New H-IIA Launch Vehicle Technology and Results of Maiden Flight

Takashi Maemura[*1] **Tomohiko Goto**[*1]
Katsuhiko Akiyama[*1] **Koki Nimura**[*1]
Atsutaro Watanabe[*2]

The H-IIA launch vehicle launched August 29, 2001 is well-balanced in payload capability, reliability, practicality, safety, and cost compared to be H-II launch vehicle. To realize these concepts, aggressive efforts to make a less costly, less risky launch vehicle have transformed the H-II into an almost completely new booster. We describe new H-IIA technologies and its maiden flight results.

1. Introduction

The H-IIA launch vehicle (standard type), which has completed its successful maiden flight, is capable of launching a satellite of about two tons into geostationary orbit. With the aim of entering this field of business, Mitsubishi Heavy Industries, Ltd. (MHI) has developed this reliable, low-cost launch vehicle using various new technologies.

The H-IIA launch vehicle was designed mainly through application of the techniques accumulated through experience in the manufacture of the H-II launch vehicle. However, in order to simplify the vehicle structure and launch operation, almost all the components used in the H-II including the first stage and second stage engines, vehicle structure and ground data equipment installed in the launch complex were modified or replaced. Furthermore, the entire vehicle was examined repeatedly for systematized function system with the aim of developing an easy-to-manufacture and easy-to-operate launch vehicle.

Consequently, the manufacturing cost of the H-IIA launch vehicle was reduced to 8.5 billion yen or less per vehicle, or approximately half the cost of the H-II, and its performance is comparable to any other commercial launch vehicle now available in the world. This paper gives an outline of the main development work assigned to MHI, the technical requirements for application of new techniques, the results of the applied techniques, and the results of the H-IIA launch vehicle's maiden flight.

The main fields of work allotted to MHI were:

(1) Support for integration of all stages and support of vehicle launching operation
(2) First stage main engine (LE-7A), (combustion system and coordination of system)
(3) First stage propulsion system and thrust vector controlling system
(4) First stage LOX/LH_2 tanks
(5) First stage center body section, engine section and power supply system
(6) Second stage main engine (LE-5B), (combustion system and coordination of systems)
(7) Second stage propulsion system and thrust vector control system
(8) Second stage LOX/LH_2 tanks
(9) Second stage structure and power supply system
(10) Coordination of guidance and control system
(11) Payload adaptor
(12) Launch complex, Aerospace Ground Equipment (AGE) (main components of propulsion system, avionics system and mechanical system)

2. Outline of the H-IIA launch vehicle

The H-IIA launch vehicle was developed from the H-II but has considerable differences in the design of vehicle structure, engine, rocket motor and many other components. Although the H-IIA launch vehicle was designed on the basis of the techniques accumulated during the development of the H-II, only a small number of component parts are used in common by these two vehicles. However, in view of the fact that the completion of the simplified and cost-reduced H-IIA depended entirely on the accumulated techniques acquired during the developing of the H-II, the H-IIA launch vehicle can be regarded as a successor to the H-II.

Table 1 shows the maiden flight results of the H-IIA. The flight achieved the target parameters shown.

The liquid fuel rocket engines of the H-IIA launch vehicle are LE-7A (first stage) and LE-5B engines, improved version of LE-7 and LE-5A which are originally designed for the H-II.

The propulsion system of the H-II was thoroughly reviewed in designing the H-IIA in order to reduce the number of system components and plumbings, and to simplify and integrate the system components. For example, cryogenic helium used in the H-II to pressurize the first stage LOX tank was replaced by a system that uses gaseous oxygen produced in the engine heat exchanger for H-IIA.

[*1] Nagoya Aerospace Systems WorksNational Space
[*2] Development Agency of Japan (NASDA)

