

Preliminary Study for Manned Spacecraft with Escape System and H-IIB Rocket

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1 Introduction

JAXA announced its long-term vision for the next 20 years called as "JAXA Vision toward 2025" in April 2005. In the vision, JAXA declared to keep establishing space transportation systems with the greatest reliability and competitiveness in the world. Certainly the JAXA's own manned spacecraft is one of the goals of these reliable transportation systems. Even though the development has not started yet, JAXA will launch the combination of largest un-manned space vehicle and most powerful rocket in Japan, HTV and H-IIB in the next year. The first flight of them will become one of the important milestones in JAXA's long-term vision. Then, we will be able to go to the next step toward manned spacecraft. The purpose of this paper is to estimate the overall configuration and size of manned spacecraft, then summarized the abort analysis for manned flight and development steps as the preparation for formal study cycles starts in the next step.



Fig. 1. H-IIB Manned Flight (Artist Image)

This paper uses several data from HTV as un-manned but smart transportation vehicle and launch capability data of H-IIB rocket for estimation as reasonable and realistic as possible. Fig. 1. is an artistic image for the launch. This image uses 3-dimensional model built through the preliminary trade-off study. It includes clarification of necessary development items for manned spacecraft from un-manned vehicles.

Also, it is emphasized in this paper about the missing part of current HTV and H-IIB for manned flight, the abort system during power flight. Launch Escape System (LES) is mandatory for human transport and should be investigated from the early designing process, but has not been done in JAXA yet. In previous manned program in US and Russia, the mass of LESs are more than half of crew modules and flight path of launch vehicles are restricted to allow crew to escape in all phases on demand. So, the configuration and size of LES was investigated in this paper with each abort scenario as the first step of estimation. Abort trajectories are parametric analyzed in Section 4 using a sample of nominal flight path suitable for manned vehicle with H-IIB and spacecraft, which has 14 metric tons as reasonable whole vehicle weight.

This paper tried to make a concept for manned spacecraft which rendezvous to spaces station within the launch capability by existing in JAXA, then estimated weight and size of each module of spacecraft with considering abort capability during launch phase. In the last half of this paper reports the analysis result about maximum G-load to crew and development plan to demonstrate major functions with step by step.

2 Design Baseline

Figure.2 shows the original HTV configuration. HTV has logistic carriers for both of pressurized and un-pressurized cargo. Crew can enter to the pressurized section without space suit to replace several logistics with wastes. Un-pressurized carrier section has several mechanics to fix or release exposed pallet utilized for un-pressurized cargo exchanging.

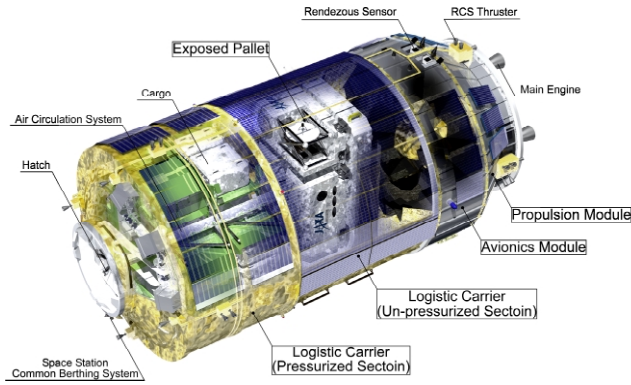


Fig. 2. HTV (Original) Configuration

Avionics module and propulsion module have several computers to control not only HTV attitude or position but also all failures in HTV. Basically HTV has two control strings for nominal operation and one contingency string to comply the ISS safety requirement same as the human vehicles.

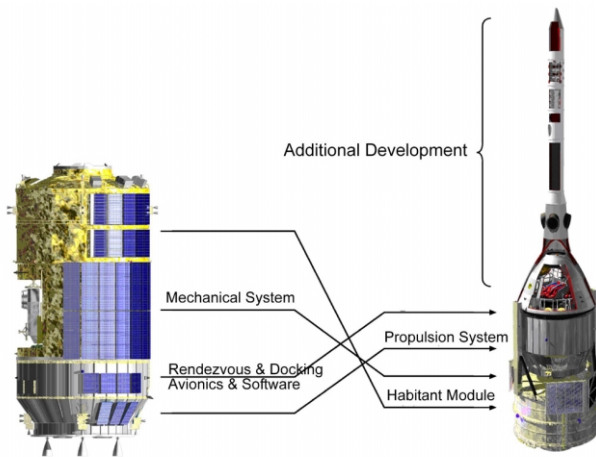


Fig. 3. Technical Relations between HTV and Manned Vehicle

Fig. 3. shows the technical relations between Manned vehicle and HTV. HTV is the latest space vehicle in JAXA and has capability to carry the cargo up to 6 tons to the ISS.

2.1 Basic Requirement to Spacecraft

(1) Number of Crew

The first thing we should to estimate the size of spacecraft is determining the number of crew in it. The more is the better but restricted by the volume of manned spacecraft.

Following are weight and diameter of manned Re-entry Modules. The number of crew does not determine the capsule size directly because of the difference of mission requirement, but 4 crews are assumed as reasonable number for 4 meter diameter capsule launched by H-IIB.

- Soyuz: 2.9 tons with 3 crew, diameter: 2.2m
- Apollo CM: 5.8 tons with 3 crew, diameter: 3.9m
- CEV: 7.3 to 7.7 tons with 6 crew, diameter: 5 to

5.5m

- JAXA's Capsule: 5 tons with 4 crew, diameter: 4m

(2) Mission Profile

Target for manned missions are classified into following points.

