Development Status of H3 Launch Vehicle
-To compete and survive in the global commercial market-

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The H3 launch vehicle is currently under development as Japan's next flagship launch vehicle, replacing the H-IIA/H-IIB. The objectives of the H3 launch vehicle are to ensure "competitiveness in the global commercial market" and "assured access to space," as well as to maintain and strengthen the country's industrial base by obtaining orders for commercial satellite launches. Mitsubishi Heavy Industries Ltd. (MHI) has organized the vehicle development as the primary contractor and taken charge of the development of the engine system. The development is currently in the middle of the detailed design phase and is progressing as planned toward the launch of the first vehicle in 2020. This report provides the development status, especially the development status of the engines along with their design features, which holds the key to the success of the entire project.

1. Introduction

The development of the H3 launch vehicle, as Japan's next flagship launch vehicle replacing the H-IIA/H-IIB, started in 2014. MHI, as the primary contractor, has organized the vehicle development and is proceeding with the development of the engine system in cooperation with Japan Aerospace Exploration Agency (JAXA).

The primary objectives of the H3 launch vehicle are to ensure "assured access to space" and "competitiveness in the global commercial market." It is intended that aerospace industrial base is maintained and strengthened by ensuring sales for a constant number of vehicles including commercial satellite launches. To this end, in addition to "high reliability," which is the advantage of the H-IIA/H-IIB, the following three points were reflected in the development specifications based on the results of interviews with customers: (1) competitive launch capability and price, (2) operational improvement at launch site and ensuring launch on desired date, and (3) a comfortable vehicle with less vibration [(1)].

The development of the H3 is currently in the middle of the detailed design phase and is progressing, as planned, toward the launch of the first vehicle in 2020. This report provides the overview and development status of the H3 launch vehicle, particularly the design features, the development plan and the latest status of the engine development, which holds the key to the success of the entire project.

2. Overview of the H3 launch vehicle

(1) Vehicle system

Figure 1 shows the vehicle configuration of the H3 launch vehicle. The H3 launch vehicle has a launch capability of about 2 to 7 tons to a geostationary orbit (with the condition of ΔV to GSO =1500 m/sec). To seamlessly respond to a wide range of required launch capabilities, the number of solid rocket boosters and the number of main engines for the first stage can be selected. The vehicle configuration is represented as H3-abc, with a) the number of

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main engines for the first stage (2/3), b) the number of solid rocket boosters (0/2/4) and c) fairing size (L/S) (**Figure 2**). The minimum configuration, which is H3-30S, is intended to be applied mainly to institutional missions, and H3-22L/H3-24L are intended to be applied to commercial missions.

For the satellite interface structure, payload adapters with standard clamp-band sizes (937/1194/1666 mm) will be provided. To flexibly respond to the demand for the launch of multiple small satellites, which has been increasing in recent years, a special payload adapter will be provided if necessary.

