Development of Japan's Next Flagship Launch Vehicle
- To compete and survive in the global commercial market -

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The conceptual design of Japan's next flagship launch vehicle, which replaces the H-IIA/H-IIB, began in 2014. Mitsubishi Heavy Industries, Ltd. (MHI), designated as a prime contractor, is proceeding with the design. The primary objectives of the next flagship launch vehicle are to ensure "competitiveness in the global commercial market" and "assured access to space," while maintaining the domestic industrial base through launching a constant number of vehicles each year by obtaining orders for commercial satellite launches in addition to institutional missions. This report provides an overview of the three concepts of the next flagship launch vehicle; (1) launch capability and competitive price, (2) launch on customer's desired date and (3) a comfortable vehicle.

1. Introduction

In the Space Basic Plan which summarizes the principles of the space policy in Japan, it is stated that maintaining launch capability without relying on other countries (assured access to space) is the basis of space policy, and maintaining the space transportation system is essential from the perspective of assured access to space. However, urgent problems endangering assured access to space have emerged, such as the difficulty of maintaining technical skills due to the lack of opportunities for new development in the 25 years since the H-II development, and the difficulty of maintaining the industrial base caused by suppliers withdrawing due to the difficult business environment of only launching 1 to 3 institutional missions per year.

Considering these circumstances, a determination has been made by the Cabinet Office Space Policy Committee in May 2013 to start the development of Japan's next flagship launch vehicle to replace the H-IIA/H-IIB. In February 2014, competitive bids for the development of the next flagship launch vehicle and the launch service were issued by the Japan Aerospace Exploration Agency (JAXA), and MHI was designated as a prime contractor.

This report introduces the purposes and concepts for the development of the next flagship launch vehicle.

2. Objectives of the next flagship launch vehicle

Regarding the significance and the positioning of the next flagship launch vehicle, two points are mentioned in the space policy document; "Assured access to space" and "Competitive launch vehicle and launch service." In order to solve the problems of the current flagship launch vehicle and to maintain the industrial base of the space transportation system, while continuing to meet the

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demands of government missions, it is essential to obtain a constant number of commercial satellite orders every year from the global market.

Figure 1 shows a prediction of the commercial satellite market for the next 10 years made by a consulting company.[1] The number of commercial satellites is around 20 each year and increasing slightly, and the satellite weight is distributed within the range of 2.5 - 7 tons. The volume zone of the satellite weight is considered to be affected and fluctuates due to the launch capability of primary launch vehicles and the prevalence of electric propulsion satellites.

