

# Development of Internationally Competitive Solid Rocket Booster for H3 Launch Vehicle

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Recently, low cost launch vehicles intended for large commercial satellites are being developed actively all over the world, including Ariane 6 by Arianspace (Europe), Falcon 9 and Falcon Heavy by SpaceX (USA), a company led by Elon Musk, Vulcan by ULA (USA) and by Russian and Indian companies. Moreover, Japan is also developing the next flagship launch vehicle called H3. This paper introduces H3 and its strap-on booster “SRB-3.”

## 1. Introduction

The development of the H3 launch vehicle was started in FY 2014 as a Japan’s flagship launch vehicle replacing the H-IIA and H-IIB launch vehicles. The development is currently in the detailed design phase, and we are aiming to launch the first H3 launch vehicle from the Tanegashima Space Center (Kagoshima Pref.) of the National Research and Development Agency, Japan Aerospace Exploration Agency (JAXA) in FY 2020.

IHI AEROSPACE Co., Ltd. (IA) is participating in the development of both the Solid Rocket Booster -3 (SRB-3) as a subbooster of the H3 launch vehicle and an attitude control gas jet to be mounted in the second stage of the H3 launch vehicle body, as a key technology manufacturer under development contract with JAXA.

The solid rocket booster refers to a rocket engine using solid fuel. Attaching the booster to the H3 launch vehicle body makes it possible to obtain high thrust and efficiently launch a heavier satellite.

This paper introduces the outlines of the H3 launch vehicle and SRB-3, and elemental technologies introduced into the development of SRB-3 in order to achieve both low cost and high reliability as the concepts of the SRB-3 development.

## 2. H3 launch vehicle

**Figure 1** illustrates the H3 launch vehicle.

The development of the H3 launch vehicle is expected to secure independence for Japan’s space transportation (space transportation without being supported or controlled by other countries) and provide internationally competitive rocket and launch services, thereby maintaining and enhancing industrial infrastructure.

Most customers of Japanese launch vehicles have been Japan’s public organizations so far. However, in the future, due to harsh national financial circumstances, it will be difficult to develop Japan’s space transportation industries only depending on public demand, and therefore in order to maintain and enhance technological infrastructure, it is necessary to take in private demand, i.e., to receive orders for

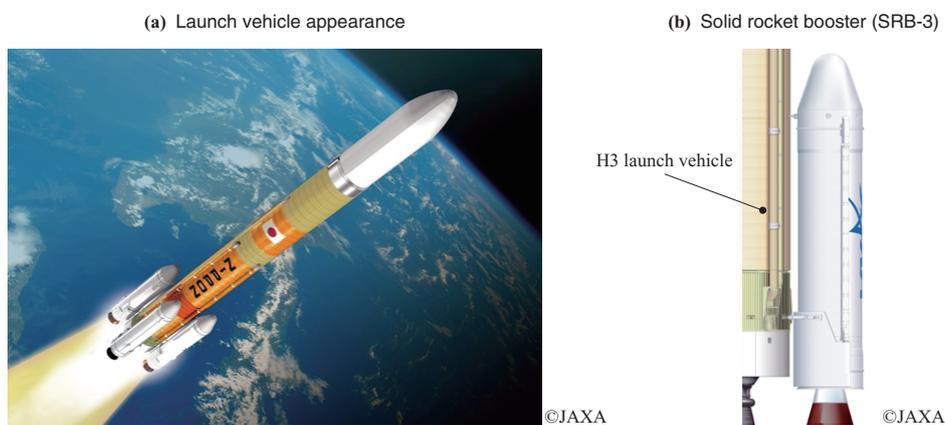


Fig. 1 H3 launch vehicle

launching commercial satellites.

What private satellite operators focus on as customers when launching commercial satellites are ① low cost, ② high reliability, and ③ flexibility to customers' demands. In particular, in recent years, SpaceX, a US private company, has launched Falcon 9 launch vehicles into the market and rapidly gained share, armed with overwhelmingly low costs of them, so it is important to respond to the reduction in cost.

The H3 launch vehicle has the following four configurations depending on the number of engines of the launch vehicle body and the number of SRB-3s.

- (1) 3 engines + 0 SRB-3s
- (2) 2 engines + 2 SRB-3s
- (3) 3 engines + 2 SRB-3s
- (4) 2 engines + 4 SRB-3s

We are planning to suppress cost by employing a configuration suitable for the size of a satellite and an injection orbit. **Figure 2** illustrates the structure of the H3 launch family.