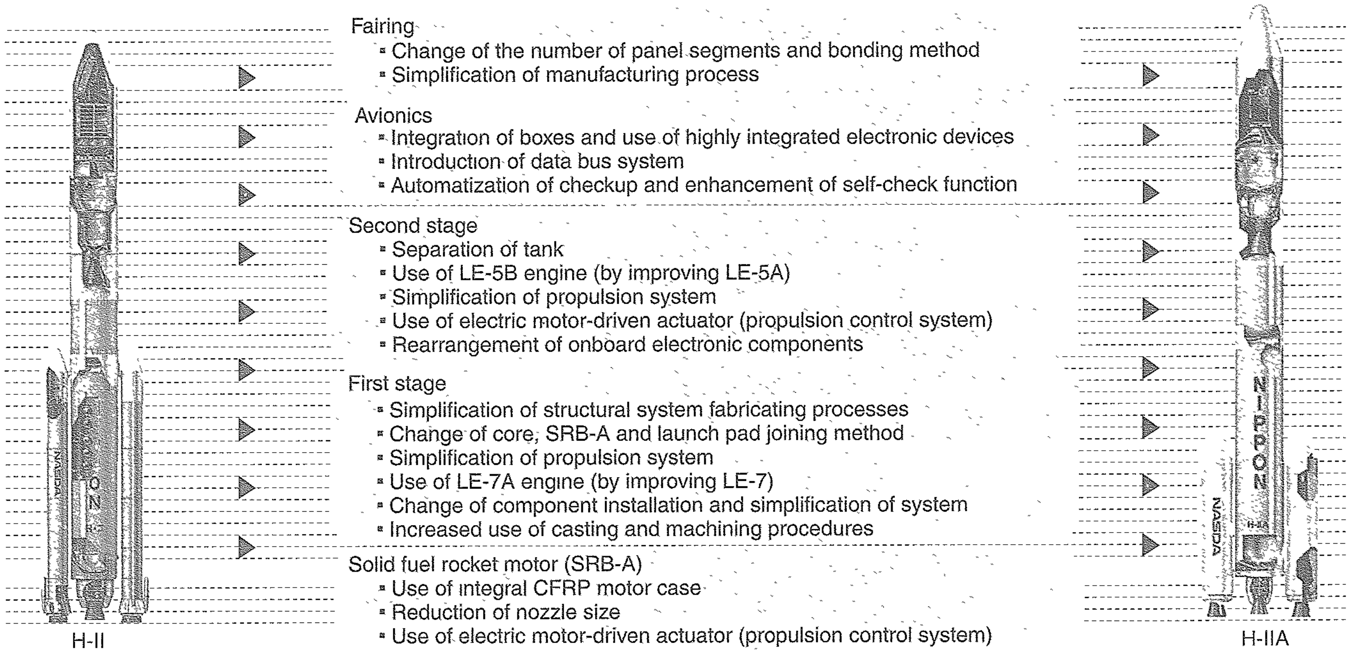

Fig. 1 H-IIA improvement
The H-IIA launch vehicle was developed from the H-II with the following improvements.

In the thrust vector control system, the structure of the first stage hydraulic supply system was simplified, the second stage hydraulic supply system was replaced by an electric motor-driven system, and the functional tests and other related tasks were also simplified.

One of the most remarkable improvements is that the shaping process of the bulk heads to seal each tank at top and bottom was simplified by applying the spin forming method to shape them from a piece of sheet material by drawing. The second stage tank of the H-II used an integrated tank structure with vacuum insulated common bulk heads, but this was replaced by separate tanks joined together with a truss for the H-IIA. This modification made it easier to fabricate the second stage structure and control the temperature and pressure (pressure difference between tanks) during loading of cryogenic propellant.

Table 1 Orbital parameters of H-IIA flight No. 1 (Maiden flight results of the H-IIA)

Parameters		Targeted	Achieved	Defference (sigma)
Apogee Altitude	(km)	36 186.200	36 190.627	1.427 (0 100)
Perigee Altitude	(km)	251.300	251.319	0.019 (0.021)
Orbital Inclination	(deg)	28.492	28.496	0.004 (0.710)
Argument of Perigee	(deg)	179.065	179.189	0.124 (1.279)
Ascending node	(deg)	36.384	36 345	-0.039 (-0 349)

The thrust developed by the solid fuel rocket motor (SRB-A) passes through the thrust struts and is received by the lug which forms an integral part of the cross beam fixed on the LE-7A engine.

The material used to construct the interstage section between the first and the second stages was changed to carbon fiber composite material (CFRP) from the conventionally used aluminum alloys (MHI's scope of work).

The electronic guidance and control system (avionics) for controlling the launch vehicle is connected to each item of equipment via a data bus which is a common data "highway." This allows

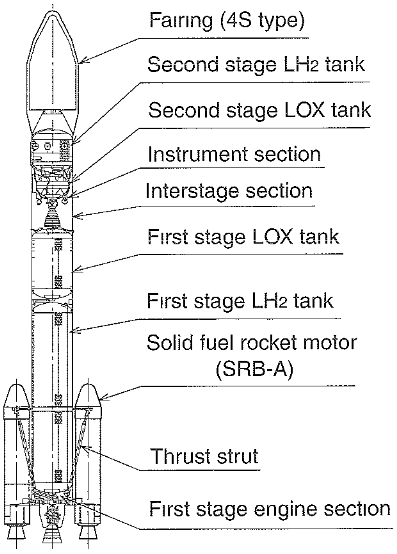

Fig. 2 Structural outline
Structural outline of the H-IIA and name of each section are shown.