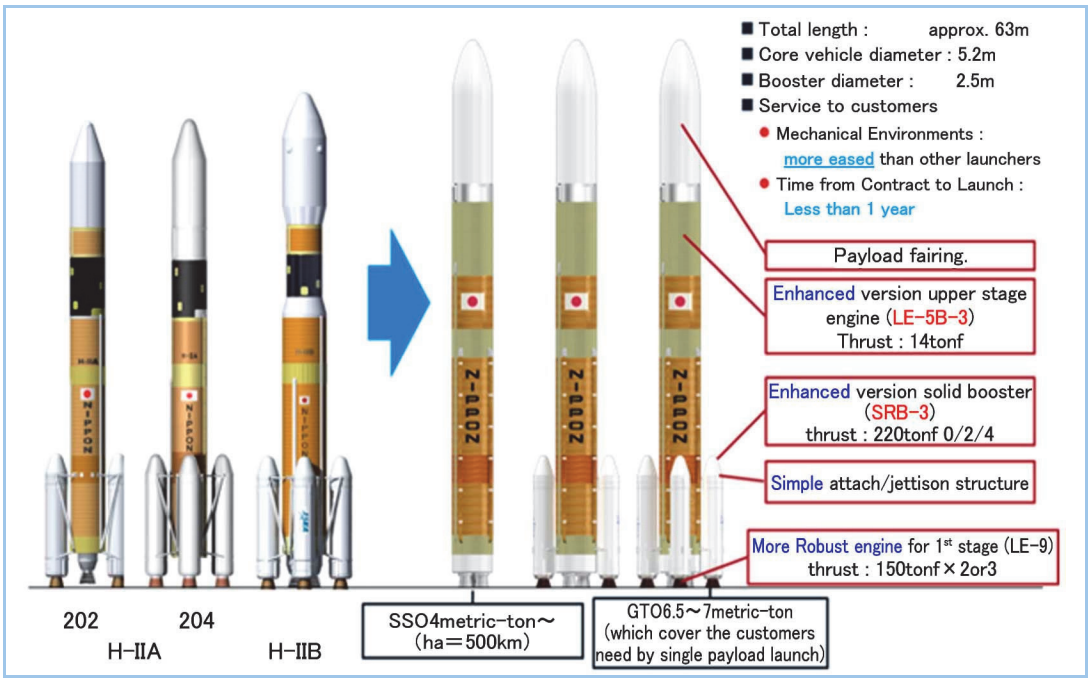


Figure 1 Vehicle configuration of the H3 launch vehicle

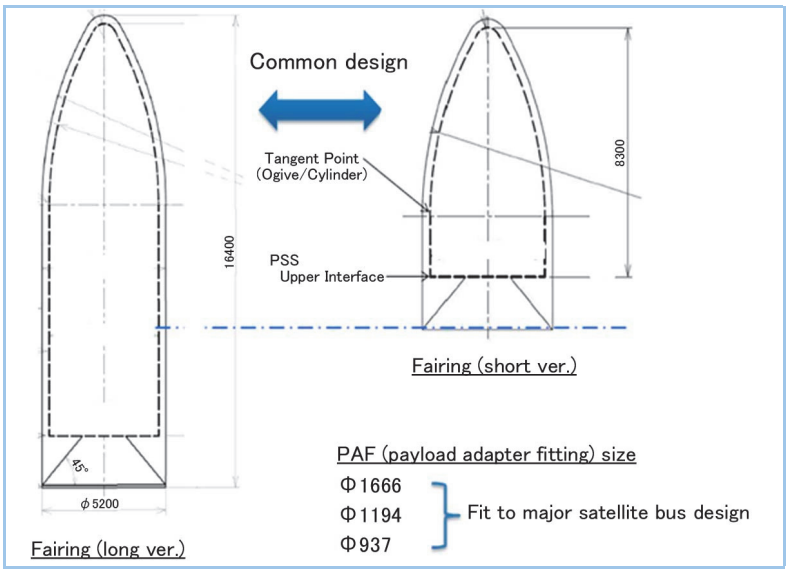


Figure 2 Payload fairing configuration

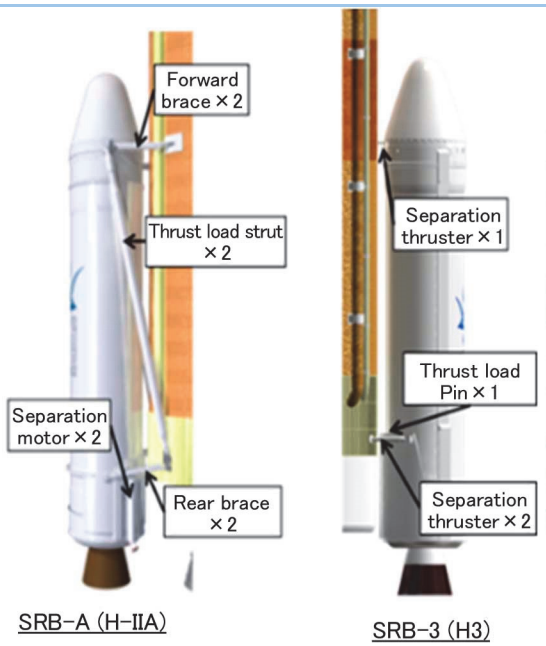
(2) Vehicle subsystem

For the H3, consideration was given to the balance between the "reliability" obtained through the development of the H-IIA/H-IIB and the incorporation of new technologies for realizing a competitive price. The specifications, the manufacturing and the operational processes of the H-IIA/H-IIB were analyzed in detail, and the cost was thoroughly reduced in all phases, including the procurement of parts and materials, as well as manufacturing and launch operations on site. In addition, simplification, commonality and generalization were considered as the basic policies common to both the vehicle system and subsystem.

As a major subsystem for a liquid rocket engine, the "expander bleed cycle" engine,

which is Japanese proprietary technology and is used in the H-IIA/H-IIB, was adopted for both the first and the second stages. In this system, the turbine pump is driven by vaporized fuel gas (hydrogen gas), which cools down the high-temperature combustion chamber. Therefore, the construction is simpler, the cost is lower, the control is easier and the safety and reliability are higher, compared to a system with a separate gas generator (auxiliary combustion chamber) for driving the turbine pump. The engine development plan and progress are described in detail in Section 3.

For the solid rocket booster, the proven technologies and specifications adopted in the H-IIA/H-IIB/Epsilon are used, securing both reliability and low cost. For the motor case size and materials, nozzle, etc., the flight-proven specifications are followed, while cost reduction is promoted through the reduction of functions (fixed nozzle), simplification of joint structure, etc. (**Figure 3**).



item	SRB-A (H-IIA)	SRB-3 (H3)
Propellant	Composite	Composite
Average thrust at vacuum	Approx. 180tonf	Approx. 220tonf
Specific impulse	283.6s	Over 283.6s
Propellant mass	**65.9ton**	**Approx. 66.8ton**