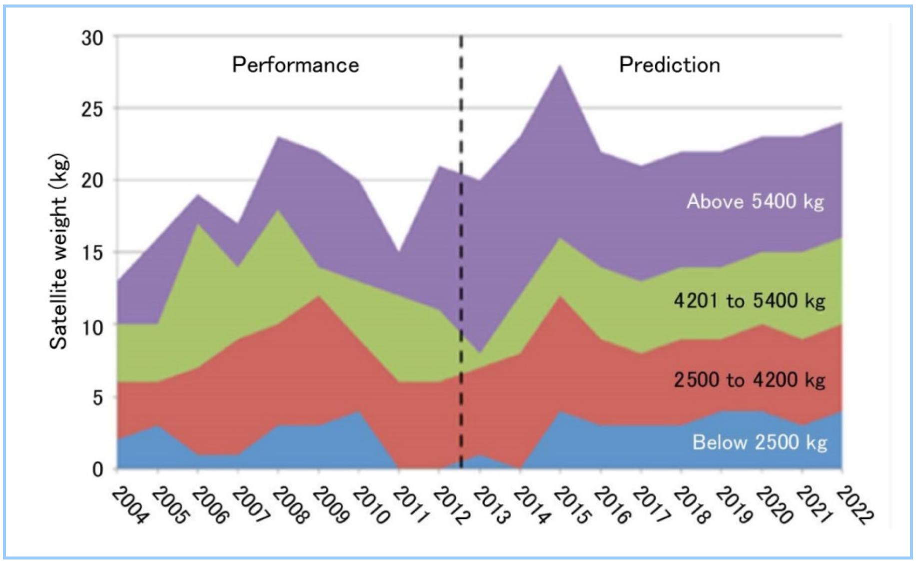

Figure 1 Commercial satellite market prediction

Figure 2 indicates the development status of new launch vehicles in various countries around the world.[2] Space-X Corporation in the U.S. has brought the Falcon 9 to the market and has acquired customers with its overwhelming low price. Moreover, they are planning an advanced type Falcon Heavy with enhanced capability. Arianespace Corporation in Europe, which is the current market leader, is also planning to release the Ariane 6 sometime around 2021 with increased price competitiveness. In Russia, the Angara, the successor of the current Proton, is under development and its test vehicle in the basic configuration has successfully flown in 2014.

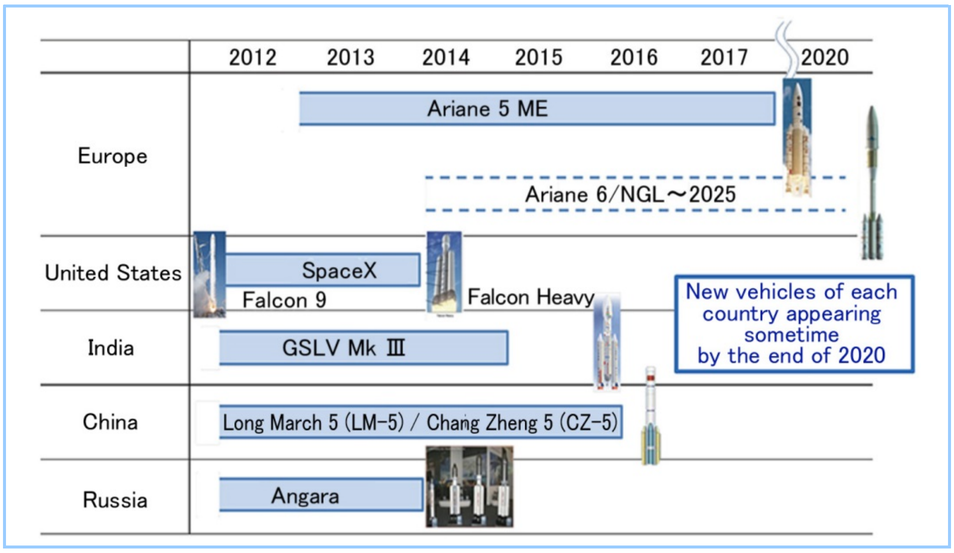

Figure 2 Development statuses of new launch vehicles around the world

The next flagship launch vehicle has to ensure competitiveness in the global market while considering the changes in the satellite market and the development status of launch vehicles in other countries. When setting the mission requirements of the next flagship launch vehicle, in addition to “high reliability,” which is the advantage of the current flagship launch vehicle (H-IIA/H-IIB), the following three requirements are reflected based on the results of interviews with domestic and overseas customers (satellite operators or manufacturers); (1) launch capability and competitive price, (2) shortening the on-site launch operation period to launch on the customer's desired date, and (3) a comfortable vehicle with less vibration.

Figure 3 shows the launch capability and the price target of the next flagship launch vehicle.[3] Meeting a wide range of launch capabilities seamlessly and reducing the launch service price to about half of the current flagship launch vehicle are essential requirements.

