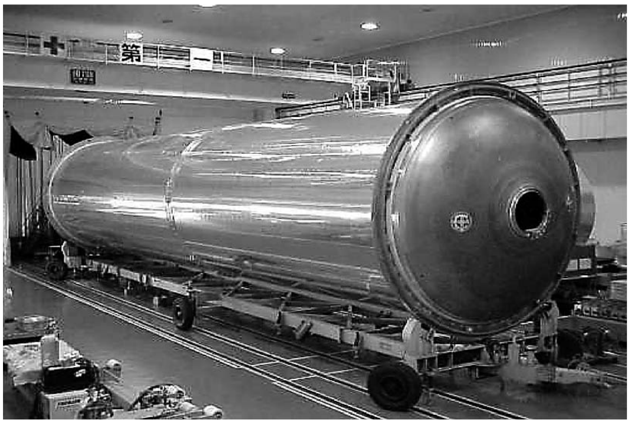

Highly Reliable Tank Structure of H-IIB Launch Vehicle

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The H-IIB launch vehicle adopts the-state-of-the art two manufacturing technologies, which process newly developed by Mitsubishi Heavy Industries, Ltd. (MHI) for the purpose of enhancing the reliability of the propellant fuel tank structure. The first purpose is to increase the high reliability of the tank structure by applying the friction stir welding (FSW) to the axial and circumferential directions with the self-reacting tool called "bobbin tool" which eliminates the use of conventional backing metals. The other purpose is to secure the flexibility of launch opportunity by applying the self-developed spin-formed integral domes not to depend the outside procured domes as H-IIA manner. This paper reports the results of efforts to develop the above-mentioned technologies and future development plans for application to flight model H-IIB launch vehicles in service.

1. Introduction

The product of rocket propellant fuel tank, which are applied to H-IIA Japan's prime launch vehicle and also exported to the Boeing Company in the united state as an application for Delta-IV launch vehicle, is one of the core competences in the Aerospace business of MHI. MHI is also developing pressurization modules for the International Space Station based on the same technologies.

In order to enhance the reliability of this rocket propellant fuel tank, MHI has developed the process for the following state-of the art two production technologies:
(1) Friction stir welding (FSW)
(2) Large-size spin formed integrally dome

These manufacturing processes are under being developed for application to the H-IIB rocket with the development of manufacturing facilities. H-IIB development is being progressed by the cooperative works with the government and private company, and private company is being expected to take the initiative in development. MHI, as the prime contractor, proposed to develop the above technologies with the basis of in house development results and accepted by the Japan Aerospace Exploration Agency (JAXA).

This paper reports the results of the above technological development and the future developmental schedule.

2. Outline of H-IIB rocket propellant fuel tank

The H-IIB rocket is intended mainly for the purposes of improving launch capability of the H-IIA rocket and to send the H-IIA transfer vehicle (HTV) into the orbit of the International Space Station, thus improving Japan's international competitiveness in the commercial rocket launching business (**Fig. 1**). Major changes from the current H-IIA rocket are shown below.

(1) First stage core size increase (diameter increased from 4 m to 5.2 m)
(2) First stage engine LE-7A clustering (increased from one engine unit to two units)
(3) Adoption of various measures for enhancement of reliability

A new propellant fuel tank compatible with the above changes will be developed.

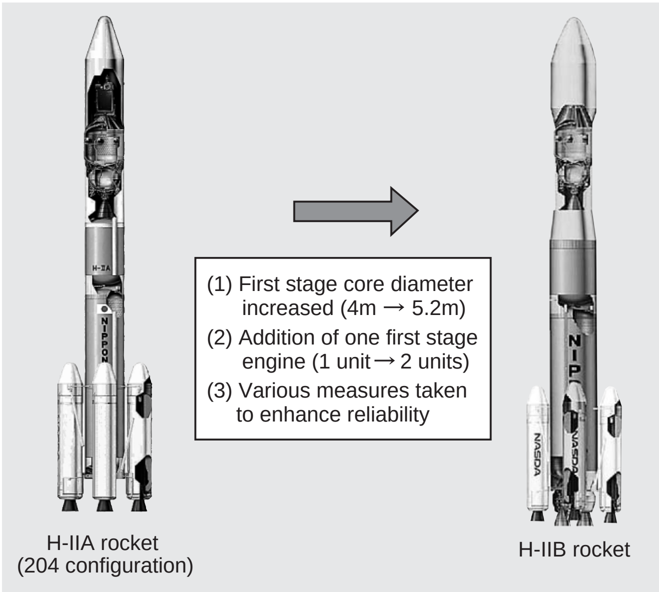

Fig. 1 Major changes incorporated in H-IIB rocket
The figure shows the major changes from the current H-IIA 204 configuration to the H-IIB.

