Success of the H-IIB Launch Vehicle (Test Flight No. 1)

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The H-IIB launch vehicle carrying the H-II transfer vehicle (HTV), launched on September 11, 2009, successfully delivered the HTV into its designated orbit. Three factors are featured for the development of the H-IIB launch vehicle: joint development between the government and private sectors; a short development term, three years from the detailed design to the launch; and, where possible, adaptation of the technology used for the previous H-IIA. The development status of the H-IIB launch vehicle is discussed in Mitsubishi Technical Review Vol. 45 No. 4 (2008). This paper focuses principally on the whole of the development and launch operations.

1. Introduction

The H-IIA-based H-IIB launch vehicle was jointly developed by the government and private sectors. The government's objective was to launch the H-II transfer vehicle (HTV), which transports supplies as a sharing role to participate in the International Space Station program. The private sector's objective was to expand the launch capability of the privatized H-IIA launch vehicle families to ensure international competitiveness. Preliminary design started in July 2005, and the basic agreement between the Japan Aerospace Exploration Agency (JAXA) and Mitsubishi Heavy Industries, Ltd. (MHI), was concluded in September to carry out the development. An unprecedented short-term period of three years from the detailed design to launch was scheduled to develop the H-IIB for an HTV launch in September 2009. The development costs were lowered by MHI since the H-IIB evolved from the H-IIA launch vehicle design. As a system integrator, MHI controlled the entire development.

At 02:01:46 a.m. on September 11, 2009, the H-IIB was successfully launched without even one second of delay, demonstrating the excellence of Japan's space development technology to the world. (The launch window did not allow even a one second delay for successfully injecting the HTV into the designated orbit.) This paper outlines the H-IIB development and includes some future mission possibilities.

2. H-IIB launch vehicle

The H-IIB is a two-stage launch vehicle using a liquid oxygen/liquid hydrogen propellant. Its overall length is approximately 57 m (including a fairing for the HTV) with a gross mass of approximately 530 tons (payload mass not included). The first-stage diameter was expanded from the 4 m H-IIA to 5.2 m, and the propellant quantity was increased approximately 1.7 times. A cluster of two first-stage LE-7A engines was used instead of a single engine to enhance the launch capability.

To maintain and improve the reliability of the launch vehicle and to increase the launch operation efficiency, MHI used common or modified already-developed parts, including the second-stage components of the H-IIA.

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The H-IIB is capable of launching 16.5 tons of payload into the HTV injection orbit (300 km apogee altitude, 200 km perigee altitude, 51.65 degrees inclination), and approximately 8 tons of payload into the geostationary transfer orbit (GTO). In the GTO mission, MHI aims to boost cost competitiveness by simultaneously launching two 2-4 ton class satellites, which account for approximately 50% of satellite demand (**Figure 1**).

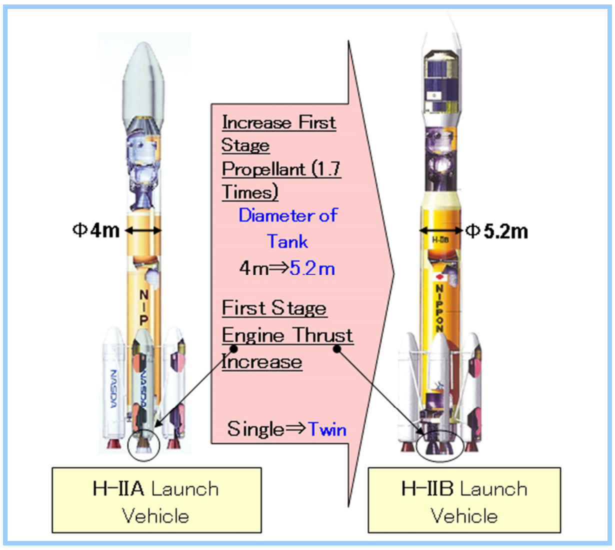

Figure 1 Changes from the H-IIA launch vehicle

3. Main technology development tests

The principle technical developmental launch vehicle issues were the 5.2 m diameter tank and the first-stage engine cluster technology.

3.1 Tank development

Integral forming technology and friction stir welding (FSW) were the key technologies in the tank development; Integral forming technology was used to fabricate the tank dome and FSW was applied to weld the tank joints. Since the integral forming technology was not available domestically, the tank domes were procured from abroad. We attempted to establish the technology necessary to manufacture a world-class tank through in-house test studies between 2000 and 2003. The goal was to improve our tank design and manufacturing technology, aiming to form the domes using our own integral forming technology and by applying the latest FSW to all welded joints.

(1) Tank dome integral forming technology

The actual dome was developed through in-house experimentation and research done at Hiroshima Machinery Works of MHI, where the available existing plant facilities were used to develop a considerable amount of heavy machinery and equipment (**Figure 2**).