Length	15.2m	14.6m
Diameter	ϕ 2.5m	ϕ 2.5m
Nominal burn time	116s	Approx. 105s
TVC mechanism	**Electronic gimbal actuator**	**None (fixed nozzle)**
Separation mechanism	**Thrust strut/ Separation motor**	**Separation thruster**

Figure 3 Specifications of solid rocket boosters

The structural system and propulsion system of the vehicle are based on the existing specifications, while cost reduction is realized through the simplification of the shape, reduction of special materials and automation of processes. **Figure 4** shows the integrally-formed dome of the H3 propellant tank. The dome spin-forming technology obtained in the development of the H-IIB was further developed, to expand the integral forming area, thereby reducing the number of parts and realizing cost reduction. For the electrical system, the control functions are distributed, and the devices are connected by a network so that high reliability is secured at a low cost and that the equipment can be easily updated in a short time. For avionics components, based on the principle that off-the-shelf commodities (aircraft and automobile parts) are used to the maximum extent, applicable types of parts were selected in consideration of the resistance evaluated by the radiation test. For each avionic device, the prospect for feasibility was almost obtained in the prototype test model (Bread Board Model; BBM) phase, and the ground test model phase (Engineering Model; EM) has been started thereafter.

Figure 4 H3 propellant tank dome under test

3. Engine development plan and progress

3.1 First stage engine LE-9

(1) Features of LE-9 engine

The LE-9 engine is the world's first engine that is a first stage engine with no auxiliary combustion chamber. It greatly contributes to the achievement of internationally competitive reliability, price and performance, which are the features of the H3 launch vehicle. The major improvements from the LE-7A engine, which is the current first stage engine, are as follows:

(a) The adoption of the expander bleed cycle made the construction simple without an auxiliary combustion chamber.

