Upper Stage Propulsion System Development for H-IIA Upgrade

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Abstract
Japan Aerospace Exploration Agency, JAXA, is now planning a step-by-step development of launch vehicles considering the future applications of space transportation systems and satellite customer needs. At the first stage of the development, we are now upgrading the upper stage of the H-IIA launch vehicle, Japanese primary launcher, for improvement of payload capacity in order to meet the launch needs of Japanese government and the satellite industry effectively. Currently, regarding GTO (Geo Transfer Orbit) missions, the upper stage engine of H-IIA burn twice and insert satellites in 28.5 degree inclination GTO. The H-IIA upgrade will aim to decrease inclination for satellites with third burn of upper stage at apogee after long-duration coast. In addition to this, SSO (Sun Synchronous Orbit) dual launch mission, two satellites are inserted into different SSOs, is also now under consideration. We try to obtain some propulsion system technologies for the effectiveness of these missions; throttling of upper stage engine, low liquid level ignition, improvement of LOX (liquid oxygen) chill-down procedure and propellant settling by using vented propellant. These technologies could be developed in a short term with lower cost and will succeed to the next generation propulsion technologies. In this paper, we will introduce the development topics of the upper stage propulsion system for the H-IIA upgrade.

1. Introduction

At the present time, the Japanese primary launcher, H-IIA, has been launched 18 times since 2001 and continuing successful launches for the 12 times in a row since 2005. The new heavy launcher, H-IIB, debuted in 2009 with a successful cargo delivery to ISS (International Space Station) using the first HTV (H-II Transfer Vehicle), also called Kounotori. The 2nd H-IIB has been also successfully launched and delivered cargo to ISS in the beginning of 2011. In the 2nd H-IIB mission, the upper stage was reentry with reignition after the payload separation from the orbital debris mitigation point of view. This operation, so-called controlled reentry, is the first trial for Japan.

While we continue to operate our primary launchers to serve national and commercial needs, a discussion of the next generation launch system has been continued for several years in JAXA. We are planning to adopt a step-by-step development approach as shown Fig. 1, and keep commonality at each step to keep vehicle reliability and to avoid excessive risk and cost for the development.

The first step, which will be presented in this paper, will be the upgrade of the second stage of H-IIA to enhance its capability without major system design change. The second step, will be the development of the next primary launch system with a new stage configuration, and then human rated launch vehicle will succeeded them [1].

Our primary launcher's launch capability is not best fit with the needs of customers today. Since the size of SSO satellites becomes smaller and the size of GSO satellites becomes larger after the development of H-IIA launch vehicle as shown Fig. 2 and 3 respectively, it is now too large for SSO satellites and a little small for commercial GSO satellites. The main objective of the H-IIA upgrade is to be adapted to these trends of satellites with short-term development and lower cost.

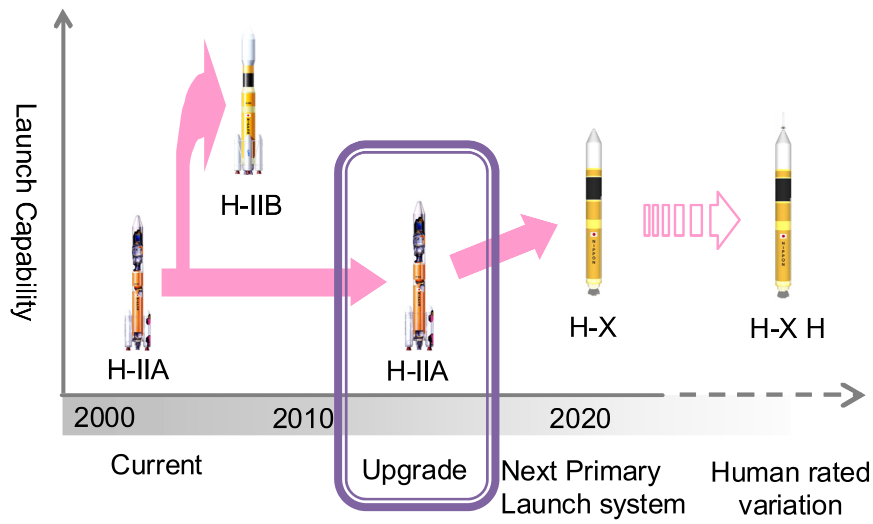

Figure 1: Launch vehicle development plan in Japan.