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Fig. 2 Rocket propellant tank appearance
The figure shows the appearance of the current H-IIA rocket first stage liquid hydrogen tank as a representative example of rocket tank.

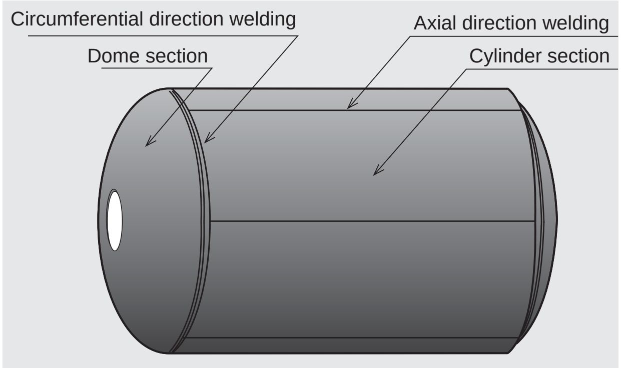

Fig. 3 Composition of main structure of rocket tank
This figure shows the composition and welding locations of the main structure of the rocket tank.

The new tank structure must be such that it can be filled with cryogenic propellants (-253°C liquid hydrogen and -183°C liquid oxygen), which must then be pressurized, and will be required to withstand not only the tank internal pressure but also the aerodynamic force and all other loads, in addition to its deadweight, to which it will be subjected at the launch pad and during its flight (**Fig. 2**).

The first stage tank is 5.2 m in diameter and the approximate total lengths of the component tanks are, respectively, 7 m (liquid oxygen tank) and 20 m (liquid hydrogen), meaning that the entire tank structure will hold approximately 170 tons of fuel in total. The tank's main structure is made of an aluminum alloy, including the cylinder section with monolithically machined ribs called "isogrids" that are bent-formed and welded together in the axial direction, and the spin formed dome (bulkhead) and welded to the cylinder in the circumferential direction (**Fig. 3**).

At present, welding is performed with tungsten inert gas (TIG). However, this method requires large amounts of labor to maintain high quality because much time is required for preliminary treatment common with aluminum alloy fusion welding, and also because it is difficult to maintain stable weld processing (special approved process). Therefore, high reliability will be realized by application of FSW, which does not require preliminary treatment to shorten the work time and whose stability of processing is high.

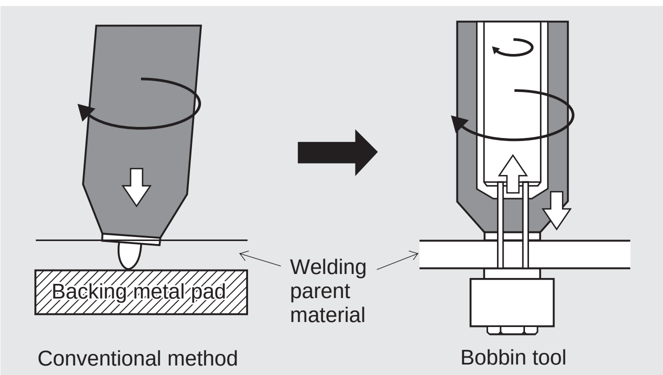

Fig. 4 Concept of FSW method with bobbin tool
A comparison of conventional tool and bobbin tool. The bobbin tool takes the welding load with its internal self-reacting mechanism.

On the other hand, there are a few overseas companies capable of manufacturing high-quality large-size integrally formed domes applicable to rocket tanks, and the present H-IIA rocket tank domes are now being procured from those manufacturers. Therefore, domestic production of such a significant part as the tank dome will assure autonomy of the Japanese rocket, which has long been a major issue in this country, as well as stable quality control for rocket manufacturing and launching.

3. Development of rocket tank manufacturing technologies

3.1 Friction stir welding

Friction stir welding (FSW) is a welding method invented by The Welding Institute (TWI) of England in the 1990s. According to this method, a tool with a projecting part is rotated and simultaneously pressed against the parent material so that welding is performed as the material is heated and softened by friction heat and is stirred by the tool. This technique is being increasingly applied in industrial areas including railways and shipbuilding in view of its advantages such as stability of processing and higher welding speed.

At the present time, the major application is limited to longitudinal direction welding (axial direction welding in the case of rocket tank manufacturing). This is because in order to generate the above-mentioned friction heat, the welding tool needs to be pressed against the parent metal, and accordingly a large backing metal pad must be pressed onto the inner wall perpendicular to the welding tool to generate a force to react against the welding tool pressure load (conventional method as in **Fig. 4**).