(b) The driving method of the fuel and oxidant supply valves was changed from the pneumatically-driven method to the electrically-driven method.

(c) New manufacturing technologies such Additive Manufacturing (AM) were adopted.

(d) The probabilistic designing method was adopted for the improvement of reliability.

For the LE-7A engine, the two-stage combustion cycle shown in **Figure 5** was adopted. The two-stage combustion cycle improves the specific impulse (fuel efficiency) of the engine, but it has a complicated structure because a number of parts such as an auxiliary combustion chamber are used, and the operating pressure and temperature are high. The LE-9 engine uses an expander bleed cycle, which allows a simple structure and reduces the production cost. In addition, since the expander bleed cycle does not require combustion gas to drive turbine pump, the engine naturally powers down without moving to a destructive mode in the event of a failure in the turbine driving system. Thus, the LE-9 engine has an intrinsic safety feature and contributes to the improvement of reliability.

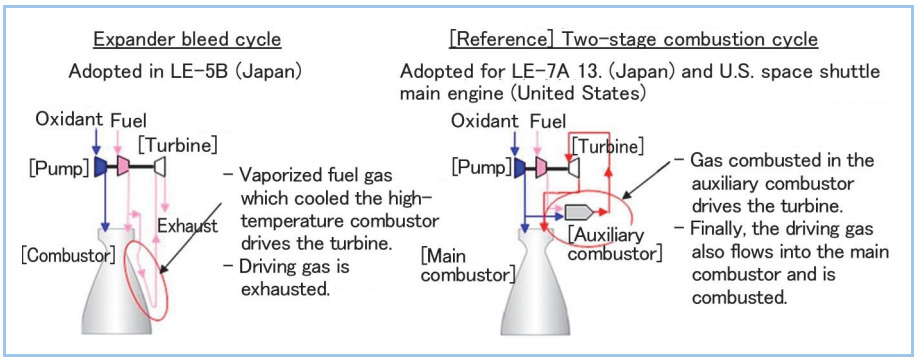


Figure 5 Operation system of engine
This indicates the drive system of the engine turbine pump schematically.

Figure 6 shows the appearance and the schematic diagram of the LE-9 engine. The LE-9 engine has four fuel and oxidant supply valves. By changing the driving method of the valves from the conventional pneumatically-driven method to the electrically-driven method, the pneumatic line can be eliminated, and the opening of each valve can be controlled arbitrarily and continuously. Conventionally, a number of firing tests are conducted for each engine to adjust the operation point, but with the LE-9 engine, only one firing test is required, resulting in the reduction of the production cost.

In the LE-9 engine, new manufacturing technologies have been positively adopted to reduce the production cost. One of the representative new technologies is 3D shaping technology, and powder bed type metal additive manufacturing (Selective Laser Melting, SLM) and material injection type metal additive manufacturing (Laser Metal Deposition) will be applied. These technologies allow for a substantial reduction of the manufacturing cost and the time to construct the complex structure, which was conventionally manufactured through a number of processes such as machining and jointing (welding, brazing).

In the development of the LE-9 engine, a highly-reliable development process is applied toward development with minimal rework in the latter stages. Specifically, in the early stages of development, possible failure modes are comprehensively listed based on FMEA (Failure Mode and Effect Analysis), and each failure mode is evaluated through element tests and analyses to quantitatively indicate that the design reliability is high. By making full use of these activities

that can be implemented at a relatively low cost, trial and error, etc., in the latter stages can be eliminated and the total development cost will be also reduced.

