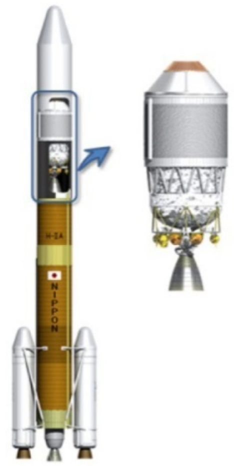
H-IIA Launch Vehicle Upgrade Development
- Upper Stage Enhancement to Extend the Lifetime of Satellites -



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Mitsubishi Heavy Industries, Ltd. (MHI) started the satellite launch service by H-IIA and H-IIB launch vehicles in 2007. Since then, the H-IIA and H-IIB have continued successful launches. In September 2013, MHI received the first order to launch a commercial satellite from TELESAT, a leading global satellite operator in Canada. The satellite will be launched using the upgraded 2nd stage of H-IIA to extend the lifetime of the satellite. MHI has engaged in the upgraded development under the contract of JAXA (Japan Aerospace Exploration Agency). This paper explains the H-IIA 2nd stage upgrade to realize a longer satellite lifetime by injection into an orbit closer to geostationary earth orbit (GEO).

1. Introduction

As of October 2014, Japan's flagship launch vehicles, the H-IIA and H-IIB, had recorded 19 and 4 consecutive successful satellite launches, respectively. This is among the world's top operational records. MHI provides a comprehensive launch service that covers manufacturing the launch vehicle, controlling the interface between the launch vehicle and a satellite, program management, and launch.

While continuing the launch service by H-IIA/B, MHI and JAXA are moving forward with a launch vehicle evolution plan in order to promote Japan's space applications and to increase competitiveness in the commercial satellite launch market[1] (**Figure 1**).

In this context, we initiated the development of the next flagship launch vehicle in April 2014, which features an entirely renewed launch system and is expected to be the main fleet in the 2020s.

Until then, we are moving forward with upgrade development to enhance the 2nd stage performance of the H-IIA launch vehicle, the so-called upgrade development, for enlarging mission flexibility. This upgrade development started in fiscal 2011, and the design and ground level-development testing were completed by the end of fiscal 2013.

This paper clarifies the issues facing the current H-IIA launch vehicle and then describes the purpose, flight profile and development items of the 2nd stage enhancement.

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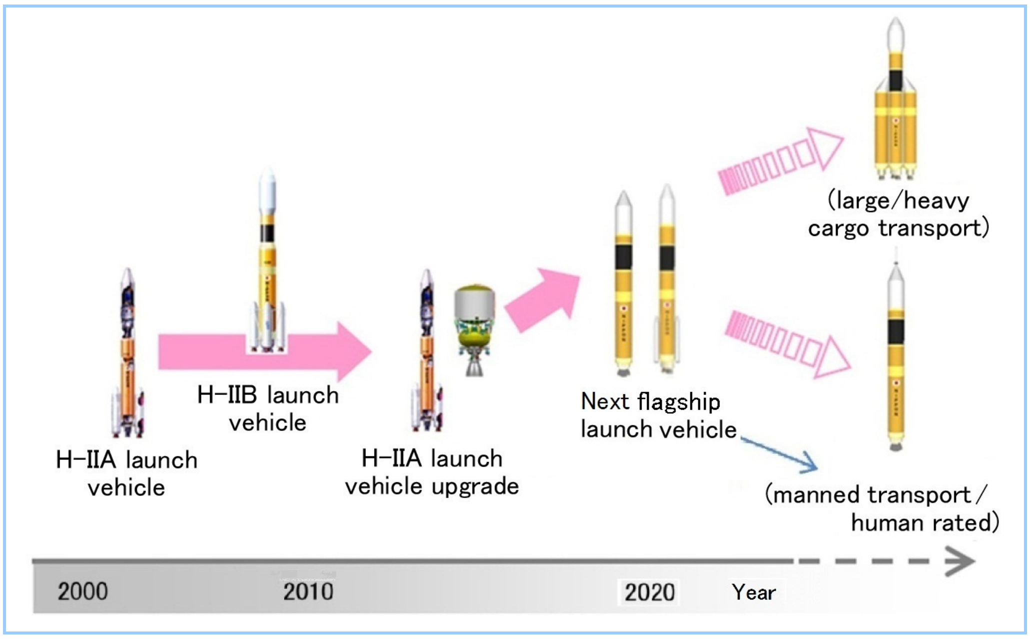

Figure 1 Continuous evolution of Japan's flagship launch vehicle

2. Current status and issues facing H-IIA launch vehicle

Figure 2 shows the past record of launches by the H-IIA and H-IIB launch vehicles as of October 2014. The success rate was 96% with the H-IIA and 100% with the H-IIB. Their missions covered a wide range of space activities/applications including earth observation, meteorology/communication/broadcasting, scientific space exploration, and logistics to the International Space Station (ISS).