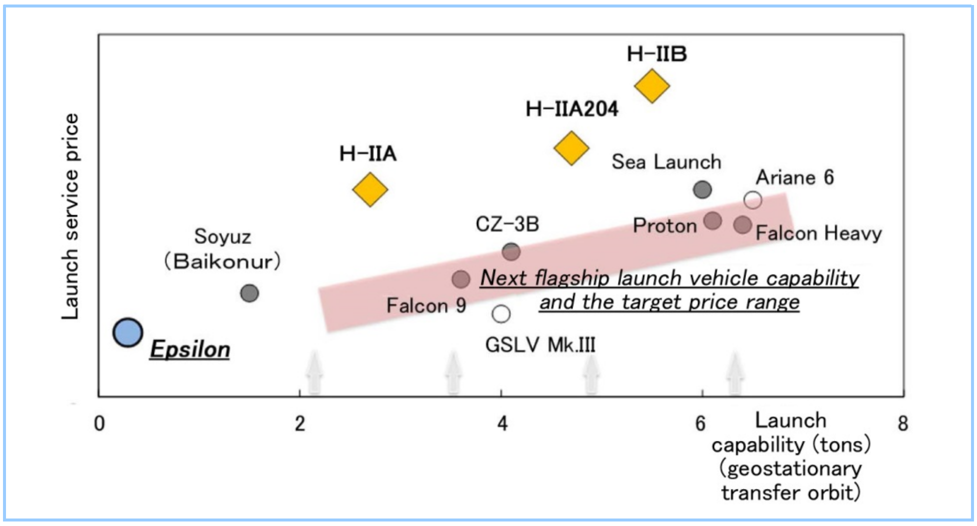

Figure 3 Launch capability and price target of the next flagship launch vehicle

3. Development of the next flagship launch vehicle

The following show the concepts of the vehicle system/subsystem and the operation to realize the mission requirements described in section 2.

3.1 Realization of required launch capability and price

(1) Vehicle system

Figure 4 indicates the vehicle configuration and vehicle family of the next flagship launch vehicle.[3] It consists of a core vehicle using liquid oxygen/liquid hydrogen and solid rocket boosters. The number of solid rocket boosters can be changed according to the required launch capability. By applying common specifications except for the number of solid rocket boosters and by manufacturing the same vehicle regardless of the mission, manufacturing and operational efficiency are improved and costs can be reduced.

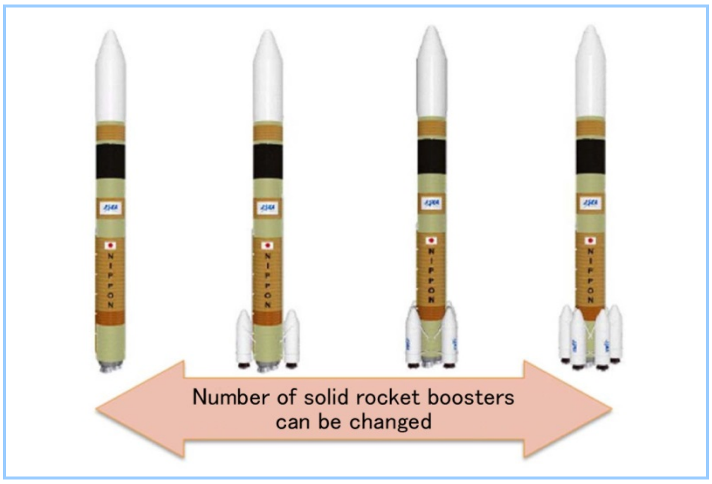

Figure 4 Vehicle configuration and vehicle family of the next flagship launch vehicle

For engines, the "expander bleed cycle" engine, which is Japanese original technology and is used in the second stage of the current flagship launch vehicle, will be newly developed and applied to both the first and the second stages. **Figure 5** indicates the engine operation system. In the expander bleed cycle engine, the turbine is driven by vaporized fuel gas (hydrogen gas) which cools down the high-temperature combustion chamber. This system construction is simpler than a system that has a gas generator (secondary combustion chamber) for driving the turbine, and is also easier to control while offering higher safety and reliability.