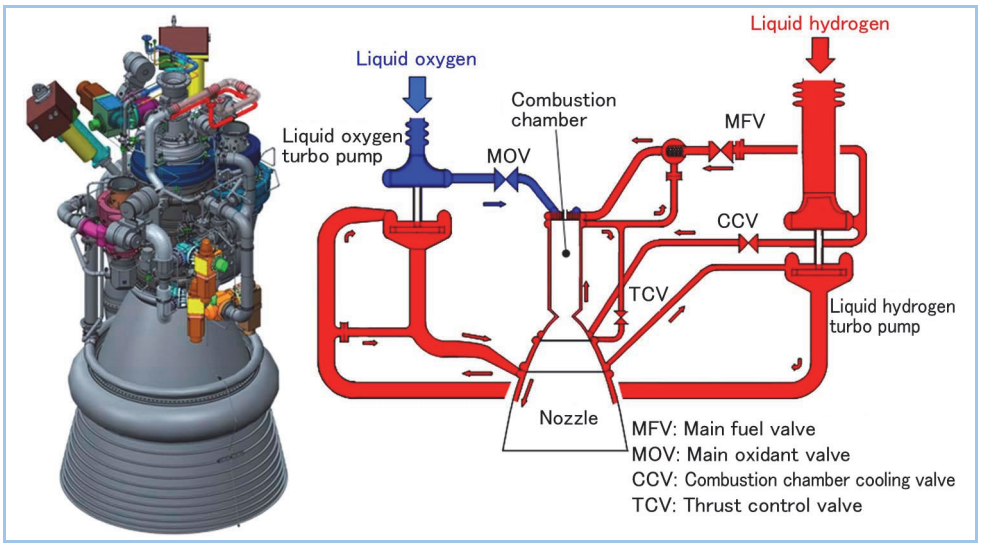


Figure 6 The appearance and schematic diagram of the LE-9 engine

(2) Development plan of the LE-9

Figure 7 introduces the LE-9 engine development schedule. The large expander engine technology demonstration program (LE-X) started in 2010, and the development of the LE-9 engine was started in 2014. In the development phase of engineering model engine, four engines will be manufactured and the basic properties such as engine performance, structural durability, operability and the production inspection process will be checked through the engine firing tests. In the development phase of qualification model engine, the engine will be qualified after implementing the required design changes identified through engineering model engine firing tests.

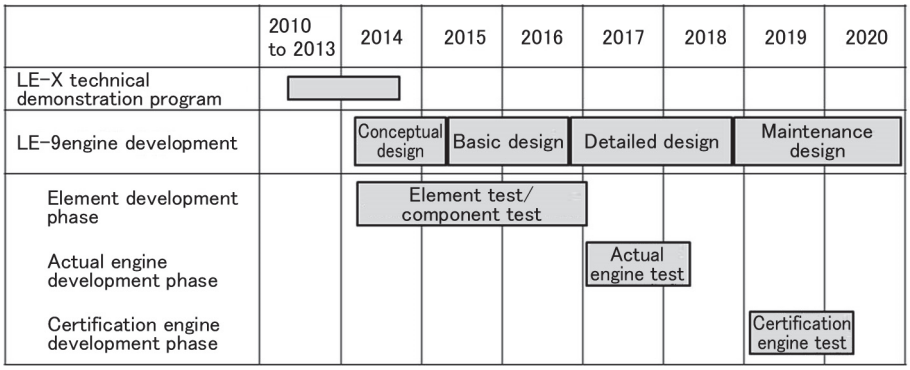


Figure 7 LE-9 engine development schedule

(3) Development status of the LE-9

From April to July 2017, the first series of firing tests using the first engineering model engine were conducted at the ground firing test site of the JAXA Tanegashima Space Center. **Figure 8** shows photos of the firing test. A total of 11 firing tests that took about 270 seconds were conducted as planned, and the following properties were obtained and confirmed:

(a) Basic performance of the engine
(b) Transient characteristics of engine start/stop
(c) Engine control characteristics with electrically-operated valves
(d) Engine precooling characteristics
(e) Inspection operability among tests

Concerning the controllability with electrically-operated valves, which is a new feature of the LE-9 engine, it was demonstrated as represented in **Figure 9** that a specific thrust and mixture ratio (mass ratio of the oxidant and fuel) were achieved when the target operation point was changed during firing test.