Before the upgrade development, however, we have had one satellite launch from abroad, which was for H-IIA flight No. 21 (a South Korean satellite for public use), and no launches for commercial satellites.

For acquiring commercial satellite launch service orders, one of the issues lies in a shorter operational lifetime of a satellite launched by the H-IIA compared with one launched by the Ariane 5 vehicle, a leading launch vehicle in the global commercial launch service. This stems from the fact that the launch site for the H-IIA is located in Tanegashima at a northern latitude of 30 degrees and the geostationary transfer orbit of the H-IIA is inclined against the equatorial plane.

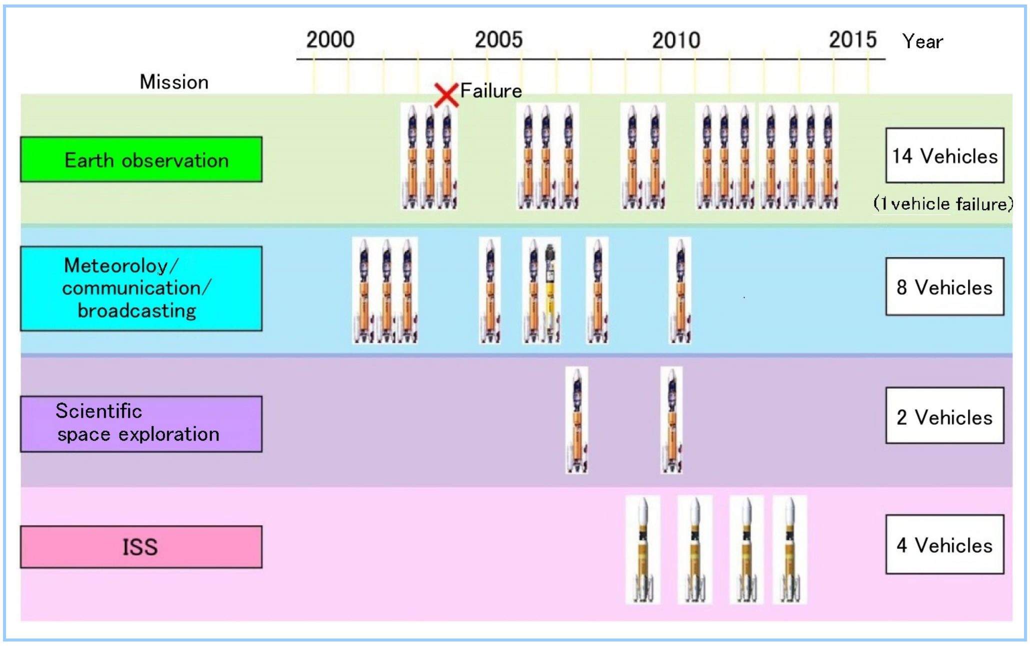

Figure 2 Launch record of H-IIA and H-IIB

Figure 3 is the conceptual image of a geostationary transfer orbit (GTO) mission by the current H-IIA. The geostationary satellite is carried into GTO by the launch vehicle and is then inserted to geostationary earth orbit (GEO) at the apogee by the satellite's own propulsion system.

The current H-IIA launch vehicle puts a satellite into GTO near perigee with perigee altitude of 200 to 300 km and apogee of 36,000 km. This GTO is inclined from the equatorial plane due to the latitude of the launch site, and the current H-IIA requires a delta-V of as much as 1800 m/s for a satellite to put the satellite into GEO.

On the other hand, the Ariane 5 is launched from its launch pad in French Guiana, at approximately 5 degrees of latitude, and nearer to the equator, and thus, only requires 1,500 m/sec of delta-V for a satellite to put it into GEO. This gap corresponds to a difference of a few years in satellite operational lifetime.

To solve this disadvantage of the current H-IIA, we make the 2nd stage coast to the apogee and carry the 3rd burn in order to compensate for part of the delta-V of the satellite for GEO insertion.