- Ballistic Flight (less than 1 revolution)
- Low Earth Orbit (a few days)
- Round trip to a base in LEO
- Round trip to the Lunar Orbit
- Round trip and landing to the Lunar Surface

Table1. Delta-V Requirements for Missions

Target	A) LEO	B) LEO Station	C) Lunar Orbit	D) Lunar Surface	Reason
Thrust	500N - 1000N (for De-orbit Mass: 7.5 ton or less)	1000N - 2000N (for de-orbit mass: 15 ton or less)	1000N - 2000N (Gimbal Engine recommended)	1000N - 2000N (Gimbal Engine recommended)	Based on HTV operation (1000N/ 15ton)
delta-V	100m/s (de-orbit only)	total: 390m/s (Rendezvous: 80m/s, de-orbit: 110m/s, Adjust/Attitude control: 200m/s)	total: 4,000m/s (Insert to Lunar Transfer Orbit: 3,100m/s, Lunar Orbit: 800m/s, Adjust/Attitude Control: 100m/s)	total: 5,700m/s (4,000m/s + Lunar Landing : 1700m/s)	Based on HTV operation
Thruster	20N class×8set× 2string (3axes control)	100N - 200N class× 14set×2string (3axes + lateral)	500N class×8set× 2string (3axes control for 100ton class)	more than C)	Based on Apollo
Propellant	510kg (empty: 7,500kg, margin 2X)	510kg (empty: 15,000kg, margin 1.5X)	101,000kg (empty: 15,000kg, margin 1.2X)	more than C)	lsp: 315sec
Tank Diameter	0.89m×4	1.12m×4	3.53m×4	more than C)	95% loading
from HTV	○ Easy	◎ Easy	× Difficult	× Difficult	

Table 1. shows necessary delta-V for each missions. Because the Lunar orbit needs plenty of propellant, round trip around Lunar is not feasible target within the current JAXA's launch capability. So, transportation between the Earth and human base in low-earth orbit was selected as the reasonable target for the manned mission in this paper. Also, HTV will demonstrate the rendezvous and berthing capability and become one major milestone for the manned flight around space station.

Based on the HTV's mission profile, rendezvous to the LEO space station needs two or three days for phase adjusting. In addition, one or two weeks will be required for on-orbit contingency.

2.2 Modules and Functions

Fig. 4. shows the configuration for the manned spacecraft investigated in this paper. To estimate the weight and size for each function, this vehicle was separated into four function modules, Launch Escape System, Reentry Module, Orbital Habitant Module, and Propulsion Module. This configuration was selected to use heritages of HTV as much as possible, and enable to develop and demonstrate by module. As shown in following sections, Propulsion Module and Orbital Habitant Module will be developed based on current design of HTV, but Re-entry Module and Launch Escape System needs to be developed from preliminary designing.

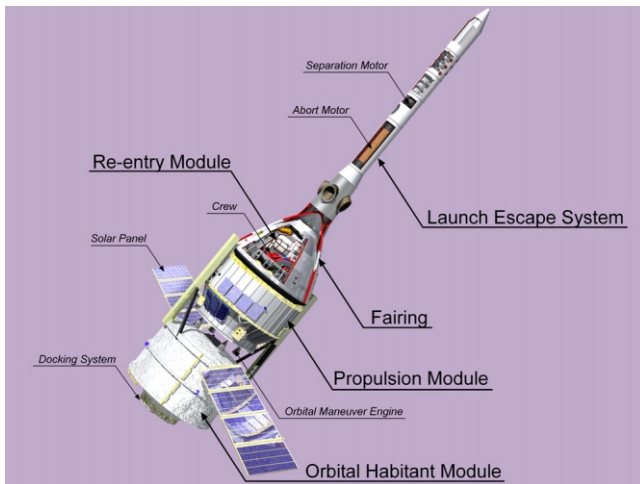


Fig. 4. Manned Spacecraft Configuration

(1) Propulsion Module

Required performance to Propulsion Module is as follows. Most of them are similar to HTV's because both of them use the same orbit to space station at low earth orbit.

- Three axes Attitude/Position Control for Docking
- Maximum Acceleration for De-orbit: 0.07m/s
- Full Redundancy, 2 fail safe
- Total Delta-V 390m/s (Orbital transfer: 80m/s, Rendezvous/Docking: about 200m/s, De-orbit: about 110m/s)

As far as total vehicle weight keeps less than 15 tons, minor modification will be required from the design of HTV Propulsion/Avionics Module.

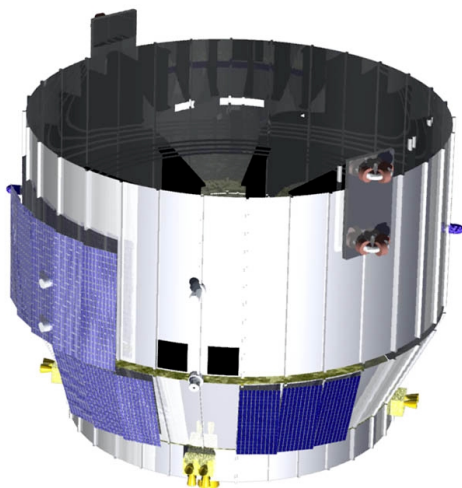


Fig. 5. Propulsion Module

(2) Habitant Module

Orbital Habitant Module has several life support systems for crews for long stay on orbit. Also, it provides resources to whole vehicle on orbit. These functions in habitant module

enable to shrink the size and weight of other modules, especially re-entry module which has minimized environmental control and life support system for crew to stay in short duration after decent from orbit.

Followings are example of requirements to Orbital Habitant Module but will be modified with the size of module and requirement for staying duration.

- Support maximum 4 crews to stay on orbit for three days (nominal for rendezvous to station) plus one week for contingency.
- Equip solar paddles to generate 3,000W (orbital average)
- Equip connecting system with Re-entry Module which is used for crew going in and out
- Equip mechanism for docking or berthing with sensor/target system for orbital service

As Propulsion Module, Orbital Habitant Module will be developed based on it of HTV. Since several functions especially Crew support system for 3 - 10 days staying is lacking in current HTV design, following items should be developed until the real human flight demonstration.