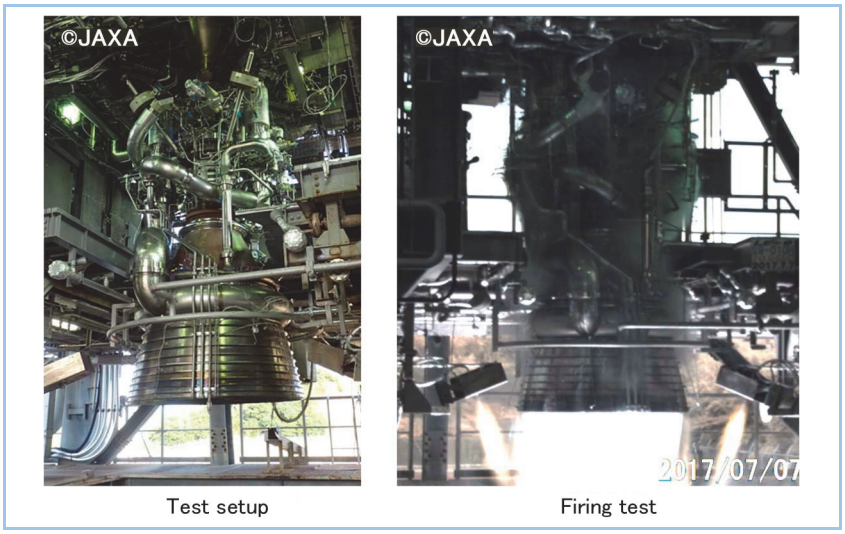


Figure 8 Scenes of the first series of firing tests using the actual engine

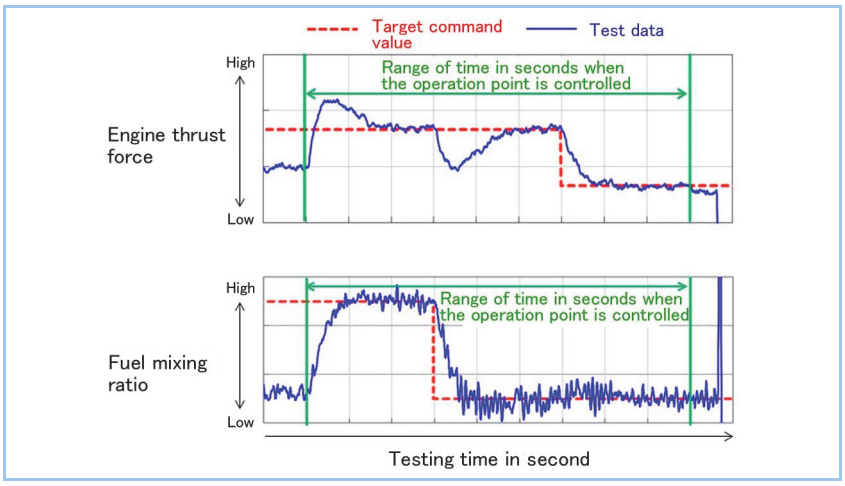


Figure 9 Control of thrust force and mixing ratio in LE-9 engine combustion test

(4) Future development

In the future development phase of engineering model engine, the characteristic data for a wider operational range will be obtained, and the structural durability will be checked. In 2019, the engine property and performance qualification tests using two certification engines will be conducted. Before the engine property and performance qualification tests, a Battleship Firing Test (BFT) will be conducted with the vehicle system and the engine combined. Three engineering model engines will be provided for the BFT, and a demonstration with the entire first-stage vehicle system will be conducted.