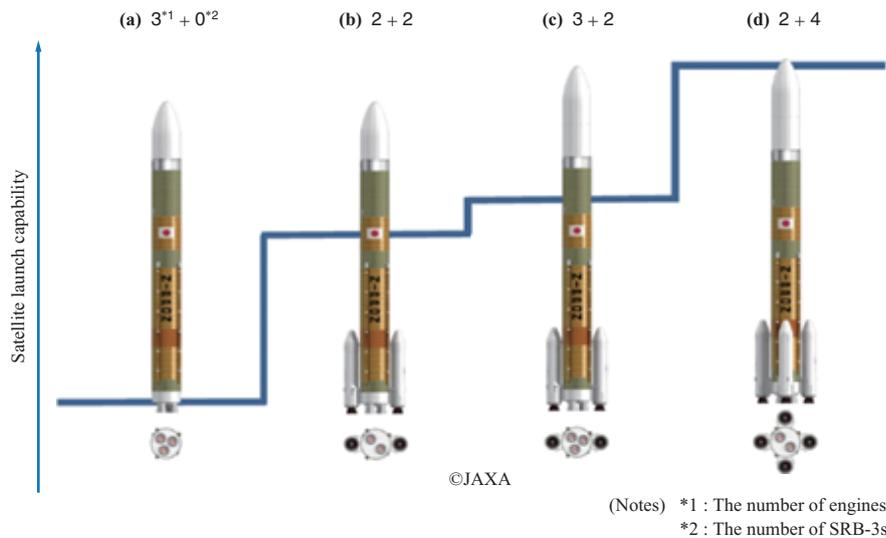
We are also planning to significantly reduce the costs of the respective components constituting the vehicle. As the launch cost of the configuration including 3 engines + 0 SRB-3s (**Fig. 2-(a)**), we are aiming to achieve approximately half the launch cost of the H-IIA launch vehicle.

### 3. Solid rocket booster (SRB-3)

The external view of SRB-3 is illustrated in **Fig. 1-(b)** and the development specifications of SRB-3 are listed in **Table 1**. SRB-3 is comparable in size to the SRB-A which is used as the booster for H-IIA and H-IIB launch vehicles and the first stage engine for Epsilon launch vehicles, and follows the basic specifications of SRB-A. By doing so, development risk due to introducing new technologies can be reduced, and by increasing the ratio of reusing the manufacturing facilities and jigs/tools used for SRB-A, development expenditure can be reduced.

On the other hand, in order to respond to customers' demands, it is necessary to significantly reduce cost while ensuring high reliability at least comparable to the reliability of SRB-A. Therefore, feasible specifications were set for SRB-3 in terms of both cost reduction and high reliability by pursuing a simple configuration, such as a reduction in the number of parts/components and simplification. The points in determining the specifications in terms of the cost reduction are as follows.

- (1) Optimization of the thicknesses of components such as a motor case and self-manufacture of materials



**Fig. 2** H3 launch vehicle family

**Table 1** SRB-3 development specifications

Item	Unit	SRB-A (for H-IIA launch vehicle)	SRB-3 (for H3 launch vehicle)
Solid propellant	—	Composite propellant	Composite propellant
Thrust in vacuum	tf	Approx. 180	Approx. 220
Performance (Isp) <sup>*1</sup>	s	283.6	283.6 or more
Solid propellant amount	t	65.9	Approx. 66.8
Total length	m	15.2	14.6
Diameter	m	φ2.5	φ2.5
Combustion time	s	116	Approx. 105
Nozzle drive system	—	Electric actuator	None (Fixed nozzle type)
Separation system	—	Thrust strut and separation motor system	Separation thruster system

(Note) \*1: Time during which a thrust of 1 kgf can be produced with a propellant amount of a mass 1 kg and maintained (similar to fuel consumption)

- (2) Simplification of connection/separation method with respect to H3 launch vehicle body
- (3) Abolishment of thrust direction control function based on nozzle thrust vector control of SRB-3 (integration of the function into nozzle thrust vector control on launch vehicle body side)

This paper introduces development for domestically producing the motor case corresponding to (1) and new development of a separation thruster corresponding to (2).

#### 4. Development for domestically producing SRB-3 motor case

A motor case refers to a pressure vessel capable of tolerating gas pressure and temperature at the time of propellant combustion, and also serves as a structural member for transmitting thrust from SRB-3 to the H3 launch vehicle body side. Since the motor case is a structural member, strength and stiffness are required and lightweight is also required. **Figure 3** illustrates a motor case overview.