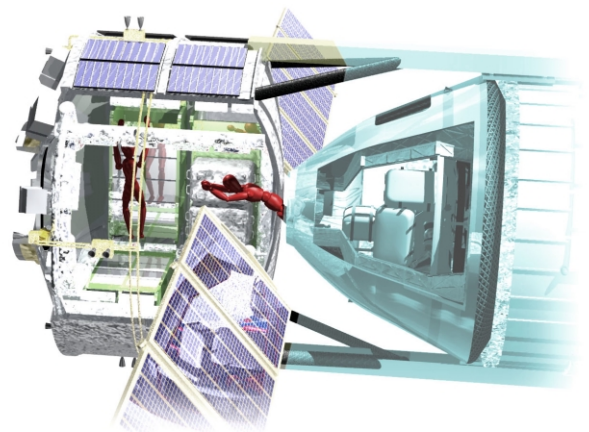


Fig. 6. Orbital Habitant Module

[Environmental Control /Life Support]

- O₂/CO₂ Control, Air Circulation
- Air Temperature Control
- Waste Manage, Food/Water, Sleeping bag, etc

(3) Re-entry Module

Re-entry Module should be fully developed but JAXA has experiences for un-manned re-entry module in previous satellite programs. OREX (Fig. 7.) was one of them and conducted de-orbit and atmosphere re-entry experience successfully in 1994. OREX re-entered on ballistic trajectory but Manned Re-entry Module should flight with controlled lift (Lift/Drag = around 0.4) for both of relieving gravity force on crews and increasing the accuracy of splashing point in the sea.

Conventional revolving shape is assumed in this paper as re-entry capsule design, but more complex and lift effective shape (lifting body) is better to decrease the maximum G-force during re-entry. Further investigations are required to determine which shape will be used for our Re-entry Module and it will be the major decision point for Manned spacecraft program.

Table 2. Component Tree of Re-entry Module

Module	Components	note
Re-entry Module	Structure	
	Primary Structure	
	Main Structure	
	Cabin Structure	
	Secondary Structure	
	Hatch (for On-orbit IVA) Support	
	Hatch (for Ground Operation) Support	
	Wire harness Support Structure	
	Propulsion Component Support	
	Parachute Support Structure	
	Thermal Protection Interface	
	Hatch	
	Hatch for On-orbit IVA	used between Habitant Module (φ600mm)
	Hatch for Ground Operation	used for crew entering on ground (□800mm)
	Thermal Protection System	
	Ablator for High-Q Area	Carbon-based ablator (TBD)
	TPS for Low-Q Area	Light weight ablator or Ceramic tile
	Flexible Thermal Protector	
	Guidance, Navigation & Control System (GN&C)	
	GN&C Computer	3 strings, subset of HTV GN&C Computer
	IMU	3 strings required
	GPS Receiver	2 strings required
	Valve Drive Electronics	for 12 thrusters, 3 strings required
	Electrical Power System	
	Power Bus and Providing Controller	from module separation to recovery
	Non-rechargeable Battery	
	Electrical Interface	
	Propulsion System	
	High Pressure GHe Tank	
	Propellant Tank	Total 80 liter
	Reaction Control Thruster	500N class, 12set
	Isolation Valve	
	Propellant Line	
	Pressure Transducer	
	Communication System	
	S Band TX/RX (for On-orbit Communication)	minimum 2 strings required
	VHF TX/RX (used in atmosphere)	2 strings, for recovery operation
	Data Handling	
	Signal Conditioner	
	Wire Harness	
	Environmental Control and Life Support System (ECLSS)	
	Air Circulation System	
	Fan	
	Air Duct/Ventilator	
	Air Conditioning System	
	O2 Storage or Generator	
	CO2 Absorber	
	Temperature Control System	
	Heater Control Computer	Subset of HTV Heater Controller
	Heater, Wire harness	
	Thermal Control System (TCS)	
	Water Loop for Thermal Exchange	
	Radiator (or Water Spray Boiler)	TPS covers module, no area for radiation
	Parachute/Floating System	
	Dragchute	3 Strings required
	Pilotchute	3 Strings required
	Main Parachute	3 Strings required
	Floating Bag	3 Strings required
	Recovery Support System	
	Beacon	2 Strings required
	Sea Coloring Agent	
	Human Interface	
	Display Panel	
	Command Panel	
	Shock Absorber Seat	
	Payload Rack	
	Crew	
	Crew	
	Space Suit	
	Payload	
	Propellant	
	Air	



Fig. 7. Orbital Re-entry Experimental Vehicle (OREX)

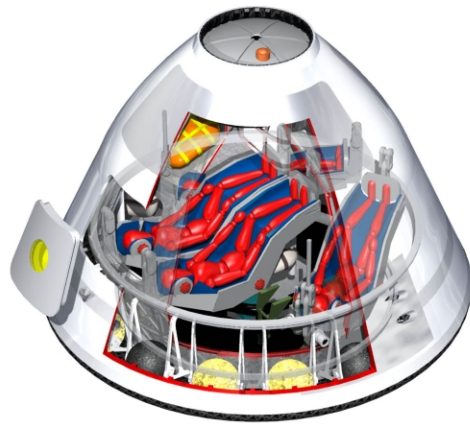


Fig. 8. Re-entry Module (Concept image)

(4) Launch Escape System

There is no reference system for Launch Escape System in Japan. Launch Escape System is not a simple solid booster but has to be designed from aerodynamics point of view. Its thrust and delta-V are also to be taken into account. Suitable responsible section is not found in current JAXA to develop this kind of system.