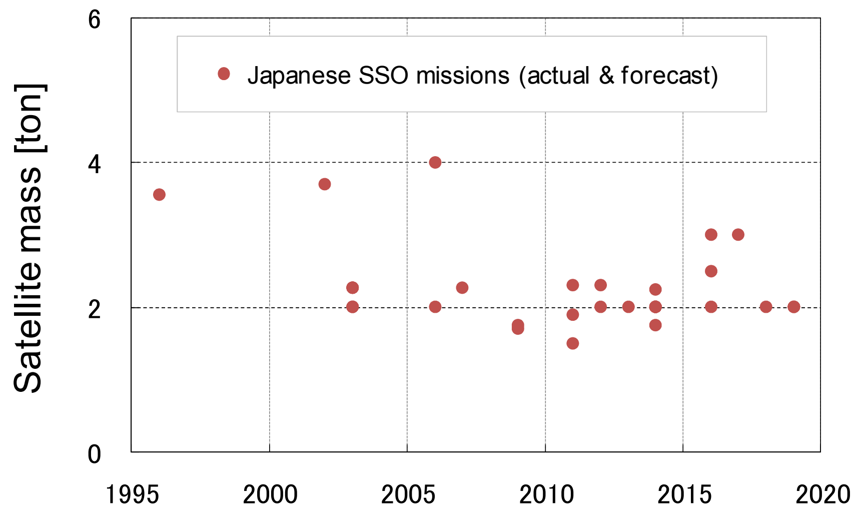

Figure 2: Trends in SSO satellite mass distribution in Japan.

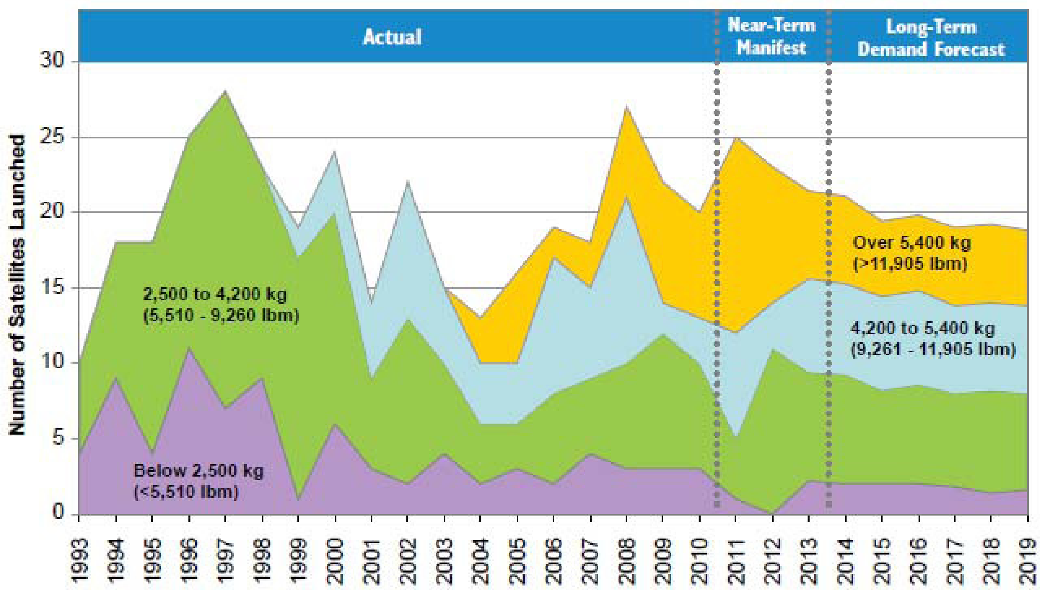

Figure 3: International trends in GSO satellite mass distribution (referred from COMSTSAC 2010).

2. H-IIA upgrade overview

As for the development of H-IIA upgrade, two targets are selected considering the needs of government and commercial customers.

(1) Increase in launch capability to GTO.

(2) Dual satellite launch to different SSOs.