3.2 Second-stage engine LE-5B-3

(1) Features of the LE-5B-3 engine

The second-stage LE-5B-3 engine for the H3 launch vehicle is an improved version from the current LE-5B-2 engine, aiming at improving the performance and reducing the product cost while keeping the development cost and the development risk to a minimum. **Figure 10** depicts the appearance of the LE-5B-3 engine. The points improved from the current engine are as follows:

(a) Responding to the vehicle requirements (improvement of performance, increased mission duration time)
(b) Ensuring stable supply and improving productivity
(c) Reducing production cost

To respond to the requirements for the launch performance of the H3 launch vehicle, the fuel mixer of the current engine will be improved, and the design will be modified so that the intake performance of the liquid oxygen turbine pump is also enhanced. In addition, to meet the requirement for increased mission duration time, the design of the liquid hydrogen turbine pump will be upgraded.

As more than 20 years have passed since the development of the LE-5B series of engines and it is required to continue stable production of the engines for another 20 years in future as 2nd stage engine for H3, update of the combustion chamber material production method and the development of substitute parts (electrical) for the parts that will go out of production will be conducted, using the opportunity of the development of the LE-5B-3 engine to increase the production yield.

In addition, for the reduction of the production cost, the simplification of the structure and the improvement of productivity are to be implemented while development risk is kept low.

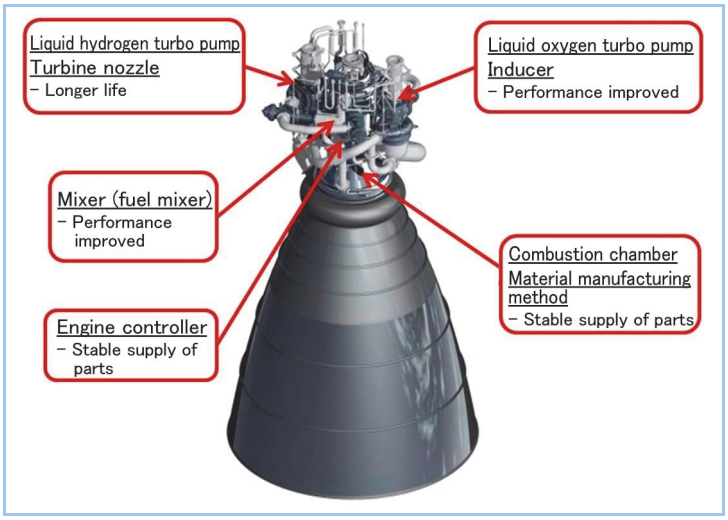


Figure 10 The appearance of the LE-5B-3 engine and the major changes from the LE-5B-2 engine

(2) Development plan of the LE-5B-3

Figure 11 shows the development schedule of the LE-5B-3 engine. The LE-5B-3 engine is developed through the improvement of the current engine, and the required mission life of many components has already been verified.

So far, the prospect has been obtained through the system (feasibility) test for checking the effect of the improved mixer and the element test, and engine development will be conducted effectively in the engine qualification phase using two engines.

	2014	2015	2016	2017	2018	2019	2020
LE-5B-3 engine development	Detailed design					Maintenance design	
Certification engine development phase				Certification engine test			

Figure 11 LE-5B-3 development schedule

(3) Development status of the LE-5B-3

In March 2017, the first series of firing tests using the first engine for certification were started at MHI Tashiro Test Facility (Odate City, Akita Prefecture) and JAXA Kakuda Space Center (Kakuda City, Miyagi Prefecture). **Figure 12** presents photos showing the firing test. A total of 23 firings (including reignition) and the required life of 3160 seconds in total were achieved, and the validity of the improved design was demonstrated.

Figure 12 Scene of LE-5B-3 engine firing test

(4) Future development

With the second engine for certification, demonstration of the required life and checking of individual engine differences will be conducted. Thereafter, the engine will be offered for the Captive Firing Test (CFT) using the vehicle system and the engine combined, and a demonstration with the entire second -stage vehicle system will be conducted.