Table 2 Design data of H-IIA launch vehicle

H-II					H-IIA					
Rocket fairing	Second stage	Solid fuel rocket motor (SRB)	First stage		First stage	Solid fuel rocket motor (SRB-A)	Second stage	Rocket fairing	Auxiliary solid fuel rocket motor (SSB)	Liquid fuel rocket motor (LRB)
12 (standard)	11	23	35	Overall length (m)	37.2	15.2	10.7	12.0	14.9	36.7
4.1 (standard)	4.0	1.8	4.0	Outside diameter (m)	4.0	2.5	4 0	4.07	1.0	4.0
1.4 (standard)	20	141 (for two)	98	Weight of each stage (ton)	114	150 (for two)	20	1.4	31 (for two)	117
	17	118 (for two)	86	Weight of propellant (ton)	100	130 (for two)	17 (when lifting off)		26.1 (for two)	99.2
	122 (12 4t)	3 530 (360.0 t) (for two)	1 079 (110.0t)	Thrust (kN) (in vacuum)	1 074 (109.5 t) Short nozzle	4 520 (460.0 t) (for two)	137 (14t)		1 490 (for two, max)	2 200 (two engines)
	598	93	345	Firing time (s)	390	100			60	200
	LOX/LH2	Polybutadiene composite solid propellant	LOX/LH2	Type of propellant	LOX/LH2	HTPB composite	LOX/LH2		HTOB composite	LOX/LH2
	452	273	445	Specific thrust (s) (in vacuum)	429 Short nozzl	280	447		282	440

Table 3 Cost and performance data of launch vehicles

Name of launch vehicle	Long March 3 (3A)	Proton K	H-II	H-IIA (standard type)	Delta III	Atlas II AS	Ariane IV (4L)	Ariane V
Country	China	Russia	Japan		USA		Europe	
LEO launching capacity (ton)	8 5	21	10.0	10.0	8.3	8 6	9.6	18
GTO launching capacity (ton)	2.6	4.9	4 0	4 0	3.8	3.8	4.5	6.8
Launching cost(100 million yen)	54 - 66	108 - 118	170 - 190	75 - 85	90 - 108	108 - 126	120 - 150	180 - 216

$1 = ¥120

simple connection of the onboard equipment to the ground station and facilitates checkup of equipment. Reliability of the onboard equipment is also enhanced by the self-checking process.

The main improvements made to the H-II are listed in **Fig. 1**, **Table 2** shows a comparison of the H-II and the H-IIA vehicles by engine specifications, and a list of estimated launching costs and performance of the launch vehicles throughout the world is provided in **Table 3**.

The following is an outline of the technical features of the H-IIA launch vehicle.

3. Structural system

3.1 Outline of the first stage structure

Fig. 2 shows an outline of the H-IIA launch vehicle structure. The solid rocket booster (SRB-A) of the H-IIA is larger in diameter and shorter in length than that of the H-II, and the thrust generated by the SRB-A is transmitted to the tail end of the engine section via the thrust struts joined to the SRB-A upper skirt that is made of aluminum alloy. The radial component of the thrust generated by the SRB-A is transmitted to the SRB-A frame welded with cylinder section of the LH_2 tank and the frame assembled into the engine section through the yaw brace, while the circumferential component is transmitted to these sections through the pitch pins. The launch vehicle is fixed to the launch pad at the tail end of the first stage engine section.

Fig. 3 shows the aerodynamic load of the H-IIA during flight. The axial force of the first stage engine

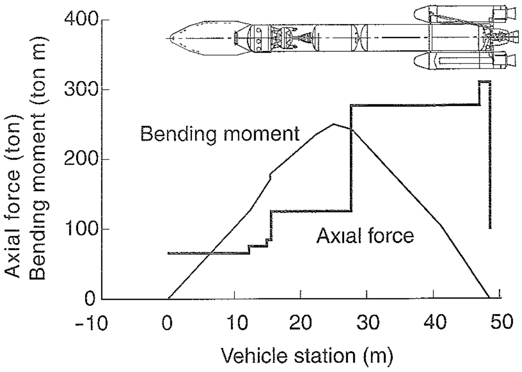

Fig. 3 Aerodynamic load during flight
Distribution of aerodynamic loads (axial force and bending moment) applied to the H-IIA in flight under aerodynamic force and inertial force is shown.

section and the LH_2 tank is greater than that of the H-II launch vehicle (the thrust of the solid fuel rocket motor is received at the center section and the vehicle is fixed to the vehicle pad with its solid fuel rocket motor). To distribute the concentrated load of the SRB-A, integrated reinforced panels and frames were utilized to assemble the engine.

The first stage LH_2 tank has an isogrid structure that is similar to the H-II. However, in order to increase the buckling strength against increase in the load, thicker plate was used for the structure and the SRB-A frame was welded on the cylinder section to receive the radial and circumferential components of the thrust developed by the SRB-A.