The standard GTO capability of the current H-IIA is 4 ton and 6 ton for H2A202 type, which has 2 solid rocket boosters, and H2A204 type, which has 4 solid boosters, respectively. The H-IIA standard delta-V to GSO is relatively large comparing to international standard. Therefore, we intend to decrease the delta-V to the international standard without using super-synchronous orbit. Longer coast time and the third burn with throttling of the upper stage engine at the apogee of the GTO can achieve this goal as shown in Fig. 4. The launch capability of the upgraded H-IIA with international standard delta-V is expected to be approximately 2.9 ton and 4.6 ton for H2A202 type and H2A204 type, respectively.

The second is to accommodate dual payloads and deliver them to different SSOs. Because the payload mass trends of SSO missions in Japan is downward from the former 4 ton class to 2 ton or less class as seen in Fig. 2, the dual satellite launch to the different altitudes is expected to improve cost-effectiveness, especially for government customers. Since SSO satellites are not usually equipped with a propulsion system to be used for orbital manoeuvre, we intend to put the second payload to designated altitude using the second and third burn with throttling of the upper stage engine after relatively long coast as shown in Fig. 5. The launch capability of upgraded H-IIA using H2A204 type is expected to be approximately 2 ton for each satellite, depending on their altitudes.

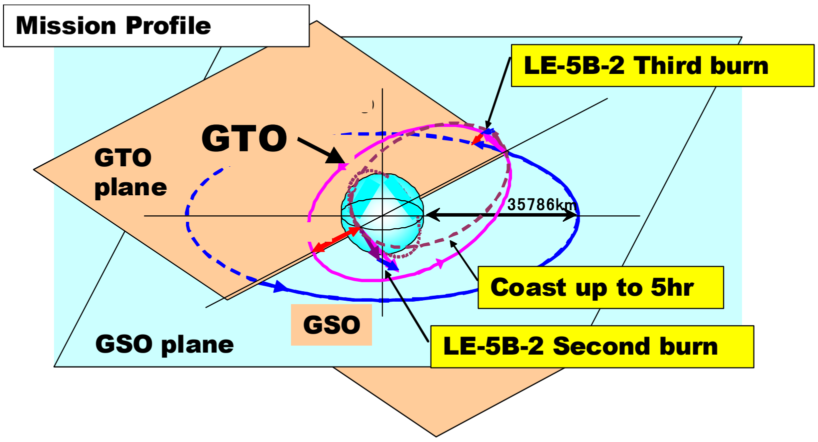

Figure 4: GSO mission sequence of H-IIA upgrade.

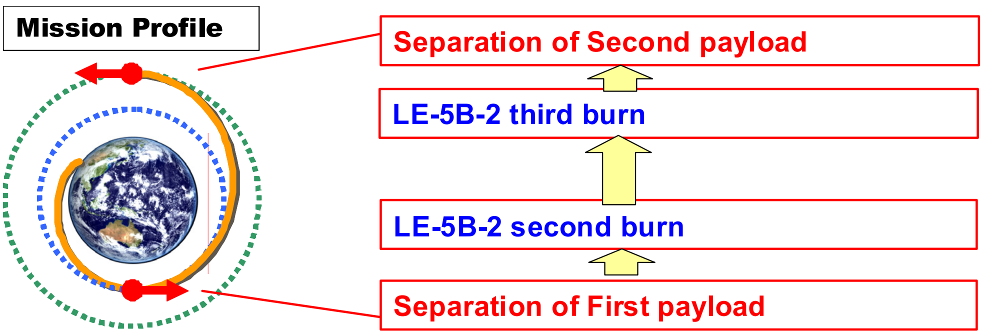

Figure 5: SSO mission sequence of H-IIA upgrade.

3. Propulsion system development for H-IIA upgrade

According to the discussions of more efficient GTO and SSO missions in the previous section, one can know that the upper stage propulsion system for the H-IIA upgrade should be adapted to the following operations.

(1) Long-duration coast of upper stage.

(2) Multi-ignition of the upper stage engine, LE-5B-2, with throttling.