If this method is applied to circumferential welding, metal pads must be provided within the tank and must be removed from the tank after completion of the welding work. In the case of a large vessel like a rocket fuel tank, the metal pads need to be very large in size, and the work involved in their removal is dangerous and inefficient.

Table 1 Advantage of application of FSW and domestic production of rocket tank dome

Item	Major advantage
FSW	(1) Enhancement of reliability • This process is comparable to mechanical fabrication and achieves improved welding stability. • Material texture improvement (reduction of texture grain size by non-fusion and stirring) generates good jointing characteristics (improved strength and toughness). • Stable, uninterrupted, high-quality welding can be applied to thicker plate jointing to meet the requirements of larger-diameter tanks. (2) Better price competitiveness • Simplification of pre-welding treatment • Shortening of welding time (including inspection time) (3) Versatility • This method enables welding of light-weight aluminum -lithium alloy (fusion-welding is unstable).
Domestic production of dome	(1) Improved autonomy • Removal of restrictions related to acquisition of export permit • Improvement of delivery time control and emergency responsiveness Realization of precise quality control (2) Better price competitiveness • Breakaway from partial monopoly of overseas manufacturers

Such being the case, MHI has developed an industrial welding process with tool called "bobbin tool" which can be used in applying FSW to rocket tanks. This tool makes it possible to balance the welding tool pressure with the internal mechanical reaction force of the tool itself, and thus to enable FSW without padding from inside (Fig. 4).

This has made possible application of FSW to axial direction welding as well as circumferential welding. No application of FSW to rocket tank circumferential direction welding has been reported in any part of the world. The application of FSW to rocket tanks achieves effects such as those shown in **Table 1**.

In-house research conducted in 2000 revealed the most suitable tool shape, parts holding method and basic welding conditions. In 2001, a circumferential welding of a sub-scale tank (diameter approximately 1 m) was performed and its strength was confirmed by pressurization test, subjecting the weld section to a stress level more than 1.5 times that expected to be applied to the tank in flight service (**Fig. 5**).

Based on the above, a prototype FSW device was produced for testing purposes. This device was successfully used for axial direction welding (in 2002, **Fig. 6**) and circumferential direction welding (in 2004, **Fig. 7**) on a part having the same diameter (4 m) as that of the standard type H-IIA rocket, leading to positive prospects for actual application. At the same time, the jointing characteristics and the non-destructive testing method of the welded sections were confirmed to establish readiness for application to fuel tanks.

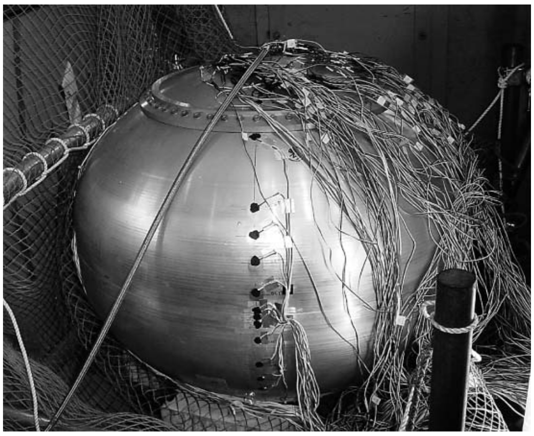

Fig. 5 Pressurization test on sub-scale tank
This figure shows a pressurization test being performed on a sub-scale tank having a spin formed dome and welded to the tank assembly in FSW.

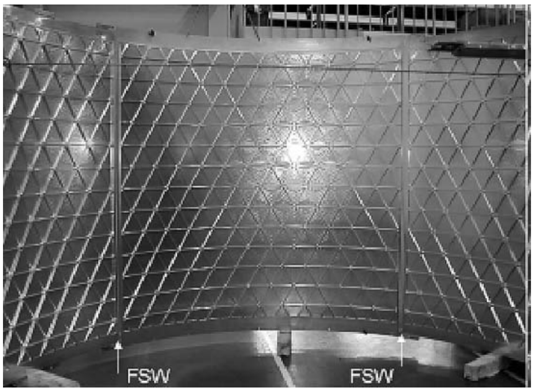

Fig. 6 FSW axial direction weld section
A large part of the tank was welded in the axial direction.

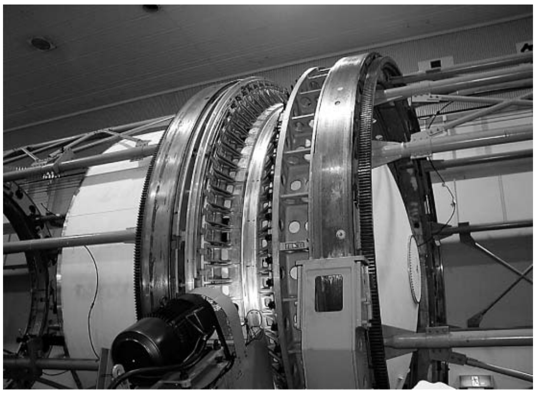

Fig. 7 Circumferential direction FSW weld test
This figure shows the circumferential direction weld under testing.