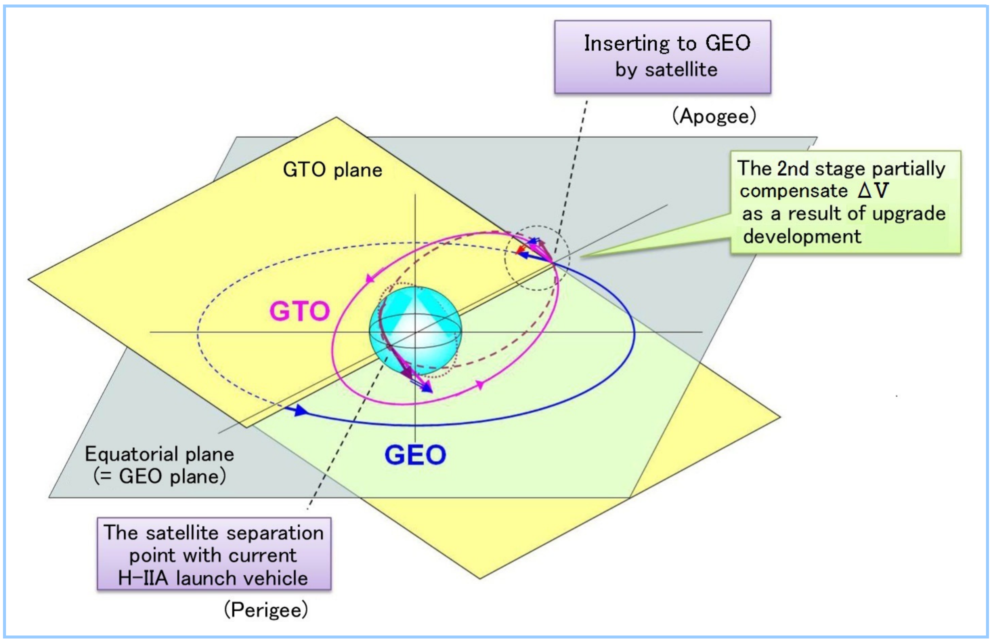

Figure 3 Standard GTO Trajectory of current H-IIA launch vehicle

3. H-IIA 2nd stage upgrade development

3.1 Reason for the development

Table 1 shows the requirements for the 2nd stage upgrade development. Aiming for a better launch service, the requirements include the reduction of the satellite separation shock to the world's top level of 1,000G or less[2], in addition to launching a geostationary satellite to GTO with delta-V of 1,500 m/sec.

The developments to reduce the delta-V of a satellite for GEO insertion, in which MHI played a primary role, are described in the following.

Table 1 Requirements of H-IIA 2nd stage development

Item	H-IIA (Upgraded)	H-IIA (Current)
Launch capability (delta-V of 1,500 m/sec)	H-IIA 202 Model : 2.9t H-IIA 204 Model : 4.6t	Launch only with delta-V of 1,800 m/sec
Satellite separation shock	1,000 Gsrs	4,100 Gsrs

3.2 Trajectory

The typical flight profile in launching the satellite into GTO with a delta-V of 1,500 m/sec is shown in **Figure 4**.

The flight profile is the same as that of a current H-IIA standard GTO mission until the 2nd burn of the 2nd stage. After that, a coasting flight (long coasting) is carried out, and the 3rd burn is executed in the vicinity of the apogee and the satellite is separated. As such, this mission is named the GTO long coasting mission.

In a GTO long coasting mission, the mission time from launch to satellite separation for the launch vehicle increase from 7,200 seconds to 20,000 seconds.