3.2 Interstage section

The interstage section is a cylindrical shape with four meters in diameter and about seven meters in height which is made of CFRP plates with a foamed core material between them. To reduce the manufacturing cost and vehicle weight by use of fewer component parts, this section was improved in all aspects, including the methods of manufacturing and inspections. **Fig. 4** shows an outline of the interstage section. Aluminum alloy skirts are installed with fasteners to the forward and rear aft of the cylindrical section. The interstage structure must have sufficient buckling strength, because it receives the mainly compressive load and bending moment during flight. After completion of the development tests including the material design data acquisition test, structural element test, manufacturing test, allowable defect test, damage-tolerant verification test and panel acoustic test, a qualification test was conducted on a prototype test model to verify the buckling strength by structural strength test. During the structural strength test, liquid nitrogen was used to cool the aft end skirt, simulating the thermal effect given by the adjacent first stage LOX tank. The test results proved that the prototype test model withstood the aerodynamic load, and the measured strain correlated well with the analysis results shown in **Fig. 5**.

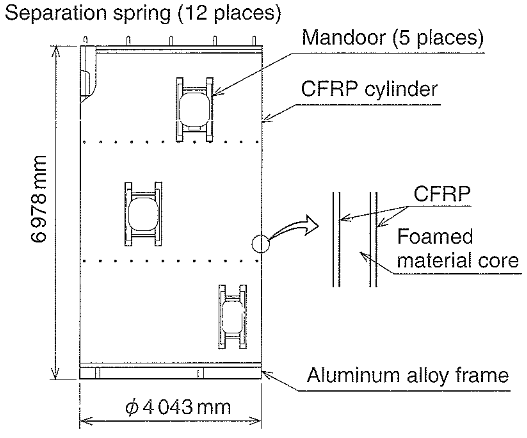

Fig. 4 Structural outline for interstage

3.3 Separation of SRB-A

The SRB-A separates from the core vehicle about 110 seconds after lift-off when firing is completed and dynamic pressure decreases at an altitude of about 52 kilometers. **Fig. 6** shows the analysis results of SRB-A separation. After the forward and aft yaw braces are cut off by the ordnance system, the SRB-A assembly departs from the launch vehicle that is held by thrust struts, and is completely separated after about two seconds at the moment the thrust struts are cut off. **Fig. 7**shows images of the SRB-A separation captuerd during flight. The recorded behavior simulate well with the separation analysis results.

4. Propulsion system

With the aim of developing a simpler and more

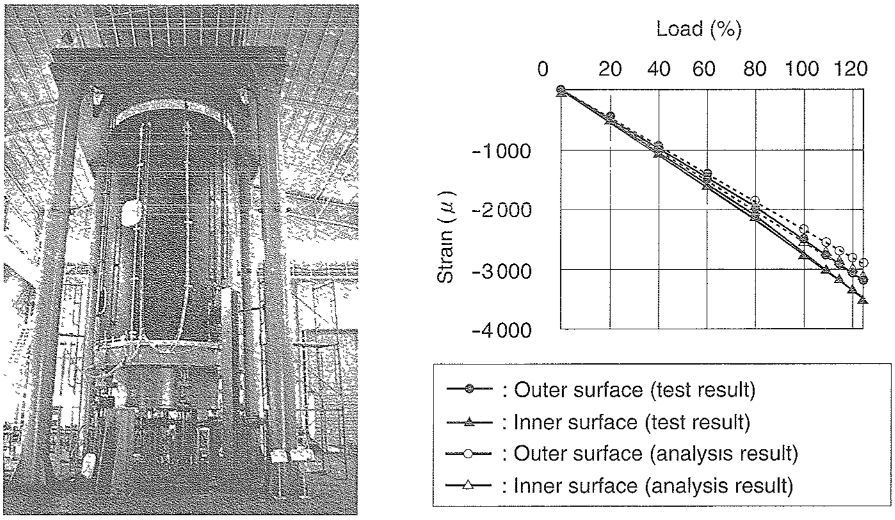

Fig. 5 Structural strength test results for interstage
General view of a full-scale interstage test model set up on the testing stand for structural strength test and comparison of meas-ured strain to analysis result are shown.

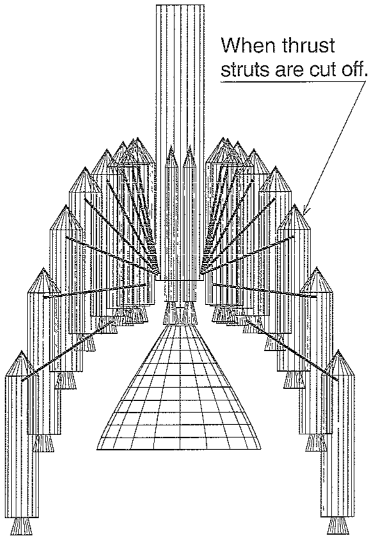

Fig. 6 Separation analysis results for SRB-A
The simulation analysis results of SBR-A separating behavior is shown.