3.2 Large-size spin formed dome manufacturing technology

Spin forming is a method of deforming a rotating plate through plastic deformation into a desired shape by pressing a fabricating tool onto the plate. This is a commonly used formation method for relatively small-size parts requiring relatively low accuracies and strengths. However, there are a few companies in the world, and none in Japan, capable of manufacturing large-size, thin-wall, high-accuracy domes of heat-treated high-strength aluminum alloy for use in rocket tanks.

Fig. 8 Dome produced on an experimental basis (diameter 900mm)
A sub-scale dome was produced on an experimental basis by spin forming.

Such being the case, a basic in-house research process for the above was established in 2000, and sub-scale domes were accordingly produced for testing purposes (**Fig. 8**). As described above, their strengths were confirmed by means of pressurization testing. It was also confirmed by using two different diameter domes that certain analogical relations exist in spin forming. Accordingly, it was possible to establish desirable molding conditions for industrial production domes based on these analogical relations.

The dome material is required to generate its design strength by means of heat treatment after forming. However, high shape accuracy is required even though its wall is thin (less than 5 mm at the thinnest point) and is easily deformable, and it is therefore necessary to avoid excessive deformation at the time of mechanical fabrication. Therefore, in order to attain the required strength while avoiding excessive thermal deformation of parts at the time of quenching, spray-type quenching was adopted because it is capable of performing precise cooling speed control and of providing the desired cooling conditions over the entire dome surface.

Based on the achievements described above, it is now being planned to develop industrial production type domes at Hiroshima Machinery Works of MHI, which has a build-up perform and record in the development of large mechanical devices, and whose existing plant facilities can be effectively utilized for the purpose. Table 1 shows the effects that can be expected from the development of rocket tank domes.

4. Plan for application to H-IIB rocket

Next, we shall report on the present status of MHI's efforts to develop application to the H-IIB rocket and its plans for the future. The tank manufacturing facility adopting the FSW and the large-size spin forming technology is currently under construction. At the same time, elemental tests are proceeding under contract with JAXA, and the preliminary verification of manufacturing tests is under way. In 2004, a cooling performance confirmation test and others at the time of quenching were executed using a 1/4 circumference specimen of a life-size dome (diameter approx. 5 m) (**Fig. 9**).

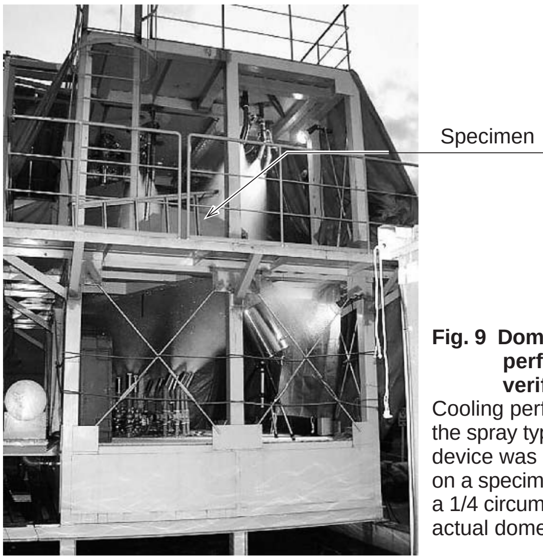

Fig. 9 Dome quenching performance verification test
Cooling performance of the spray type quenching device was confirmed on a specimen simulating a 1/4 circumference of an actual dome.

In 2006 when the tank manufacturing facility is completed, manufacturing tests (material characteristics verification tests, etc.) will be performed for final confirmation of the production process and confirmation that the technical requirements have been satisfied. Tanks for qualification test will accordingly be manufactured to finalize the development of the tank as a structural system. Its application to actual rockets is expected to become possible in or after 2008.

5. Conclusion

This report has discussed two new manufacturing technologies under development for the H-IIB rocket tank and their prospects for the future. The H-IIB rocket requires even greater developmental efforts (Mission) including faster development, unprecedented joint development by the Government and private companies, the international responsibility concerning the timing of the launch of the HTV which is the payload of the first vehicle. Based on the knowledge accumulated so far, related risks will be duly identified [Prediction] and all personnel concerned will cooperate in accomplishing the developmental targets [Commitment]. MHI Nagoya Aerospace Systems Works is determined to firmly keep to its slogan "M.P.C." in developing rocket fuel tanks whose technical reliability can be an example to the world.


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