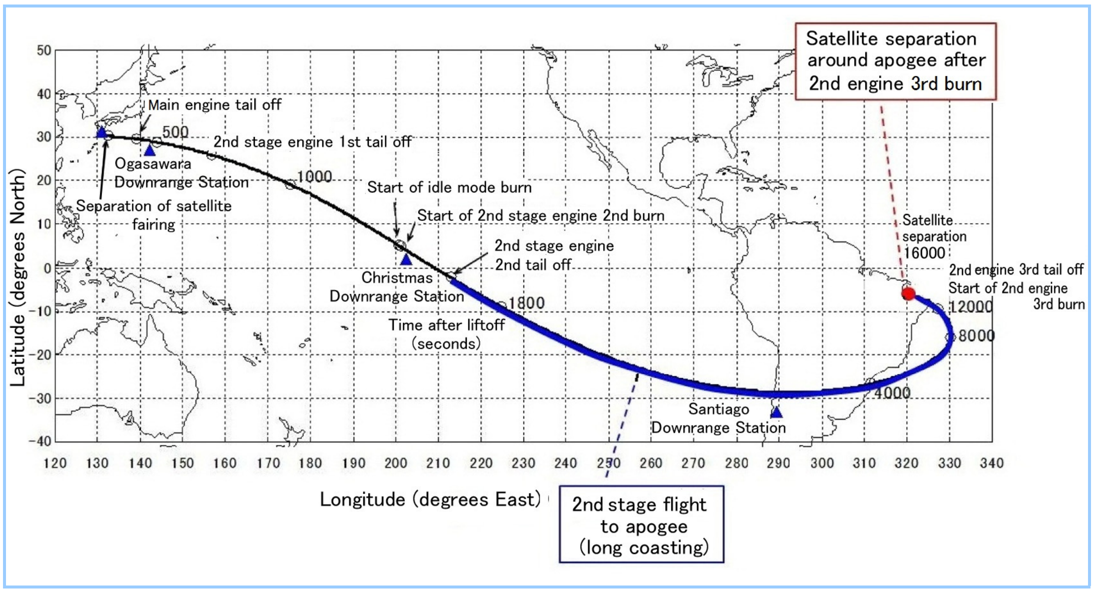

Figure 4 Trajectory of GTO long coasting mission

3.3 Development items

Generally, satellites operators, that is, customers of satellite launch services, focus on launch vehicle reliability. Accordingly, we established the upgrade development policy of maintaining the vehicle's reliability while adding functions based on the technologies accumulated in the development and flight results of the H-IIA and H-IIB launch vehicles. That is, we decided to enhance the 2nd stage without configuration change, such as the stage sizing, the engine performance, and electronics and propulsion components.

According to this policy, three kinds of items were newly developed in order to execute the 3rd ignition near the apogee following long coasting, as shown in **Figure 5**.[3]

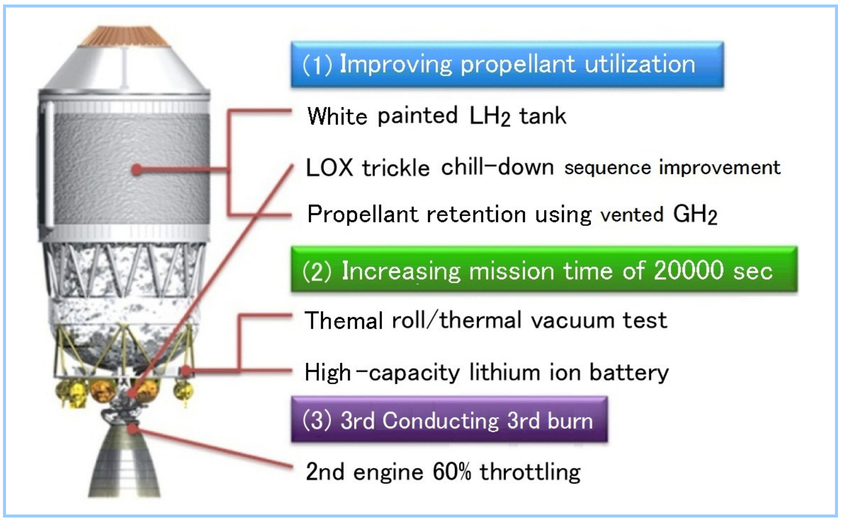

Figure 5 Development details for upgrade development

(1) Improving propellant utilization

Improving propellant utilization is substantial to achieve launch capability without major configuration change of the 2nd stage. We developed the following three items for each propellant on the 2nd stage, i.e., liquid hydrogen (LH2) and liquid oxygen (LOX) for the main propulsion system and hydrazine for the reaction control system (RCS).

(a) White-painted LH2 tank

LH_2 is evaporated by the radiation heat of sunlight during long coasting. To reduce the evaporation rate, we put white paint on the thermal insulation of the LH2 tank.

After the element and manufacturing tests for understanding the characteristics and for establishing a manufacturing process, respectively, we carried out the flight test of the white-painted LH_2 tank (**Figure 6**) by using H-IIA Flight No. 21 (launched in May 2013). Based on the flight data obtained during one orbit around the earth after satellite separation, we confirmed that the evaporation rate of LH_2 was reduced as expected and that the design and manufacturing process were appropriate.