SRB-A employs a motor case integrally molded by a filament winding method using a Carbon Fiber Reinforced Plastic (CFRP) in order to raise combustion pressure to improve booster impulsive characteristics. Also, for SRB-A, foreign technology is introduced because of short-term development.

As with SRB-A, SRB-3 employs an integrally molded motor case using CFRP. The points of change from SRB-A include (1) the domestic production of materials, and (2) IA's design independent of foreign technology.

IA has accumulated design, manufacturing, and quality assurance technologies and knowhow on a large CFRP motor case through the development of the upper stage motor cases for M-V launch vehicles, research for domestically producing the SRB-A motor case, development of the upper stage motor cases for Epsilon launch vehicles, and development experience of other models for defense.

Specific elemental technologies include ① the design of a sealing part for combustion gas, ② the design of the joint

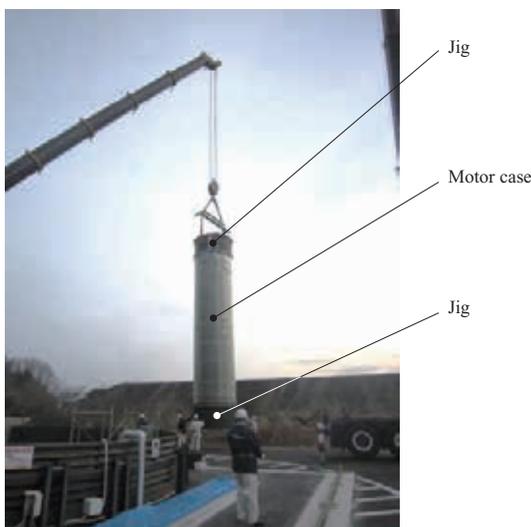


Fig. 3 Motor case overview

part between a load transfer structure and a pressure vessel part, ③ strength and stiffness design, ④ the database on CFRP physical properties, ⑤ CFRP molding technology, and ⑥ quality assurance technology including non-destructive inspection.

By utilizing these accumulated results, the following effects can be produced.

- (1) When domestically producing materials, CFRP and a rubber material used for the joint part between the load transfer structure and the pressure vessel part are switched from the current US-made materials to materials domestically made by IA. In doing so, it is expected to increase the degree of freedom of materials procurement and significantly reduce cost by manufacturability improvement activities associated with the domestic production.
- (2) The IA's design enabled the safety factor to be reduced from 1.5 for the conventional SRB-A to 1.25 by utilizing the strength and stiffness design knowhow and results of improving the accuracy of the database on CFRP physical properties. This makes it possible to reduce the use amount of materials and significantly contribute to cost reduction. Further, since the design is entirely carried out by IA, the need for a license fee associated with foreign technology introduction is eliminated.

We have to remember to ensure high reliability while reducing cost. Space development requires enormous expense even for a single launch, and failure is not allowed. Therefore, we perform tests in an environment simulating the most actual flight environment possible with “Test as you Fly! Fly as you tested!” and “End to End Test” as catchphrases. The development of SRB-3 also follows such an idea, and full-scale ground combustion and separation tests are performed several times.

When developing the motor case, full-scale prototype tests (pressure, strength and stiffness, and destructive tests) are performed twice each. A full-scale motor case is used to confirm that the motor case can tolerate internal pressure and an external load as load conditions, as well as to acquire a vehicle body stiffness value. In addition, by performing the internal pressure destructive test as well, the marginal performance of the motor case is grasped to further understand the design and manufacturing of the motor case.

#### 5. New development of SRB-3 separation thruster

The separation thruster is mounted between the H3 launch vehicle body and SRB-3, and has a function of connecting/retaining them. In addition, the separation thruster has a function of, after the end of SRB-3 combustion, using the combustion gas pressure of explosive, releasing the connection between the launch vehicle body and SRB-3 and generating separation force to jettison SRB-3.

In the H3 launch vehicle, an SRB-3 connection/separation system was changed from the “thrust strut/brace separation motor” system employed for the H-IIA launch vehicles to a

“thrust pin separation thruster” system. **Figure 4** illustrates the SRB separation system.

This system allows the number of connecting points between the launch vehicle body and SRB, which was six in the H-IIA launch vehicles, to be reduced to four, and contributes to a reduction in part size, reduction in the number of parts, and improvement of launch site maintainability, thus reducing cost.