Table 3. Component Tree of LES

Module	Components	note
Launch Escape System	Structure	
	Primary Structure	
	Ballast	Aerodynamic analysis required for determination
	Main Structure	
	Re-entry Module Attachment	
	Re-entry Module Fairing	for Thermal protect during motor burning
	Secondary Structure	
	Abort Motor Support	
	Separation Motor Support	
	Attitude Control Motor Support	
	Mechanics	
	Re-entry Module Separation Mechanism	withstand thrust of Main motor
	Control Surface Deployment Mechanism	
	Solid Rocket Motor	
	Abort Motor	Thrust 800kN, Propellant: 1,220kg
	Separation Motor	for nominal separation
	Attitude Control Motor	
	Control Surface (TBD)	
	Aero Dynamic Control	
	Aero Dynamic Control Surface	
	Actuator	

3 Trade-off Study for Spacecraft Configuration

Followings are the result of preliminary investigations about vehicle configuration. Fig. 9. shows artist image.

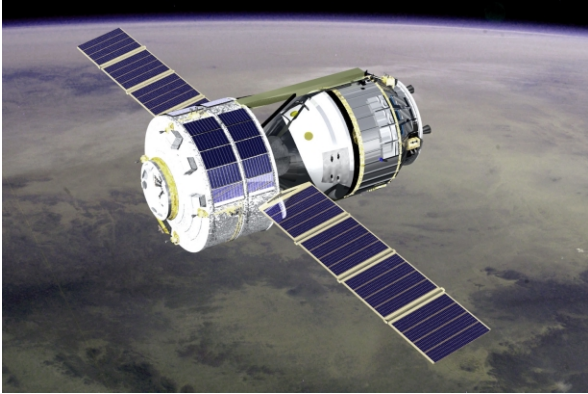


Fig. 9. Flight Configuration (Artist Image)

3.1 Vehicle Construction

(1) Use Technical Heritage from HTV

One of the technical key features of HTV design is that each function is clearly divided into functional modules. It enables to use the design as module level if it is required in the other programs.

In this paper, Avionics/Propulsion Module in HTV will become the design base for Propulsion Module in manned vehicle. A part of Avionics in HTV will be installed into Orbital Habitant Module for electrical power service and environmental control. Most of structures of HTV's pressurized carrier will become the baseline of Orbital Habitant Module.

By selecting module design concept, JAXA's manned spacecraft can use lots of design heritages of HTV.

(2) Capability to Support Future Mission

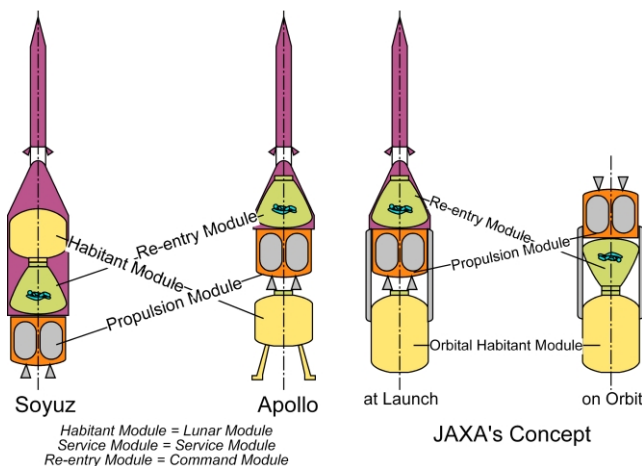


Fig. 10. Module Construction

Fig. 10. Shows differences in Soyuz, Apollo, and JAXA's concept for module configuration. Soyuz type is simple for

operation but it is not selected in this paper mainly because of the weight penalty for Launch Escape System (LES has to kick Habitant Module for Re-entry Module separation). Also, Apollo type is better to enhance functions in Habitant Module such as longer on-orbit staying time capability. Two points major difference between Apollo and JAXA's concept in this paper are as follows.

- Mechanical guidance is used for orbiting connection of Re-entry Module and Habitant Module.
- Orbital Habitant Module has service functions such as electrical power supply, crew support, rendezvous/docking

JAXA developed "Rail & Wheel System" for HTV Exposed pallet in un-pressurized carrier and the experience could be usable for mechanical guidance design for module connection on orbit. Service functions were installed into Orbital Habitant Module with considering the operation scenario to re-use Orbital Habitant Module on-orbit as one module of space station.

(3) Effective Development

Module design in (1) and vehicle configuration in (2) have advantage in development scenario since each module can be developed by separated step and schedule. Propulsion Module has minor risk in development because it uses similar system as HTV. But Re-entry Module and Launch Escape System should be developed through critical milestones and demonstrations. This configuration enables to start each development independently and minimize the affect of design modification from other modules during development.

3.2 Weight/Scale Estimation for Each Module

In this section, size and weight of each module were estimated based on HTV and previous manned vehicles.

(1) Re-entry Module

Weight can be roughly estimated by diameter of capsule. As shown in section 2.1, 4 meter is suitable size to load in top on H-IIB launch vehicle with Propulsion Module/Habitant Module similar to HTV's.

The diameter is similar to Apollo Command Module which has 5.8 ton. We estimated our Re-entry Capsule will be lighter than Apollo CM since CM has several special equipments for Lunar mission and life support system for longer mission. Our concept uses independent Habitant Module for life support on orbit and most of support equipments for longer staying can be moved from Re-entry Module to Habitant Module. So, Re-entry Module in our concept is estimated at 5 ton in this paper.

(2) Propulsion Module

Propulsion Module weight and size can be estimated by data from HTV because it is subset of Avionics/Propulsion Module in HTV.

Fig. 11. shows dimensions of Propulsion Module in each

mission with estimated weight from HTV design.