4. Conclusion

In the development of the H3 launch vehicle, the conceptual design was started in April 2014, preliminary design review (PDR) was completed in April 2016, and the detailed design phase is currently progressing (**Figure 13**). For both the first and second stage engines of the H3 launch vehicle, the expander bleed cycle using liquid oxygen and liquid hydrogen as fuel was adopted. The first stage LE-9 engine is the world's first large-thrust expander bleed cycle engine for the first stage, and the second stage LE-5B-3 engine is an improved version of the current LE-5B-2 engine.

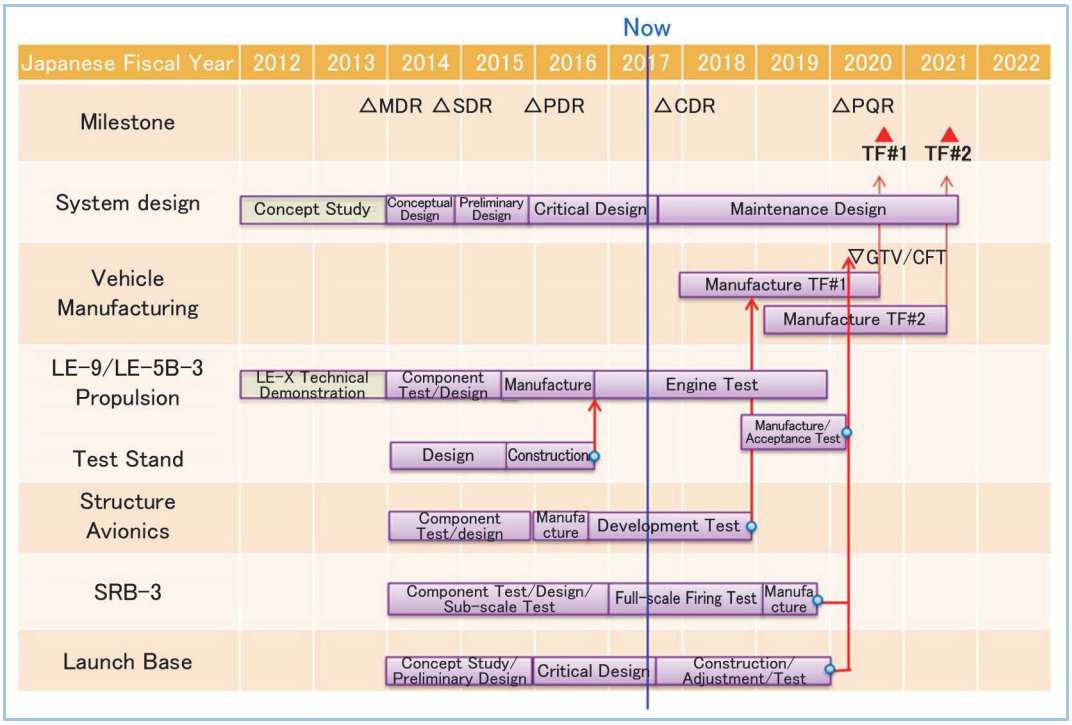


Figure 13 Development schedule

At present, for the LE-9 engine, #1 series of engineering model engine firing tests were completed, and for the second stage LE-5B-3 engine, #1 qualification model engine firing tests were completed. The prospect for the feasibility of the engine performance was obtained, and the development step has made significant progress. In the future, the engine unit firing test will be continued to accumulate data. Furthermore, in the autumn of 2018, the BFT for the first stage will be conducted, and in the autumn of 2019, the CFT for the second stage will be conducted to verify the combined performance of engine and vehicle system.

Half of the development period has passed toward the launch of the first vehicle in 2020. To achieve the challenging objectives of reliability being equivalent to or higher than the H-IIA/H-IIB with the launch service price being reduced by half, the relevant parties both inside and outside our company will strive to make cooperative efforts.

References

1. Tamura, A. et al., Development of Japan's Next Flagship Launch Vehicle - To compete and survive in the global commercial market -, Mitsubishi Heavy Industries Technical Review Vol. 51 No. 4 (2014)