(a) About one second after cut-off of yaw braces.

(b) About 2 5 seconds after cut-off of yaw braces.

Fig. 7 Captured image for SRB-A separation during flight
Images photographed at the moment of SRB-A separation by onboard camera are shown.

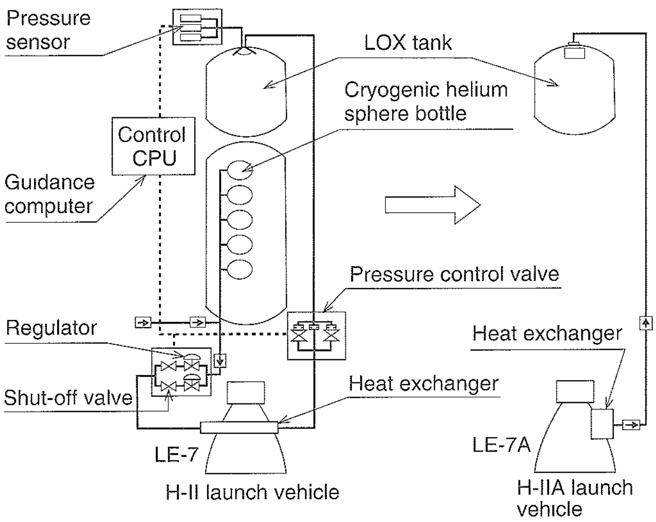

Fig. 8 First stage LOX tank pressurization system
Comparison of newly developed system for the H-IIA to the H-II system is shown.

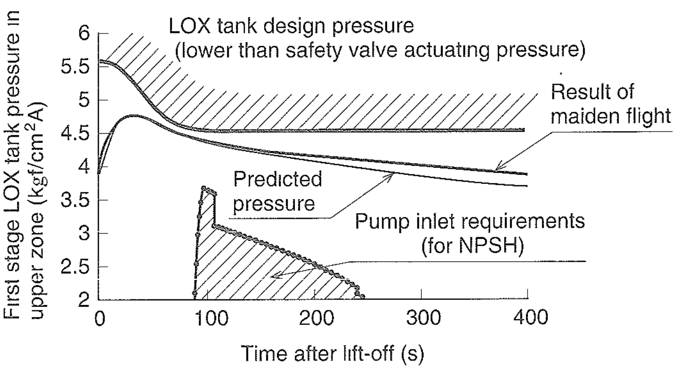

Fig. 9 First stage LOX tank pressure
Predicted pressure phenomena and results of maiden flight are shown.

reliable propulsion system than that used in the H-II launch vehicle, MHI has improved the propulsion system for the H-IIA vehicle mainly in the following sections.

4.1 First stage LOX tank pressurization system

The H-II and H-IIA launch vehicles have a tank pressurization system for supply of propellant to the engine turbo pump at a specified pressure.

In the first stage LOX tank pressurization system of H-II, the tank pressure was controlled by reducing the pressure of high-pressure cryogenic (20 K) helium in the helium sphere bottles located inside the LH_2 tank, by warming it with the heat of engine and then by changing the flow rate with the onboard flow control valve. However, the LOX tank of the H-IIA is pressurized with a constant flow of gaseous oxygen which has been gasified from the high-pressure LOX in the engine heat exchanger. **Fig. 8** shows the difference between the LOX tank pressurization systems of the H-II and the H-IIA.

Although use of LOX as gaseous oxygen is disadvantageous to the payload, considerable reduction in the number of component parts compensates for such disadvantages and contributes to improving the system reliability and lowering the manufacturing cost.

In addition, because the tank pressure is not controlled in an active manner, prediction of tank pressure has become an important technique, and accordingly, the influence of the following phenomena were discussed:

- Condensation of gaseous oxygen and evaporation of liquid oxygen
- Interference of pressurization gas flow through tank inlet diffuser with the liquid surface (gas pressure drops with disturbance of liquid surface)

The data on the influence of these phenomena were obtained from the stage firing tests (battleship firing test and captive tank test) and used to optimize the operating conditions of the actual tank pressurization system.

The maiden flight of the H-IIA launch vehicle has proved that the pressure of the first stage LOX tank showed the predicted pressure history and satisfied the engine inlet requirements within the designed tank pressure. **Fig. 9** shows the results of the first stage LOX tank pressure during flight.