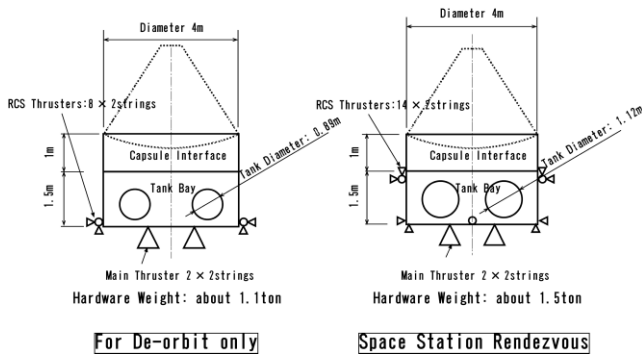


Fig. 11. Propulsion Module Sizing

(3) Orbital Habitant Module

Weight of primary and secondary structure for Orbital Habitant Module is about 3 ton if the same size of HTV was used for Manned vehicle also. Weight of crew support system has not been estimated exactly yet but roughly set total weight of Orbital Habitant Module as 5 ton in this paper.

(4) Launch Escape System

Fig. 12. shows typical contingency operation scenario of Launch Escape System used in Soyuz. Similar system will be integrated into JAXA's spacecraft at least crew goes on board.

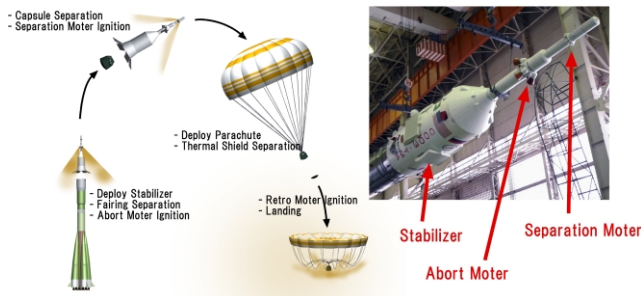


Fig. 12. Launch Escape System (Soyuz)

Launch Escape System will be used if some critical failure occurred in launch system and it was concluded to abort mission by safely separate re-entry module with crew from rocket. LES is required to have following functions for on-demand escape during before vehicle entering orbit.

- LES has to work through all critical phase with rocket (from prior launch to orbit)
- LES has to generate impulse to climb enough altitude to activate parachute for safely landing or splashing to sea
- LES has to have enough thrust to separate LES and re-entry module under the maximum air drag
- LES has to avoid re-contact after once separate from rocket
- LES has to separate from re-entry module after the end of necessary phase

Now we have no design reference in JAXA for estimation of Launch Escape System. Only weight ratio in Soyuz and Apollo are usable information for estimation. In previous programs, LES has almost 60% weight of escape weight. In this paper, escape weight (Re-entry Module) is estimated as 5 ton and we assume LES weight as 3 ton.

Table 4. compares every Launch Escape Systems. Fig. 13. shows cutaway of LES.

Table 4. Parameters in Launch Escape Systems

	Apollo	Soyuz	JAXA's Spacecraft
LES System Weight	3,600kg	3,400kg	3,000kg
Escape Weight (LES+Manned Module)	9,400kg	7,600kg	8,000kg
Thrust	660kN	760kN	800kN
Max G during Ejection	7G	10G	10G
Propellant	1,410kg (Includes 40% margin)	800kg (Assumption)	1,220kg (Motor inclination: 40deg, Isp:280sec, 40% margin)
Burn Time	3.2秒	1.62秒	2.3秒
Climb Requirement from Ground	1,200m	850m	1,200m
Delta-V (in Vacuum)	225m/s	162m/s	225m/s
Climb Altitude (in Vacuum)	2,582m	1,398m	2,582m
Air Drag Surface	12.3m ² (Diameter: 3.96m)	16.1m ² (Diameter: 3m+1.5m×4)	12.6m ² (Diameter: 4m)
Drag Co-efficient	0.8 (TBD)	0.8 (TBD)	0.8 (TBD)
Air Drag at Gmax=40kPa	394kN	515kN	403kN

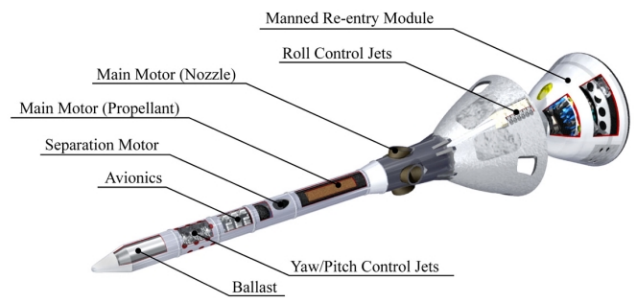


Figure 13. Launch Escape System

As shown in Table 4. , there is a certain relation between the maximum air drag and thrust level of main motor (Abort Motor). Each escape system has nearly ten times of ejection weight but such large thrust (may damage to crew by G-force) is not required if LES was planned to be used from ground. It came from the situation in that LES is used under the maximum air drag. It needs large thrust level to separate from rocket.

Smaller and heavier capsule design is better to reduce thrust of main motor and relief G-force during launch abort, but smaller diameter loses lift co-efficient and increases G-force during re-entry.

So, dimension, weight, and shape (lift co-efficient) of Re-entry Module determines LES thrust, weight, and size. Optimizing all of them is the important process in the early design phase to minimize G-force on crew during escape and re-entry.

4 Abort Analysis for Boost Phase

4.1 Abort from Ground with LES

There are several abort cases during launch phase, but two typical scenarios are selected to determine the main parameters of Launch Escape System. The first scenario is abort from ground.

When time-critical emergency occurred before lift-off, Launch Escape System has to separate the crew module enough high and far by rocket motor in it.

Fig. 14. shows altitude and velocity in typical escape pattern from ground based on the assumed thrust and weight in previous section.

This analysis used simplified atmosphere model but it shows reasonable result comparing with parameters of Apollo and Soyuz. It takes about 15 second to reach to the highest altitude and all sequences prior deploying parachute should be completed within the period. Re-entry Module and Launch Escape System have to turn around and Re-entry module should fly from bottom for deploying parachute. It will be very time critical operation and needs several analyses for all abort cases with reasonable performance of parachute deploying system (how quick it can?).