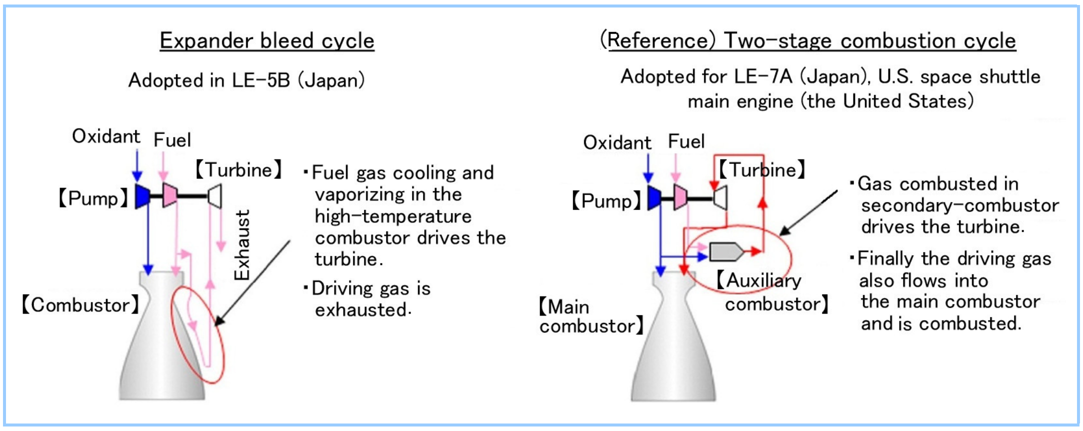

Figure 5 Operation system of Engine
This indicates the drive system of the engine turbine pump schematically.

The technical feasibility of the engines has been confirmed through the combustion chamber firing test (equivalent to the first stage engine; conducted through the research and development of JAXA) and the prototype engine firing test (equivalent to the second stage engine; conducted through the in-house research and development of MHI). These tests have been carried out prior to the official start of the next flagship launch vehicle program. **Figure 6** indicates the situation of the firing tests.

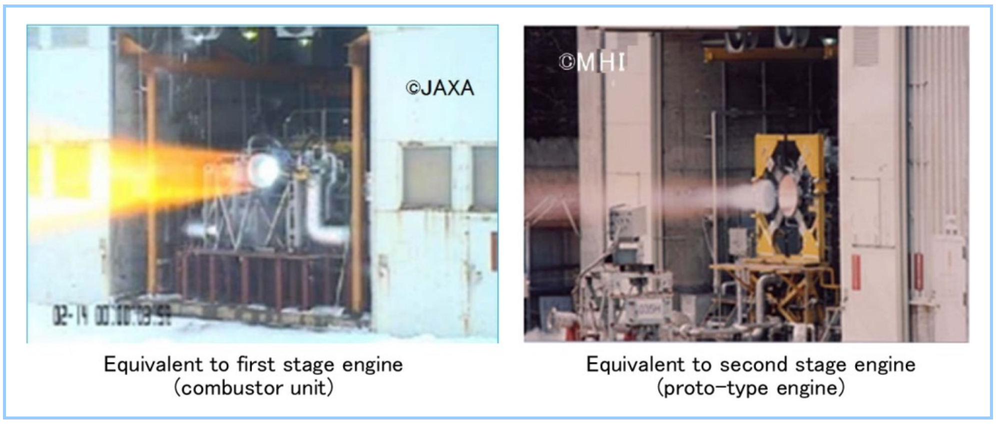

Figure 6 Engine firing test at 'Tashiro' Test Stand

(2) Vehicle subsystem

Simplification, generalization and commonization are the basic policies common to both the vehicle system and subsystem to realize a competitive price. Moreover, the possibility of cost reduction is evaluated in terms of all phases of operation from the procurement of material and parts to launch operations on site. Simplification includes the reduction of the number of parts through the integration of components, improvement of material and machining costs by preparing raw material close to the end-product shape, and the adoption of an easy-to-manufacture shape (Design for Cost), etc. Component production using a 3D printer, which has been spreading rapidly, is also examined as one idea for cost reduction through a simplified production process.