Separation thrusters having the same functions include ones such as a thruster made by a US manufacturer employed for the Atlas V launch vehicles of United Launch Alliance (ULA, USA). In the case of SRB-3, in order to jettison SRB-3 having larger mass than those of such separation thrusters, larger energy (for accelerating SRB-3 having a mass of up to 11 t to 4 to 5 m/s) is required, and therefore severalfold withstand load and separation force are required. This is development with novelty in the world.

Next, the main specifications of the separation thruster are described below. In addition, **Fig. 5** illustrates separation thruster designs and release process.

- (1) At the time of connection, four lock keys arranged at regular intervals in the circumferential direction of the cylinder portion protrude outward in the radial direction of the cylinder portion and are retained by the internal piston. This allows the relative position between the cylinder portion and the end portion on the launch vehicle body side to be fixed.
- (2) At the start of release, the Gas Generator (GG) is ignited to generate energy necessary for disconnect and jettison. As a result, the combustion gas pressure of GG allows the internal piston to break the shear pin A, and the piston moves toward the launch vehicle body side to thereby withdraw the lock keys inward in the radial direction. This makes it possible for the cylinder portion to extend its stroke toward the SRB-3 side, and continuous combustion gas pressure provides SRB-3 with separation velocity.

- (3) The cylinder portion fully extends, and the shear pin B is broken by inertia force to thereby release the connection with the launch vehicle body.

In terms of reducing development risk and ensuring reliability, as the elemental technologies for the separation thruster, technologies for existing developed products, such as technologies on ① the type of a GG main explosive charge, ② the specifications of seals inside the cylinder, and ③ shear pin-based mechanism control, were preferentially utilized. In addition, high technical risk items were extracted from the results of Failure Modes and Effects Analysis (FMEA) with the separation anomaly of SRB-3 as a top event, and corresponding element tests were performed. The high technical risk items and the outlines of the element tests are as follows.

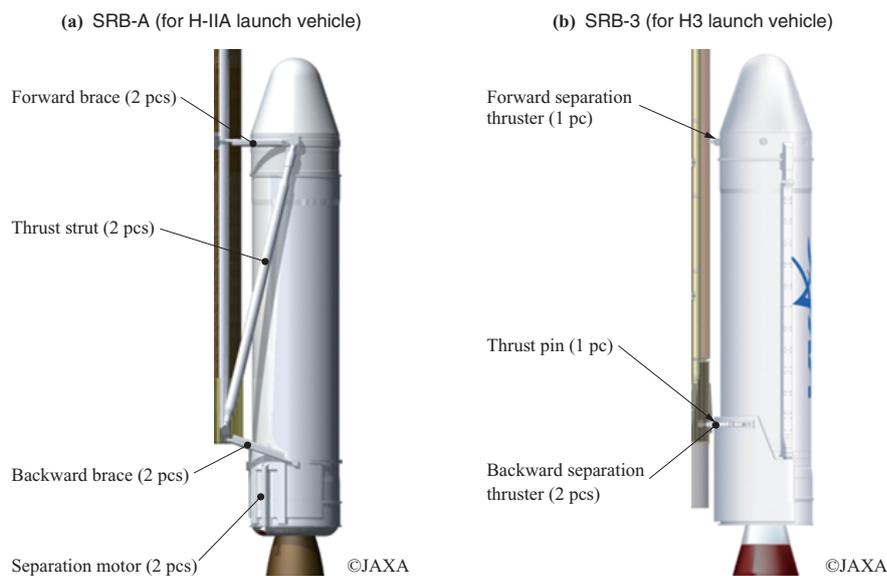
### 5.1 GG combustion characteristics under high pressure environment

GG used for the separation thruster has to generate high pressure gas in a short time. Pressure generated inside the thruster at the time of GG combustion exceeds a conventional applicable pressure range of the main explosive charge, and is considered to be in a range where a burning rate parameter of the main explosive charge varies. For this reason, it was necessary to check the combustion characteristics of GG.