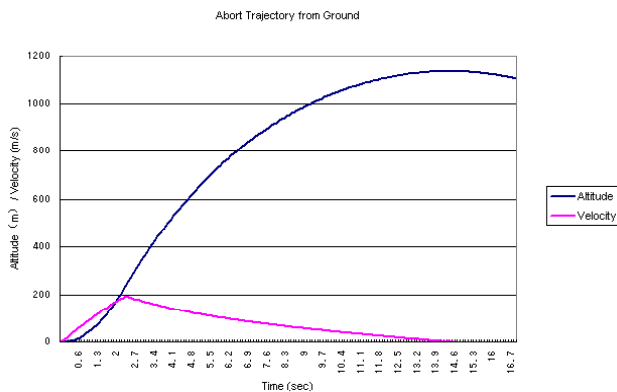


Fig. 14. Altitude/Velocity Profile in Ground Abort

4.2 Abort at Maximum Air Drag

Separation under the maximum air drag is the one another determination point for basic performance of Launch Escape System. It needs enough thrust to overtake the air drag needs to separate manned re-entry module from rocket.

Sustain thrust is required after separation also because Re-entry Module and LES reduce speed suddenly by air drag even though Launch vehicle is much heavier and keep speed.

Fig. 15 shows relative distance between crew module and H-IIB after the emergency separation at maximum air drag. (note: 38kPa is used as maximum dynamic pressure. SRBs continue thrusting but main engine is cut-off during this analysis.)

This graph suggests that it takes only 10 sec for re-contact to rocket. Launch Escape System should avoid re-contact by own maneuver enough to depart. As wrote in previous section, Launch Escape System is better to have some active attitude control system to avoid re-contact not only for turning-around

in ground abort case but also depart from rocket under the maximum air drag.

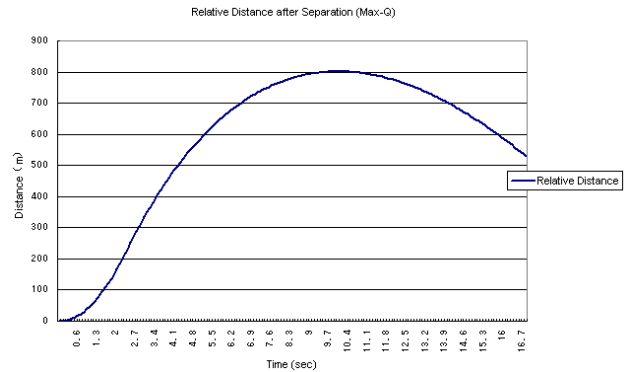


Fig. 15. Relative Distance under Maximum Air Drag

4.3 Abort at the End of SRB Burn

H-IIA and H-IIB rocket have Solid Rocket Booster (SRB) which is difficult to be immediately cut-off in emergency case. So, abort analysis for maximum acceleration by SRB is necessary in addition to the maximum air drag case. Time for re-contact under the maximum SRB acceleration case (near to the end of SRB burn) was estimated by simplified analysis and it is more than 11 sec because of the smaller air drag. Time criticality for separation and avoiding re-contact to rocket is higher in the maximum air drag than SRB maximum acceleration and characteristics of SRB (can not be cut-off immediately) does not spoil the capability of Launch Escape System.

4.4 Abort Trajectory and G-force Analysis

Launch Escape System is not all of aborting method for emergency during launch phase. Re-entry Module should return safely with crew in any time even after Launch Escape System separated. It is known that descent from higher altitude with insufficient velocity causes very high gravity forces and crew may be damaged. G-forces caused by descent for launch abort are parametric analyzed for every situation in this section.

Fig. 16. and Fig. 17. shows a sample trajectory for manned flight in nominal and abort with H-IIB rocket. This flight pattern was designed to keep altitude less than 120km in most of boost phase to avoid steeper re-entry after emergency separation. Original H-IIB has launch capability up to 16.5 ton into low earth orbit but gravity loss spoils it and only 14 ton can be inserted in this flight path. Following G-force analyses for abort trajectories used this flight path with spoiled payload weight for manned vehicle.

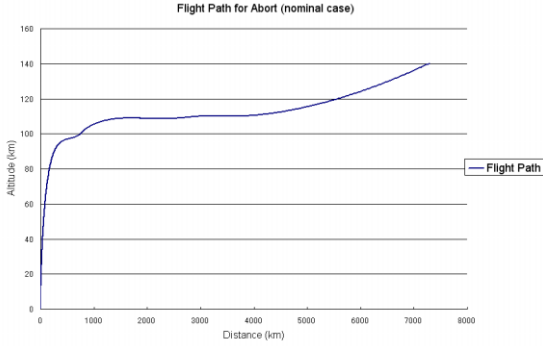


Fig. 16. H-IIB Manned Flight Path

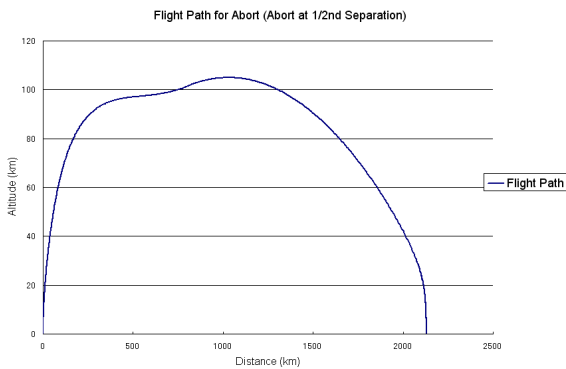


Fig. 17. Abort Flight Pattern (Example)

(1) G-force difference by Abort Timing

Fig. 18. shows the analysis result with zero-lift capsule in ballistic trajectory (note: zero-lift type is not recommended for manned flight. It was used for this analysis only).

This graph suggests that separation point of 1st/2nd stage (375sec in H-IIB) is the peak point to cause higher G-force during abort.