Figure 6 White-painted LH_2 Tank (H-IIA Flight No. 21)

(b) LOX chill-down sequence improvement

For LOX, we enhanced the turbo-pump chill-down system before engine restart. The turbo-pump is chilled down by LOX propellant to avoid the evaporation of LOX at engine restart. The LOX evaporation causes insufficient suction of the turbo-pump.

The current chill-down system is designed mainly for chill-down before engine restart, and the flow rate is high. In the 2nd stage upgrade development, a LOX chill-down system called a trickle chill-down system was newly added (**Figure 7**) to effectively cool the turbo pump with a small flow rate of LOX during long coasting, and the chill-down sequence was optimized. The flow rate and sequence was established through past H-IIA flight data and ground vacuum testing. In the ground vacuum test, the trickle chill-down system is attached to a turbo pump in the vacuum chamber.

The trickle chill-down system was also tested with H-IIA Flight No. 24 (launched in May 2014) and the predicted characteristics were confirmed.

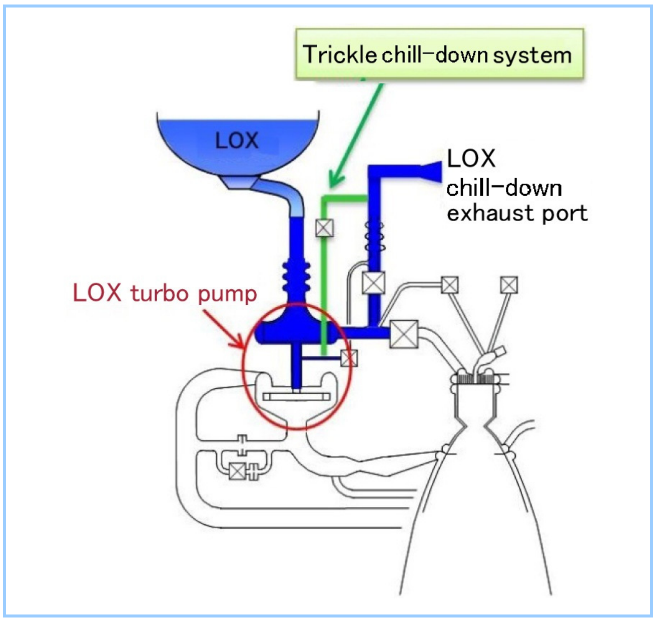

Figure 7 LOX trickle chill-down system of 2nd engine

(c) Propellant retention using vented GH_2

RCS is also used to preserve the propellant at the bottom of the tank during coasting (so-called "retention"), in addition to attitude control. A gaseous/evaporated Hydrogen (GH_2) vent retention system is attached (**Figure 8**) to reduce the hydrazine consumption for retention during long coasting. It allows us to avoid the additional load of a hydrazine tank.

The GH_2 vent retention system was confirmed through ground testing for retention nozzle thrust and propellant sloshing analysis.

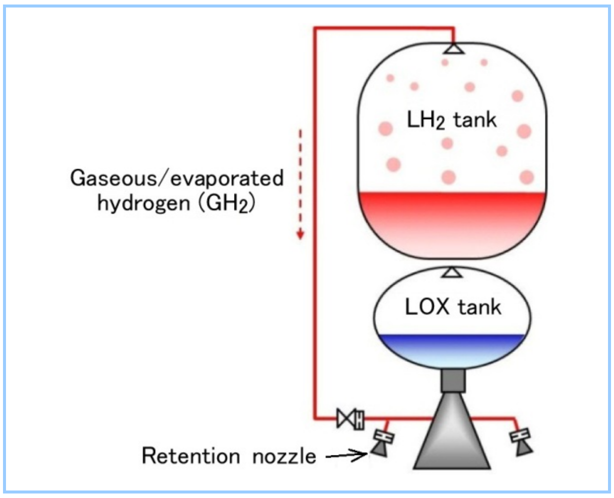

Figure 8 GH_2 vent retention system

(2) Increasing Mission Time of 20,000 sec

The challenges to extend the mission time from 7,200 sec to 20,000 sec include maintaining the thermal condition and securing power resources during coasting.

(a) Maintaining Thermal Condition

In order to maintain the thermal condition of both the 2nd stage and the satellite, the 2nd stage is rotated around its vehicle axis during coasting so that the vehicle axis during flight is perpendicular to sunlight. This contributes to averaging the thermal distribution of the 2nd stage and the satellite and is also preferred in terms of securing the necessary power resources (generated by solar power) for the satellite during coasting.