The upper stage of H-IIA is a LOX (liquid oxygen) and LH2 (liquid hydrogen) cryogenic liquid stage, and the main engine, LE-5B-2, generates approximately 14 tonf thrust and 450 s specific impulse with expander bleed cycle. We picked up four propulsion technologies for above, i.e., throttling of upper stage engine, low liquid level ignition, improvement of LOX chill-down procedure and propellant settling by using vented propellant, as shown in Fig. 6. These technologies could be developed in a relatively short term with lower cost and will succeed to the next generation propulsion technologies.

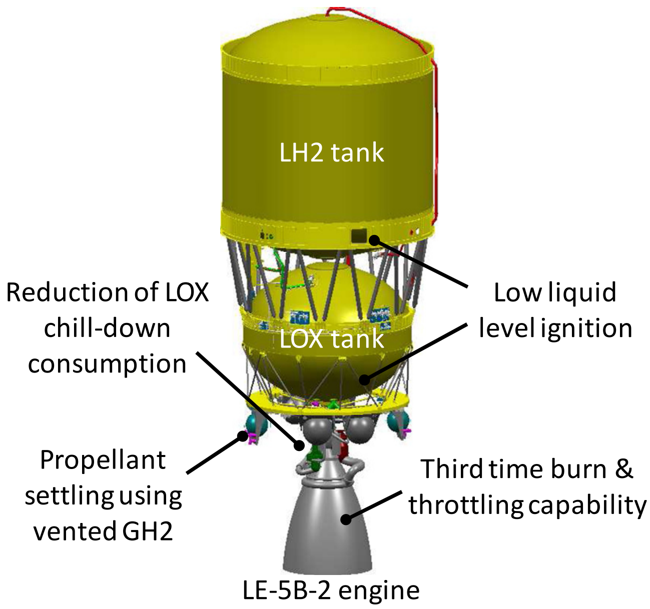

Figure 6: Upper stage propulsion system of H-IIA and development items for H-IIA upgrade.

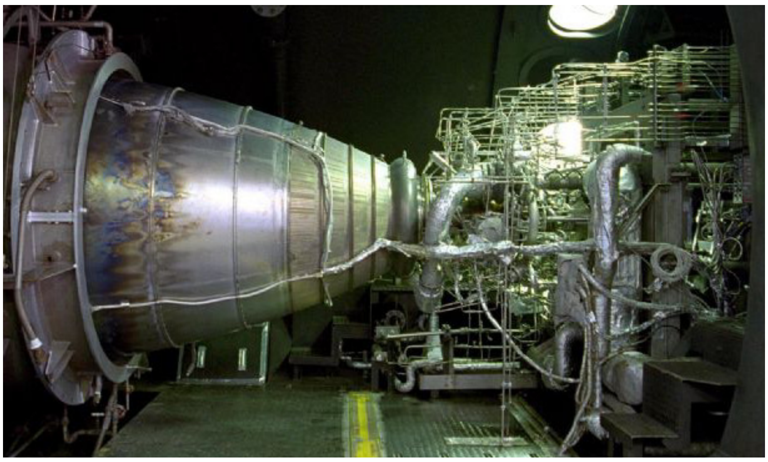

Figure 7: LE-5B-2 upper stage engine in HATS (High Altitude Test Stand).

3.1 Throttling of upper stage engine

With the diversification of mission requirements, an upper stage today needs to be fit for many varieties of mission types. We are expanding the capability of LE-5B-2 upper stage engine step-by-step for adaptation to the various mission requirements. In 2010, the pressure fed mode of LE-5B-2 engine, which was originally employed to make the injector surface free from ice in restart mode for a short duration, was ground tested and qualified for a long duration firing and was tested in the H-IIA flight after payload separation. This mode can be used for small delta-V burn, and was applied to the controlled reentry of the upper stage, whose purpose is orbital debris mitigation, in the 2nd launch of H-IIB in the beginning of 2011.
Regarding the H-IIA upgrade, for the GTO mission with long-duration coast and the dual satellite mission to different SSOs, engine burn for small delta-V is needed and the several levels of throttling capability of the upper stage engine play the crucial role. Our upper stage engine, LE-5B-2, already has the capabilities of 60 % throttling mode and the 3 % pressure fed mode. We intend to fully utilize the capabilities of the engine as well as to explore the possibilities of other options for lower thrust level with higher performance. Therefore, in addition to 60 % and 3 % throttling modes, a hot firing test campaign of LE-5B-2 was conducted to check the feasibility of 30 % thrust level by using the High Altitude Test Stand (HATS), located in JAXA's Kakuda Space Center as shown in Fig. 7. We have confirmed feasibility of the 30 % throttling mode and obtain the performance. The specific impulse of the 30 % throttling mode is almost the same as the rated power level, about 450 s. We are now planning to improve some components for more high-performance and high-reliability.