4.2 First stage hydraulic blow-down system

For engine gimbaling and attitude control of the vehicle, the H-II and the H-IIA launch vehicles have a gimbaling system that adjusts the thrust vector of the engine by shifting the engine itself. A hydraulic actuator is installed in the first stage section to

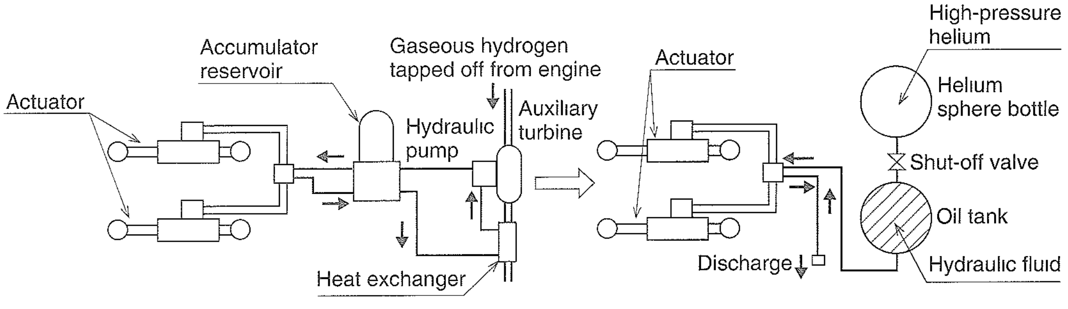

Fig. 10 First stage thrust vector controlling system
Differences between the system configurations of the H-II and the H-IIA launch vehicles are shown.

operate the gimbaling system.

Fig. 10 shows the first stage thrust vector controlling systems for the H-II and H-IIA launch vehicle. The hydraulic fluid circulation system used in the H-II launch vehicle requires various components such as turbine, pump, accumulator, heat exchanger, etc. To reduce the manufacturing cost and increase the system reliability of the H-IIA at the same time, the conventional hydraulic system was fully replaced by the blow-down system that pushes hydraulic fluid out of an oil tank with the pressure of helium which is contained in the sphere bottles. The helium sphere bottles, which had already been developed for the propulsion system, were used also for the oil tank of the H-II to save on extra expenditure for development. As a result, the blow-down system was manufactured at a cost of only about one half that of the conventional fluid circulation system. The then-existing helium sphere bottles that were connected to each other were partly modified for use as oil tank. For example, in order to prevent gaseous helium from dissolving in hydraulic fluid before the start of the launching operation, the helium sphere bottle is isolated from the oil tank with a shut-off valve, and sponge-like baffle material is placed in the oil tank to prevent the gas produced by sloshing of hydraulic fluid during flight from being sucked into the actuator. The maiden flight data proved that this system operated well without any occurrence of gas suction or extraction of dissolved gas (**Fig.11**).

4.3 Restart of the second stage engine

It is absolutely necessary to restart the second stage engine in a high vacuum and low gravitational field. The control of propellant in a low gravitational field is particularly difficult, because the control result cannot be experimentally checked on the ground.

During an inertial flight period of about 700 seconds immediately before restarting the second stage engine, a micro-acceleration of about 1×10^{-3} G is applied. However, when the tank supplies (discharges) propellant, the subsidence in the liquid surface – which does not occur until the propellant has been completely discharged in ground tests in a 1 G field – occurs earlier in a low gravitational field in which the inertial force becomes a governing factor, and a large amount of propellant may be left unused in the tank.

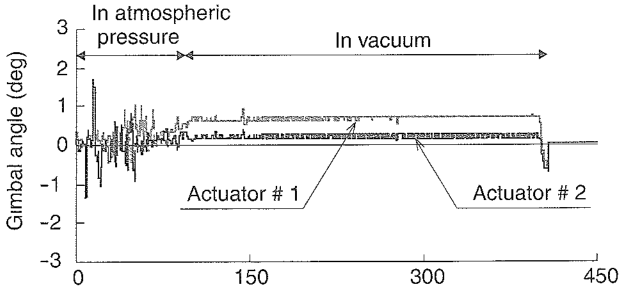

Fig. 11 First stage thrust vector angle
Flight data on gimbal angle of actuators are shown.

As the remaining unused propellant lowers the flight performance of the launch vehicle, various improvements were made to the tank suction section to minimize the amount of unused propellant. To confirm the effect of the improvements in a low gravitational field, drop tests were conducted using a 50-meter drop test tower in the Tashiro Test Field.

Due to the fact that the duration of a drop was only about three seconds, confirmation of the continual behavior of the propellant in a low gravitational field had to be made by evaluating the data collected during the maiden flight.

To evaluate the estimated phenomena and use the evaluated results for the improvement of the propellant management technique, it was planned to record the image data of the behavior of the liquid surface during the maiden flight of the H-II through a monitor window installed on the top of the LH_2 tank.