The thermal vacuum testing was conducted to verify that the interface temperature to the onboard component is maintained within the current specification by a thermal roll. The test was aimed at improving the accuracy of the thermal analysis model. Thermal testing using STA (structural testing article) of the truss section and guidance section was conducted in the 8-m-diameter vacuum chamber at the JAXA Tsukuba Space Center. System thermal analysis by using a model correlated based on thermal vacuum testing (**Figure 9**) evaluated that the thermal environment of the truss section and guidance section was maintained within the specifications of current H-IIA avionics and propulsion components only by the addition of several flight heaters.

(b) Securing Power Resource

The 2nd stage is not equipped with solar cells (batteries). To increase electric power supply for long coasting mission, a high capacity lithium-ion battery is adopted.

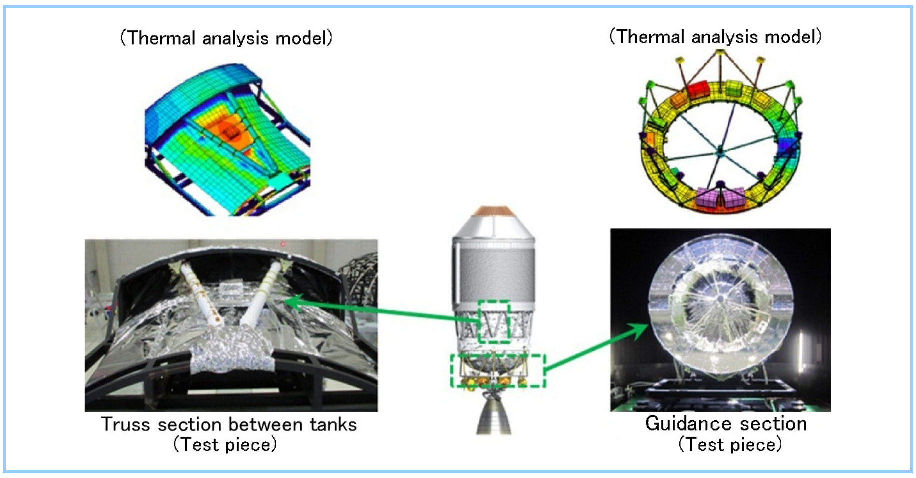

Figure 9 Thermal vacuum test of truss section and guidance section

(3) Conducting 3rd burn

The delta-V of 2nd stage 3rd burn executed near the apogee is small, that is, 300 m/sec. From the viewpoint of orbit injection accuracy, it is preferable to extend the burn time by reducing the engine thrust. The first model of the 2nd stage engine, the LE-5B, was designed for 60% throttling, and its feasibility was confirmed in the flight test of H-IIA test flight No. 2 (launched in 2002). To realize 60% throttling for practical use, the operation point of 60% throttling was established in the 2nd stage enhancement. The engine firing test at the High Attitude Test Stand (HATS) in JAXA Kakuda Space Center was completed and 60% throttling was verified (**Figure 10**).

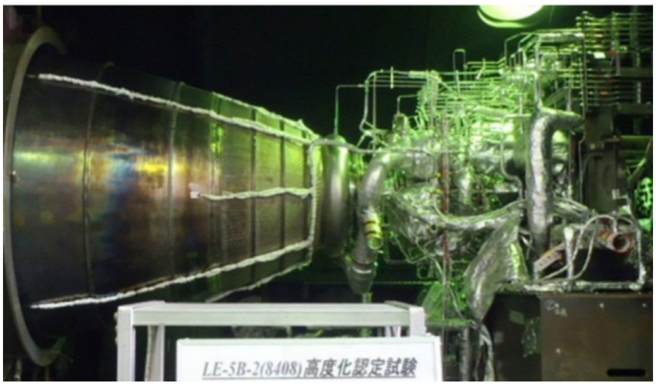

Figure 10 2nd engine 60% throttling certification test

4. Conclusion

Through the upgrade development to improve its 2nd stage, the H-IIA launch vehicle can allow a satellite in geostationary orbit to have a longer lifetime. As a result, international competitiveness is increased and the first commercial satellite order was received. The ground-level development has been completed and the first satellite launch is planned in the fall of 2015.

(Acknowledgement)

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