dispersion from the target point is estimated less than 5km circle at the parachute deploying altitude (10,000 m). As the pathfinder for a human spacecraft, HRV guidance and navigation system should keep the function under the communication black out, and recover quickly when a serious failure occurred. The flight path also resembles human space flight and gravity force should be less than 4 G during the all re-entry flight as shown in fig. 12.

Fig. 11  Candidates for Splashdown Sea Area

Fig. 12 Guidance Techniques toward Splash Point

3.2 Avionics

One of the avionics ideas of HRV is shown in fig. 13 as a schematic diagram. The avionics should have sufficient redundancies, while it is also preferable to allow for future enhancements for a manned vehicle. To enhance the system, emergency components are installed into the schematic to satisfy safety requirements after any two failures occur.

Fig. 13  HRV Avionics System Schematic Diagram

3.3 Propulsion

A modern re-entry manned vehicle should have thrusters to control its attitude. In particular, the importance here is greater than for capsule type re-entry vehicles because of the lack of air control surfaces to adjust the angle of attack. Figure 14 shows an example of the layout of thrusters for the HRV. To minimize the thermal input during re-entry, all thrusters are located on a half side of the vehicle.

Thrusters consume little propellant during re-entry because of the short period for control. So, a propellant-efficient system is not the highest priority in the HRV. Figure 15 shows an example of a mono-propellant propulsion system for the HRV, which has a simplified and light weight system, ant it is selected from the perspective of the hardware/propellant balance.
3.4 Failure Management (Erroneous Data Rejection)

The failure management is prioritized in the HRV as the base design of a manned vehicle. JAXA developed a firmly management system for failures in the HTV to satisfy the all safety requirements as a manned system. As shown in fig. 16 and 17, lots of filters are integrated into the HTV on-board software to reject erroneous data before implementing in the navigation. Same kind of filters are required in the HRV software too.

3.5 Failure Management (Data Comparison)

Data comparison is used as the main method to detect an error in the HRV navigation system. Figure 18 suggests that it is not easy to implement the method into the real navigation system because of "undetectable error" between the specified nominal value and the detectable error by comparison. As the human rated system, the HRV is required to cover all possible errors by the failure management system.

Figure 19 shows a case in the HTV software which manages all possible errors includes un-detectable during the capture operation below the ISS. Errors that cannot be identified by the comparison method are integrated into the navigation as the error source. JAXA verified that the HTV shall not go out of the threshold for capturing even though any un-detectable errors occurred in the navigation. The same kind of error management algorithm is required to the HRV software too.
3.6 Failure Management (Independent Assessment)

“Independent Assessment” is an important keyword which was frequently used during the HTV development for satisfying the safety requirements as a human rated module in the ISS. Figure 20 shows a series of assessments in the HTV navigation system during the approach to the ISS. The relative GPS navigation is used as the primary navigation method and is compared with the ranging and ranging rate data from the communication system between the ISS and the HTV. They are fully independent because of the difference of calculating method. The same kind of comparison is prepared between the rendezvous laser sensor and the relative GPS navigation.

The HTV-R and the HRV will have the same idea in navigation system if they conduct approach to a human vehicle or a space station.

4. Future Option

A few optional configurations of HTV-R is under the study. Even though the aerodynamic design and size of the HRV is no modified, the supporting system may be changed to enhance the efficiency of development and the future use of HTV-R.

Figure 21 shows an idea to re-use the HTV-R after recovered in the ocean. Thrusters and navigation system are installed into the HRV and will be re-use for the next mission after the refurbishment. An integrated navigation system in the HRV should be developed to satisfy all rendezvous and re-entry operation. The developing process in this idea will be complicated and require the larger resource than the original configuration plan of the HTV-R.

5. Conclusion

The guidance and navigation system in the HTV-R is challenging but attractive system for engineers in JAXA. The further investigations will use plenty of technical heritages from the HTV.

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