By certainly dealing with the action items arose during the process when scale-model dome of the test studies was scaled up to the actual dome size, we were able to achieve a world-class integral forming dome, 5.2 m in diameter (**Figure 3**).

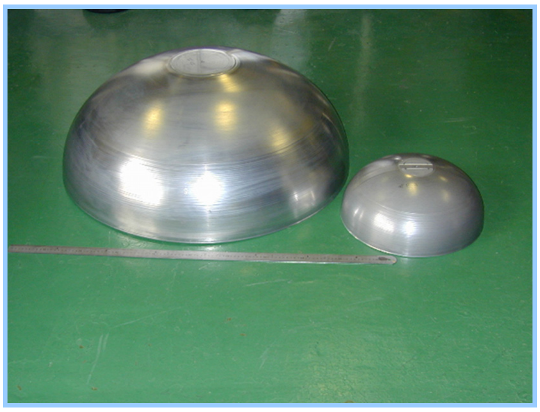

Figure 2 Spin-formed domes manufactured as part of an in-house test study (diameters of 900 and 400 mm)

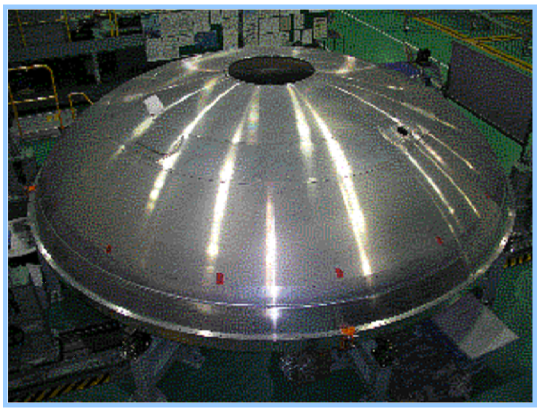

Figure 3 Actual formed dome (after machining)

(2) FSW technology development

FSW is a method of joining materials by stirring while softening them with frictional heat, by pressing a rotating tool with a protrusion against the desired joints (**Figure 4**). This technology was adopted for the H-IIB, because it provides good weld quality, while also reducing manufacturing costs. It can also potentially weld aluminum lithium alloy. FSW had previously been limited only to longitudinal joints (longitudinal direction in the tank), but here was expanded to circumferential joints (**Figure 5**).

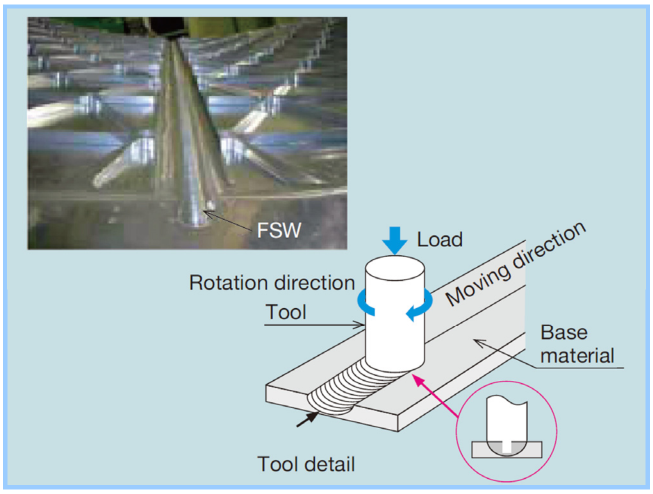

Figure 4 Overview of FSW

Figure 5 Liquid hydrogen tank welded by FSW

3.2 Clustering technology development

Clustering engines is indispensable when increasing the size of launch vehicles. Typical clustering examples include the Saturn launch vehicle, with five first-stage engines, and the space shuttle, with three first-stage engines.

The H-IIB has a two-engine cluster in its first stage. However, for the sake of risk reduction, the propellant supply systems were located independently to each engine using the technology and components acquired during the H-IIA development.

The main issue created by clustering was the influence on the acoustic vibration and thermal environment caused by interference of the plumes from the two engines. We analyzed this influence using computational fluid dynamics (CFD), and incorporated the results in the design. The CFD was conducted by both JAXA and MHI technical headquarters, who also performed the calibration.

We conducted demonstration battleship tank-firing tests (BFT) eight times between March and August in 2008, and completed all tests as planned (**Figure 6**).

In addition to confirming the basic performance, we improved the verification level of the combustion test by conducting tests assuming maximum dispersion for the various parameters in the BFT, thereby making the development plan more reliable.