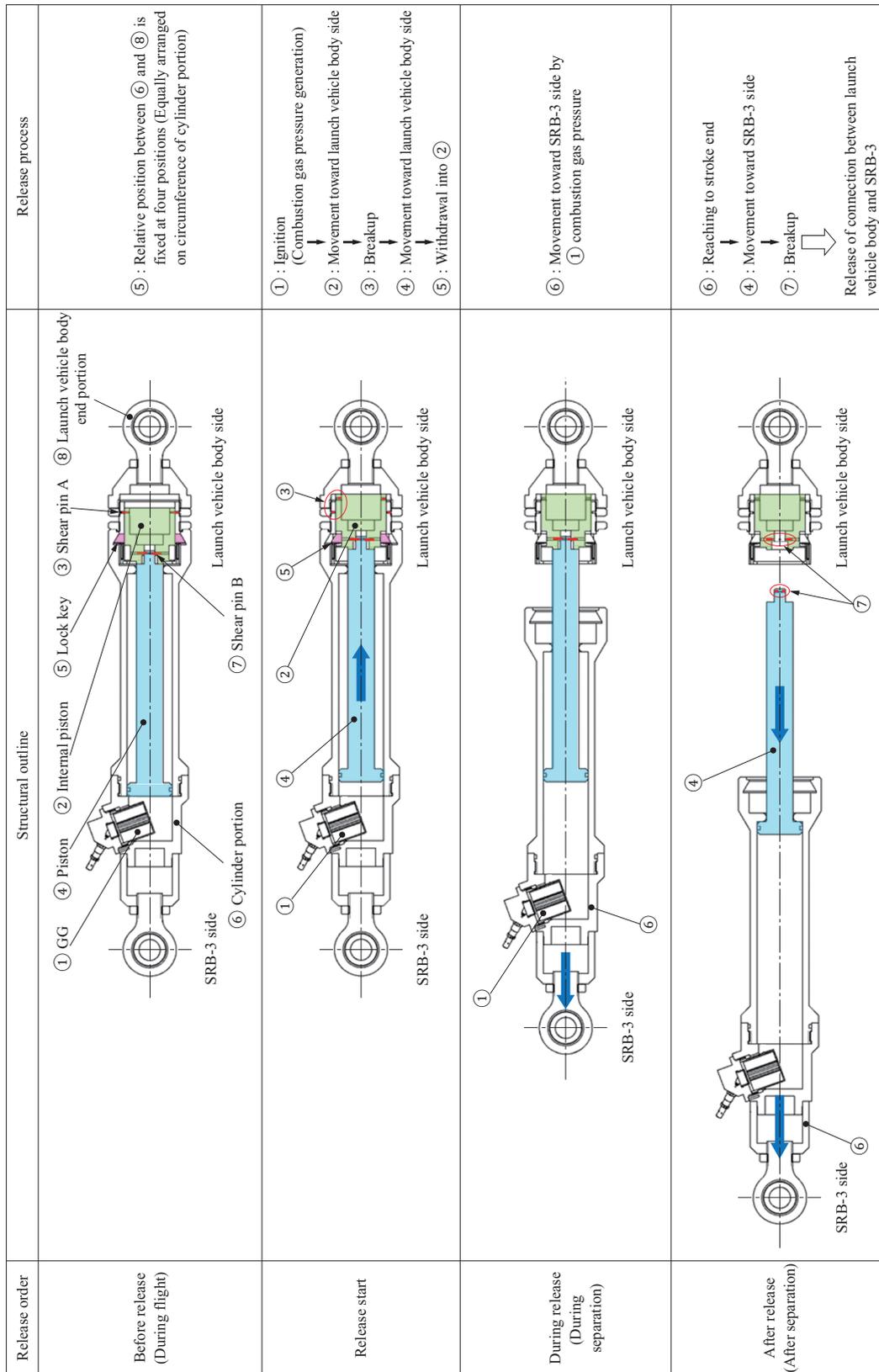
A test for acquiring burning rate data in a high pressure range was performed, and data indicating that the burning rate parameter of the main explosive charge changed within a design range was obtained. Therefore, design has to take account of whether or not stable combustion occurs.

### 5.2 Operation characteristics of mechanical section

Since the separation thruster was a new product, it was necessary to manufacture a prototype test model in the early stage of the development, verify the attach, disconnect, and jettison functions, and improve technical maturity. For this purpose, a test was performed to, while operating the separation thruster using GG as a driving force source, confirm that the internal pressure, separation load, and



**Fig. 4** SRB separation system



(Note) All symbols ① to ⑦ in the figure respectively represent the same items.

Fig. 5 Separation thruster designs and release process

separation velocity were obtained as predicted.

As a result of the test, measured values and corresponding predicted design values exhibited similar trend, and a good result was obtained, indicating that the predictive values fell below corresponding test values by approximately 5% at the maximum separation load value. In the future, we will adjust some functions such as power conditioning and finish the separation thruster with high degree of completion.

## **6. Conclusion**

The outlines of the H3 launch vehicle and SRB-3, and the elemental technologies introduced for SRB-3 were described (intermediate situation at detailed design phase). In the future, we will perform large scale tests such as full scale ground combustion and separation tests. We certainly proceed with the development and aim to finish the development in FY 2019.