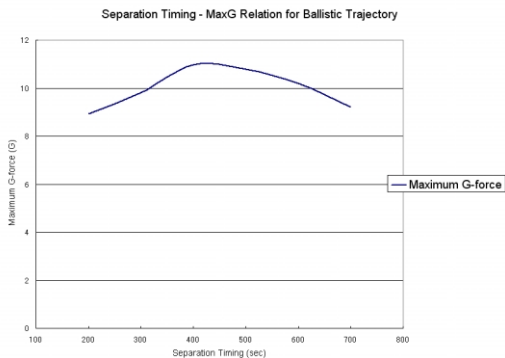


Fig. 18. Max G-force by Abort Timing

(2) G-force difference by Abort Altitude

Fig. 19. shows the result. 1st/2nd stage separation is selected for abort start timing since the result in (1). The result shows lower altitude is better and causes smaller G-force than higher altitude. The ratio is about 0.7G by 10km.

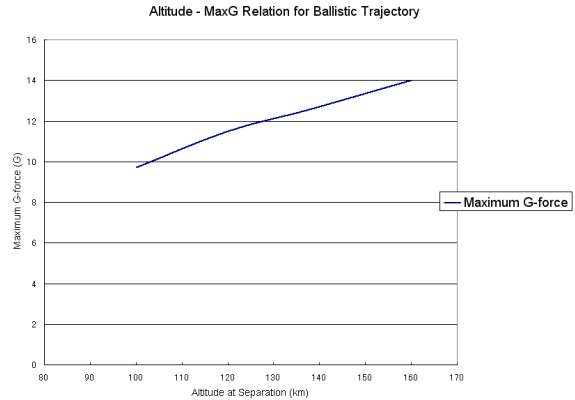


Fig. 19. Max G-force by Abort Altitude

(3) G-force difference by Re-entry Capsule Weight

Fig. 20. shows the result of analysis in which mass of re-entry module changed with the same diameter (parametric study for ballistic coefficient).

The result shows that maximum G-force during re-entry is not sensitive to ballistic coefficient. Heavier capsule re-enters lower altitude (higher atmosphere density) before reaching to the peak of G-force and the result shows similar G-force as lighter capsule.

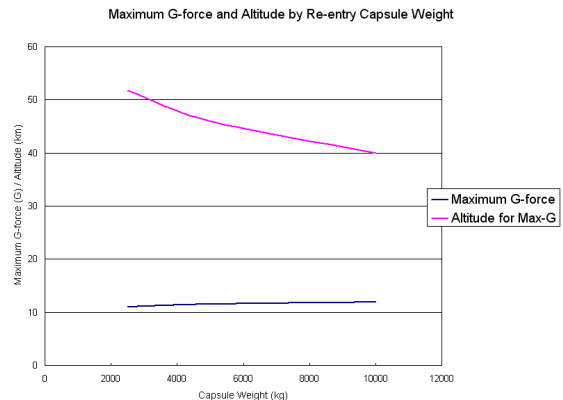


Fig. 20. Max G-force and Altitude by Abort Weight

(4) Effect of Aerodynamics in LES Design

As wrote in Section 3.3, large thrust of Launch Escape System is not desirable for G-force caused by ground abort. Smaller thrust can be selected if Drag/Weight ratio was decreased.

Heavier escape weight with the same air drag area (such as Soyuz design) enable to reduce G-force and looks good idea to satisfy both of thrust requirement air drag and G-force during ground abort. But aero dynamic (center of mass) has to be considered to design Launch Escape System. Configuration in Soyuz has Re-entry Module and Habitant Module in the aft part of vehicle during abort and center of mass locates in

backward. So, Soyuz has to have four folding drag plates at the aft end of abort configuration to fly property balanced from aerodynamic point of view from zero to a few mach number. They increase the total drag area and need higher thrust for separation under the highest air drag condition. Also, Launch Escape System has to re-developed if enhancement of Habitant Module added weight.

Launch Escape System should be carefully designed not only thrust level and propellant mass but also aerodynamic and mass balance includes future enhancement.

5 Development Steps

High priority development items for each module are picked up in following especially focusing on Re-entry Module and Launch Escape System.

(1) Whole Vehicle

- Weight Estimation for Each Module
 - Crew Support System Weight in Re-entry Module and Habitant Module
 - Drag/Parachute and Floating Bag Weight, Volume

(2) Launch Phase

- Abort Function with Launch Escape System
 - Abort Trajectory Analysis
 - Abort Demonstration from Ground with Parachute and Floating Bag
- Abort Analysis during Boost Phase
 - Rocket Trajectory Analysis for Manned Vehicle
 - G-force Analysis for Abort in Boost Phase
- Escape System Function Analysis
 - Nominal Separation Analysis
 - Aerodynamic Analysis after Abort/Separation
 - Attitude Control Analysis with Pitch Control Motor
 - Re-contact Analysis for Maximum Air Drag, Maximum Acceleration by SRB

(3) On-orbit Phase

- Re-entry Module/Habitant Module Connecting Mechanism
 - Feasibility Analysis for Rail/Rotation System from HTV
- Hatch Design between Re-entry and Habitant Module
- Solar Paddle Design

(4) Rendezvous Flight

- Crew Support System Design for Habitant Module

- System Tree for ECLSS
- Rendezvous Flight Control
 - Attitude/Trajectory Control, Navigation Component Tree
 - Propellant Consumption Analysis

(5) De-orbit and Re-entry

- Separation Analysis for Re-entry Module
- Aerodynamic Analysis for Lift Controlled Re-entry
- Drag/Parachute Deploy Analysis
- Recovery Sub-system Analysis
 - Drag/Parachute Size, Number
 - Volume Estimation in Re-entry Module

(6) Splash and Recovery

- Recovery Area Survey
- Team Scale Estimation for Sea Recovery
- Time Schedule
- Support System Requirement for Recovery

Even though HTV design and experiences will be usable for manned vehicle development, several technically challenging points are still remaining. Especially Re-entry Module design and operation includes sea recovery have to be demonstrated prior human flight. Launch Escape System is also.