The image data collected by the onboard equipment during the flight were transmitted to the ground station in the form of digital signals and used to confirm various aspects of the propellant: smoothness of the liquid surface in a low gravitational field, behavior of the liquid surface when disturbed with

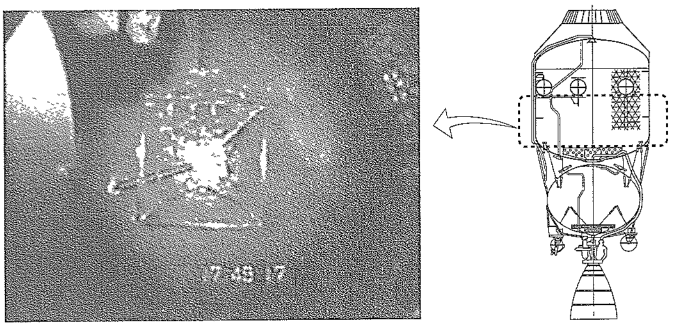

Fig. 12 Inside image of LH2 tank
Image of behavior of propellant inside LH2 tank photographed with onboard camera during flight is shown.

pressurization of tank, behavior of propellant sloshing with vehicle spinning, etc. (**Fig. 12**).

These unique moving images that disclose the behavior of the propellant inside the launch vehicle in flight will be used to verify the simulation analysis data on the behavior of the propellant during flight, and thus to help establishing of a more accurate propellant management technique in future.

5. Guidance and control system

The guidance and control system were developed mainly to lower the manufacturing and operation costs of the H-II launch vehicle. Typical improvements made to the systems were as follows:

(1) Vehicle self-check system by data telemetering
(2) Use of serial communication link system in umbilical line
(3) Use of electric motor-driven actuator in second stage engine gimbaling system
(4) Program rate reset system

5.1 Vehicle self-check system by data telemetering

The vehicle check system for the H-II monitored the telemeter data transmitted from the vehicle to ground data equipment. The H-IIA launch vehicle used a vehicle self-check system with an onboard computer for monitoring the telemeter data. This onboard functional self-check system, the first of its kind in Japan, worked satisfactorily at the time of the launching operation (**Fig. 13**) for decisions regarding abnormalities.

5.2 Use of serial communication link system in umbilical line

The umbilical line used to interface the H-II launch vehicle with the ground data equipment consisted of a bundle of a large number of signal lines, because the signal transmission was based on the "one line for one signal" system. To make the umbilical line simpler and more compact, a serial communication link system was employed for the launching of the H-IIA vehicle. For this purpose, an umbilical controller (UMC) for receiving various onboard data and providing ground data equipment with information through a serial data bus was newly developed. In developing the UMC, because it was not an onboard device, many commercial parts (including general industrial sequencers) were used to reduce the manufacturing cost. This controller worked satisfactorily during the preparatory operation for launching and did not affect any other functions during the maiden flight of the H-IIA vehicle (**Fig. 14**).

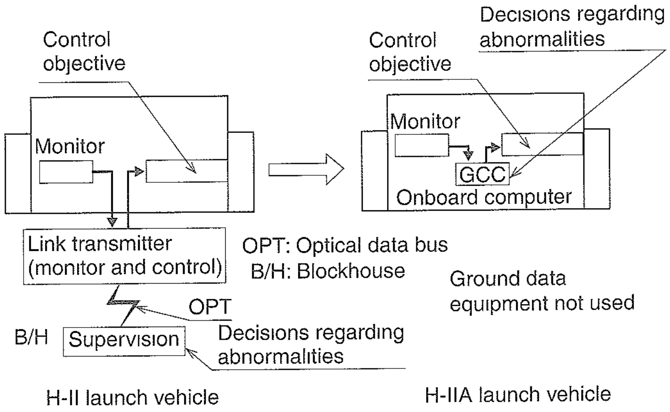

Fig. 13 Vehicle self-check system
Unlike the H-II, the H-IIA launch vehicle has a self-checking system working inside the vehicle independent of the ground data equipment.

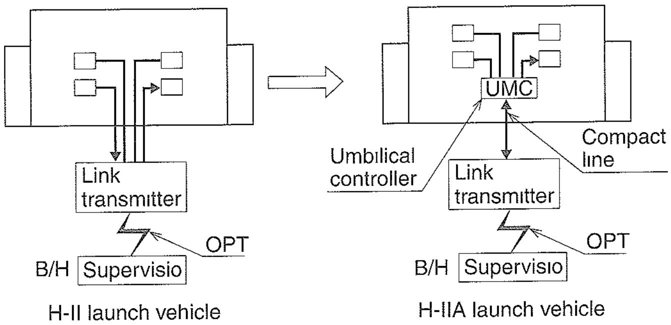

Fig. 14 Serial communication link for umbilical line
The interface between the H-IIA and ground data equipment is simplified by using a serial communication link.