For generalization, the utilization of COTS (Commodity Off The Shelf) products (aircraft and/or automobile electrical parts) for avionics components and propulsion system equipment (valves and sensors) is examined. As components for space-use are usually very expensive due to special specifications and the limited number of uses, the effect of applying highly reliable and low-cost COTS products is significant. Evaluation on using COTS products for the launch vehicle is conducted with JAXA because the feasibility is related to component selection standards and safety standards, which are the responsibility of JAXA.

An example of commonization is valves and actuators driven by electricity as a common energy source. The vehicle system can be greatly simplified by eliminating the need for a high pressure gas system and a hydraulic system as the driving energy source. In addition, pressure devices and the work of preparing/connecting the vehicle to ground facilities just for inspection become unnecessary, which improves efficiency.

3.2 Operational improvement

(1) Capability to launch on desired date

In order to ensure launch on the customer's desired date, even if another mission is planned immediately before or after the launch, the operation period at launch site is reduced to about 1/3 of the current period

Shortening the launch operation period is also important from the perspective of launch service cost reduction. Access-free vehicle design is applied to shorten the period so that functional checks are automated, and access to the vehicle and preparations such as connecting inspection equipment become unnecessary. The vehicle and the ground facilities are connected via a network through the umbilical system (the junction of the piping and electrical wiring that connects the vehicle and ground facilities together), and data acquisition and health monitoring are conducted automatically.

(2) Improvement of launch operation environment for the satellite system

For the improvement of the operation environment for the satellite system, which is highly demanded by customers, the improvement of ground facilities and the moderation of regulations will be conducted in cooperation with JAXA in order to solve the current issue of operational limitations and interference caused by the launch vehicle and other satellites, and to provide 'global-standard' launch services.

3.3 Improvement of vibration environment

(1) Acoustic environment

To realize a comfortable vehicle, flight data of the current flagship launch vehicle have been evaluated in detail, and vibration and sound generating sources have been identified. Design solutions to reduce those vibrational sources are considered at the beginning of the design for the next flagship launch vehicle and reflected in the specifications.

For acoustic environment reduction at lift-off, the shape and opening of the exhaust duct of the launch pad and a water injection system with a high sound reduction effect are examined. In addition, for acoustic environment reduction during atmospheric flight, the effect that the exterior shape of the payload fairing has on pressure fluctuation is evaluated. Based on these results, design specifications for the launch vehicle and ground facilities are established to meet the acoustic environment requirements (**Figure 7**).