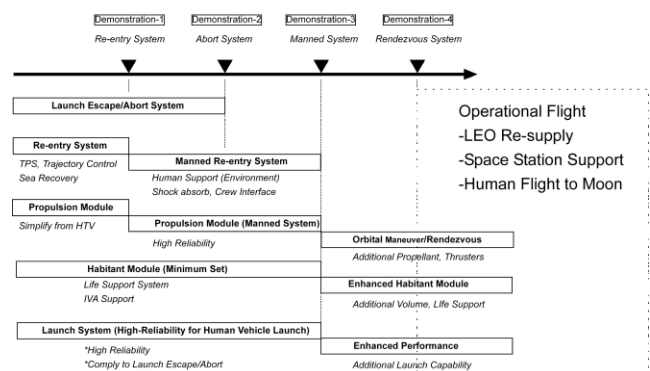
In this section, phased development plan for each module is recommended for cost/time effective development. H-IIA has a half of launch capability of H-IIB, and it is enough to demonstrate functions of Re-entry Module and Launch Escape System by un-manned flight.

Table. 5. Shows demonstration items in each development phase.

Following four flight configurations were assumed as demonstrations to validate the functions for human flight.

(Launch Vehicle Configurations are shown in Fig. 24.)

Table 5. Demonstrations in Each Development Step



[Demonstration-1]

- Un-manned Flight
- Demonstrations for Re-entry Vehicle, Recovery in Sea
- Total Weight: 6 ton + Margin
 - Re-entry Capsule: 5 ton
 - De-orbit Module: 1 ton

[Demonstration-2]

- Un-manned, but Manned Flight Path
- Demonstrations for Launch Escape/Abort System
- Total Weight: 9 ton + Margin
 - Re-entry Capsule: 5 ton
 - De-orbit Module: 1 ton
 - Launch Escape System: 3 ton
- Flight Path and Abort Flight (Re-entry Module L/D=0.4) is shown in Fig. 21 to Fig. 23.

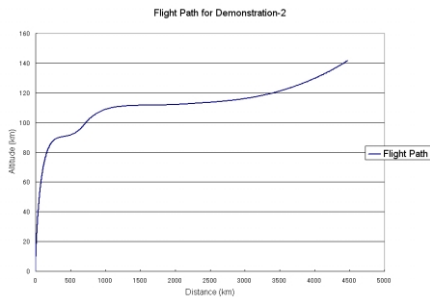


Fig. 21. Altitude Profile for Demonstration-2

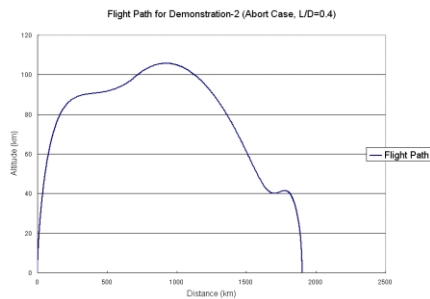


Fig. 22. Abort Path Sample for Demonstration-2

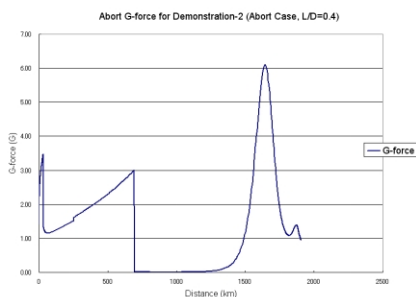


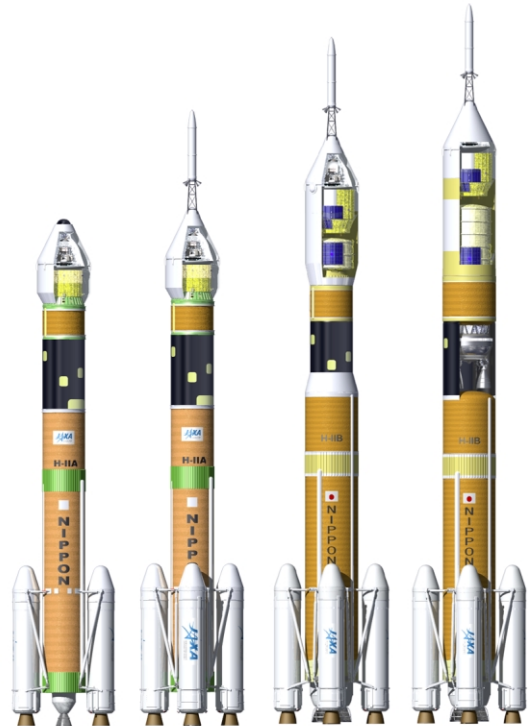
Fig. 23. Abort G-Load Profile for Demonstration-2

[Demonstration-3]

- Manned Flight
- Demonstrations for On-orbit Flight
- Total Weight: 14.3 ton + Margin
 - Re-entry Capsule: 5 ton
 - Propulsion Module: 1.3 ton
 - Propellant (off-loaded): 1 ton
 - Launch Escape System: 3 ton
 - Orbital Habitant Module (subset): 4 ton

[Demonstration-4]

- Manned Flight
- Demonstrations for all Mission
- Total Weight: 16.8ton + Margin
 - Re-entry Capsule: 5 ton
 - Propulsion Module: 1.3 ton
 - Propellant (full-loaded): 2.5 ton
 - Launch Escape System: 3 ton
 - Orbital Habitant Module: 5 ton



(from left to right: Demonstration 1 - 4)

Fig. 24. Launch Profile for Demo-missions

6 Summary

There are several technical missing parts to build Japanese manned spacecraft but the combination of HTV and H-IIB will become the base design by their performances to launch and transfer manned module. Technically challenging points found in LES and Re-entry module should be investigated soon to minimize the risk during development.