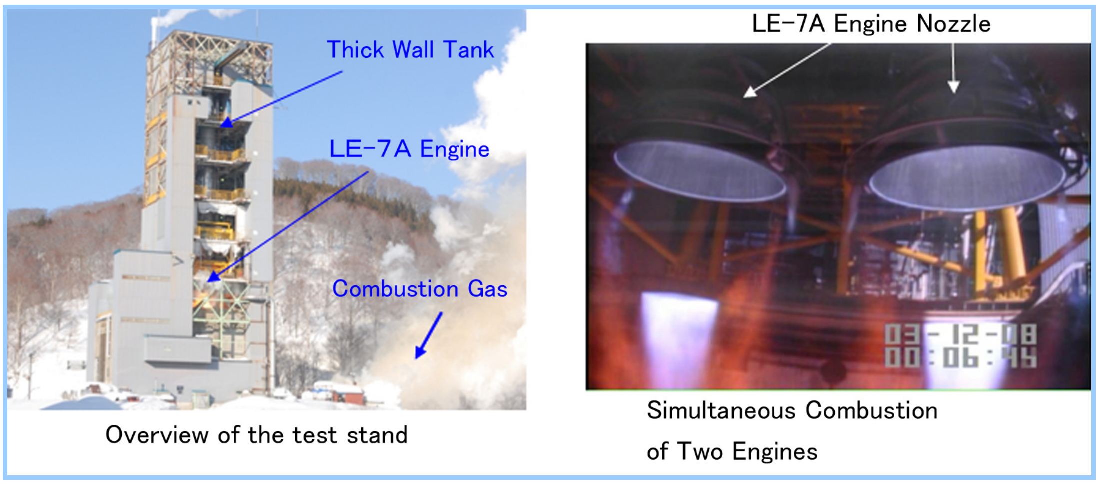

Figure 6 BFT overview

4. CFT / GTV and Flight #1 launch at Tanegashima Island

After completing each subsystem development test, the launch vehicle for the first flight was manufactured at the Nagoya Aerospace Systems Tobishima plant and shipped to the Tanegashima Space Center on February 17, 2009, for a captive firing test (CFT), a grand system test (GTV), and the launch.

4.1 CFT and GTV

In Tanegashima Space Center, after the test flight vehicle was installed on the launch pad and the ground facilities which had been modified for the H-IIB, the CFT and GTV were conducted (**Figures 7 & 8**).

Figure 7 CFT combustion test

Figure 8 GTV test (vehicle in motion)

For the CFT, we conducted two combustion tests, 10 seconds and 150 seconds in length, on April 2 and April 22, respectively, and completed the development of the first-stage propulsion system with the clustered engines. After finishing the CFT, we exchanged the two first-stage LE-7A engines for the flight ones, and changed to the launch configuration by installing four actual SRB-As. We then conducted the GTV. The launch rehearsal on July 11 simulated the sequence up until launch. This confirmed the interface performance and established the launch-site operation procedures.

This was our first experience using a vehicle that went through combustion tests for an actual flight. We measured the vibration, temperature, and strain on each part in the combustion tests, and confirmed that the launch vehicle condition was acceptable for flight in accordance with these test data. (The only difference between the test and the launch was that two first-stage LE-7A engines were exchanged for the actual flight engines after the combustion tests.)

4.2 Flight #1 launch

To accurately carry the HTV to the space station orbit, it was imperative to launch the H-IIB at the designated time without even one second of delay. This was a serious restriction for the Flight #1 launch. We therefore prepared for the launch by examining the assumed malfunctions which may occur on the launch day and conducting virtual training in case malfunction occurred at the last minute. Although several expected, and unexpected, malfunctions occurred on the day of the launch, working together we were able to deal with them. Flight #1 launched from the Tanegashima Space Center at 02:01:46 a.m. on September 11, as scheduled, and successfully injected the HTV into the designated orbit.

5. Conclusion

The development and launch of the H-IIB launch vehicle was successfully completed. Summarizing the whole development, we had few malfunctions that brought us back to the initial design stage. We consider the following as the reason.

(i) Under the condition of short-term development and fewer budget, we reduced the risk of new development by using the H-IIA launch vehicle technology.

(ii) The members who participated in the H-IIB development and launch had fully experienced the H-IIA development and launch. We were therefore able to use the lessons of past experience to plan the H-IIB program before components were fabricated and tests were run.

Launch vehicle development in Japan has continued from the N to the H-IIB launch vehicles without pause, and we have evolved the technologies through the development. During the H-IIB development, young engineers were nurtured by experiencing large-scale development tests, such as combustion tests, with experienced engineers. In that regards, we shall and must promote the development of a transportation system subsequent to the H-IIB.

The H-IIB is scheduled to launch the HTV once a year for seven years. We have set a goal to launch large satellites that are more than 5 tons in the geostationary transfer orbit, while simultaneously launching two 2–3 ton mid-range satellites.

In addition, it is possible to enhance the launch capability of the H-IIB by expanding the second-stage to the same 5.2 m diameter as the first-stage. Using this configuration, the launch vehicle will be available for various other planned missions, such as the moon or interplanetary exploration.

The H-IIB launch vehicle has the potential to be developed as a space transportation vehicle in the future. MHI will actively come up with development proposals by investigating applicable missions.