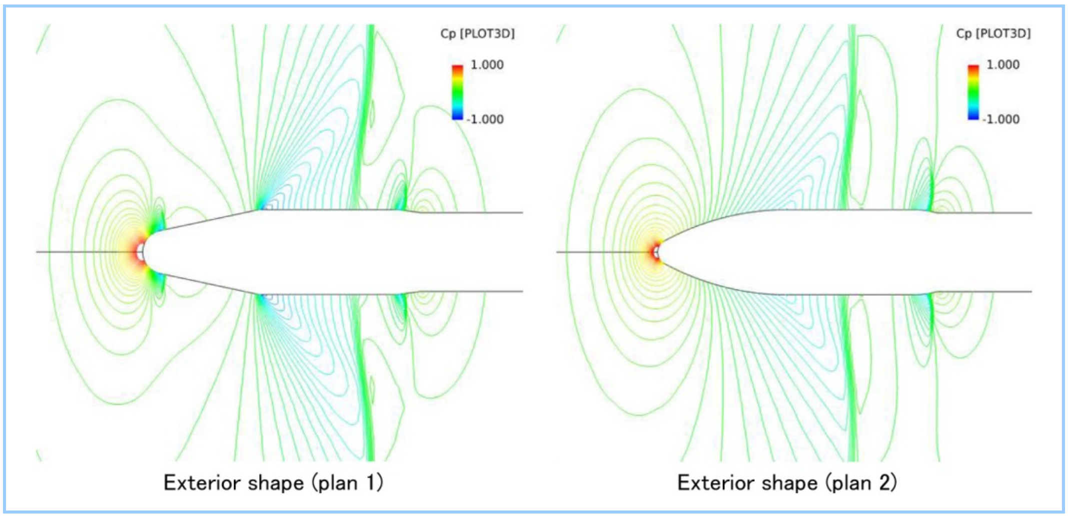

Figure 7 Pressure distribution of the fairing exterior
An example which calculates the difference in pressure fluctuation using CFD due to the exterior shape.
The pressure fluctuation is smaller in (plan 2) with a smoothly curved exterior shape.

(2) Vibration environment

In terms of the vibration environment, countermeasures to continuous vibrations due to engine combustion have become necessary for the current flagship launch vehicle. To prevent a similar problem, design consideration is made at the beginning of the design for the reduction of the combustion pressure fluctuation of the engine, and for the stiffness of the engine mounting point (**Figure 8**).

Such moderation of the in-flight vibration environment will provide additional value for customers by reducing the load of the satellite during vehicle flight and the burden of the development testing of the satellite.

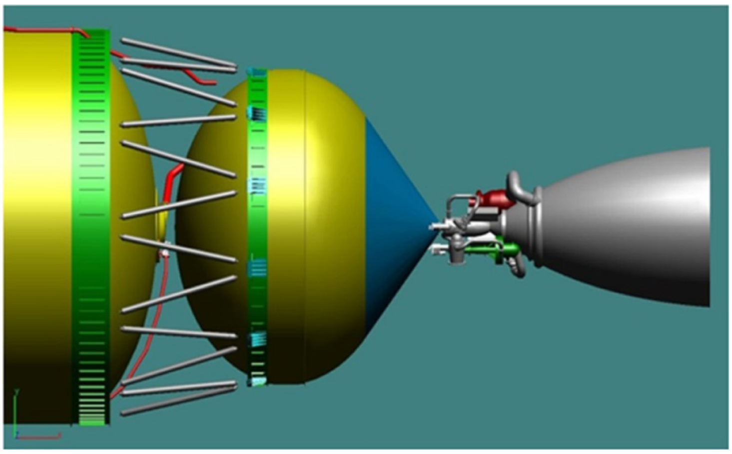

Figure 8 Example of engine mounting structure (plan)
An example of second stage engine mounting structure of the next flagship launch vehicle. It is attached via a conical structure without being attached directly to the tank dome to ensure the required stiffness of the mounting point.

4. Conclusion

The conceptual design of the next flagship launch vehicle began in April 2014. MHI, as a prime contractor developing the vehicle and providing launch services, is proceeding with the design together with JAXA. The mission requirements are established based on customer requests to realize "a vehicle and launch service with competitiveness in the global commercial market," one of the goals of the next flagship launch vehicle. In this, there are three points; (1) launch capability and competitive price, (2) launch on customer's desired date, and (3) a comfortable vehicle.

A System Requirements Review (SRR) was conducted in July 2014, and the design specifications of the launch vehicle and the ground facilities are being examined in the current phase. The Systems Definition Review (SDR) is to be completed by the end of fiscal 2014 followed by the preliminary design phase. The inaugural flight is scheduled in 2020.

This is going to be a challenging project to develop a new launch vehicle in 6 years and to realize a launch service price that is about half of the current flagship launch vehicle. To achieve the goal of the next flagship launch vehicle – "to compete and survive in the global commercial market" – MHI will work hard together with all participants inside and outside of MHI, utilizing the best practices and knowledge established through various space programs of the past.

References

1. COMSTAC, 2013 Commercial Space Transportation Forecasts, https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2013_GSO_NGSO_Forecast_Report_June.pdf
2. Asada, S., The Journal of The Society of Japanese Aerospace Companies, Vol. 719 (2013.11) pp.1-5
3. The Material of The Space Policy Committee of Cabinet Office, Government of Japan (2013.4)