5.3 Use of electric motor-driven actuator in second stage engine gimbaling system (engine)

An electric gimbaling system was used in the H-IIA second stage engine instead of the hydraulic gimbaling system which had been employed for the H-II launch vehicles. For this purpose, an electric actuator and its gimbaling system for the second stage engine were developed.

A standby redundancy system was incorporated in the avionics system. The maiden flight has proved that this system worked well for the attitude control of the second stage engine. The system was applied also to the No. 8 H-II launch vehicle.

5.4 Program rate reset system

A program rate reset system, by which the flight program can be modified even on the launching day by making the angle of attack smaller depending on

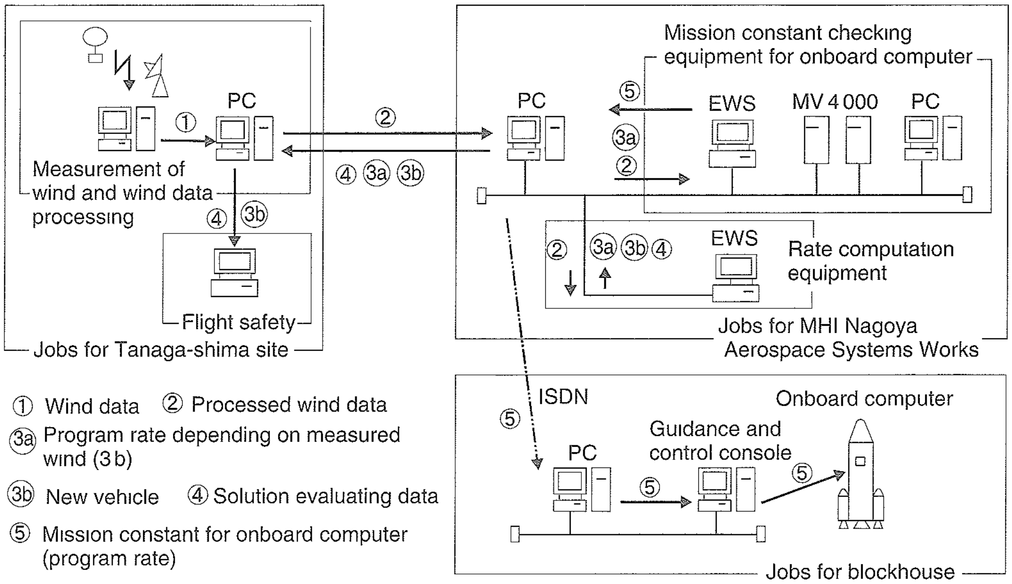

Fig. 15 Schematic diagram of program rate reset
Program rate is reset depending on the measured wind and reset data are loaded into vehicle.

the velocity of the wind at higher altitudes that the vehicle may encounter after lift-off, was prepared for launching of the H-IIA vehicle.

Fig.15 shows the configuration of the program rate reset system. The data on the wind measured at the Tanega-shima site on the launching day were transmitted to the MHI Nagoya Aerospace Systems Works for computation of the flight program to make the angle of attack smaller and also for checking the mission constant to be applied to the vehicle. The flight program thus checked was loaded into the H-IIA launch vehicle via the ground data equipment in the blockhouse at the Tanega-shima site.

Conventionally, the vehicle body needed to be designed after estimating the angle of attack, which depended on the difference between the average wind during the period in which launching of the vehicle was scheduled and the wind which the vehicle might encounter on the launching day. The application of this program rate reset system made it possible to reduce the vehicle load and the body weight of the H-IIA launch vehicle by making the angle of attack smaller pursuant to the wind close to that the vehicle may experience at higher altitudes. This system worked satisfactorily during the H-IIA maiden flight.

6. Conclusion

MHI has successfully performed the H-IIA launch vehicle's maiden flight. However, in order to enter the commercial aerospace business field, it will be necessary to achieve continuous success in the launching of No. 2 and No. 3 H-II launch vehicles, make efforts to further enhance the flight reliability and reduce the launching costs so that the H-IIA launch vehicle may be widely recognized as a hundred-percent reliable, safe and low-cost launch vehicle. MHI is now developing an augmented-type vehicle which will have a greater launching capability than the standard type vehicle described in this report, and is directing its efforts toward the successful completion of this project.

References

(1) Yukio Fukushima, et al.,"Vehicle structure of H-II rocket"(Japanese), Journal of the Japan Society for Aeronautical and Space Sciences, Vol. 46, No. 535 (1998-8), p.10
(2) Mitsuru Kobayashi, et al., "Development of H-IIA CFRP inter-stage structure"(Japanese), Proceedings of 24th Composite symposium (1999), p.125
(3) Web site of National Space Development Agency of Japan (NASDA)