3.2 Low liquid level ignition

At the third time burn, the liquid levels of the propellants become low. Therefore, understanding the limit liquid level at engine ignition (to prevent against gas ingestion to the turbopump) and control of the liquid motion are strongly required. We are now planning to conduct CFD analysis for low liquid level ignition and to develop sloshing suppression devices for low liquid level sloshing through both scaled water experiment and CFD.

3.3 Improvement of LOX chill-down procedure

For the adaptation to the long-duration coast without major system design change, reduction of propellant usage will play a crucial role to achieve the target launch capabilities. As for the liquid oxygen, two methods of reduction of LOX chill-down consumption are now under consideration.
One is called LOX recirculation system (left of Fig. 8), in which LOX is circulated between LOX tank and LOX turbopump cooling the hardware. This method is applied some launch vehicles [2], can reduce the chill-down consumption in all mission phases (both before engine firing and during long-duration coast), however, the recirculation pump, cryogenic-compatible light-weight pump, is needed and careful heat management and control of liquid motion under low acceleration environment are necessary. We successfully facilitated a development model of recirculation pump and obtained some basic performances, suction performance and head curve under cryogenic environment. We are now planning a system level test with fully utilizing the two-phase flow simulation techniques as a next step.
The other method is called "trickle chill-down system", shown in the right of Fig .8, is now under development. The feasibility of this system was demonstrated in the HATS with the LE-5B-2 engine firing test. The result indicated very small amount of LOX flow (several g/s) can cool the bearings of the LOX turbopump rather than our conventional long-coast chill-down procedure, impulse chill-down method. In addition to this, we are trying to modify the chill-down sequence before engine ignition. The modified chill-down sequence is assembled based on the engine test data and the flight data as well as simulation considering two-phase flow heat transfer.

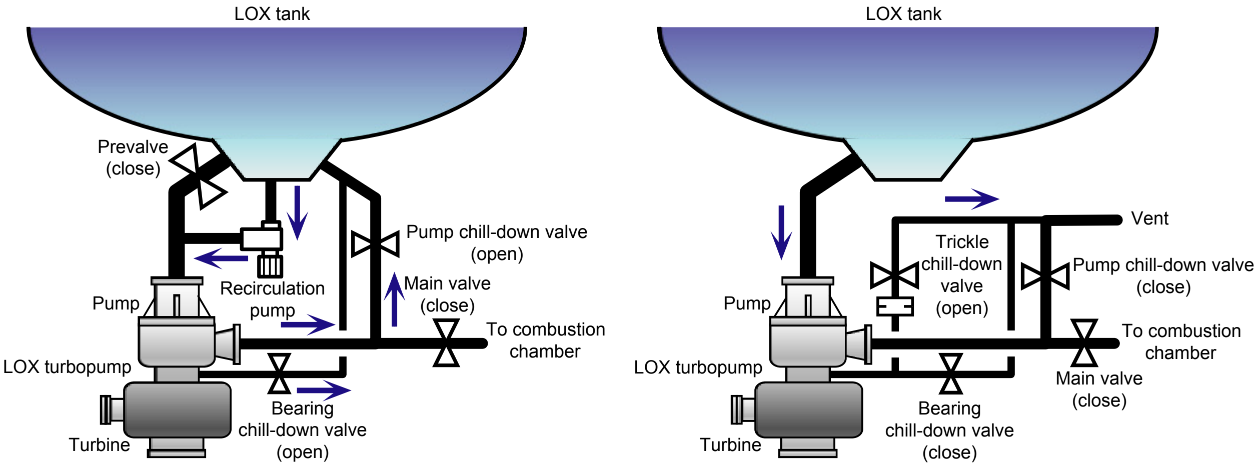

Figure 8: Schematics of recirculation chill-down system (left) and trickle chill-down system (right).

3.4 Propellant settling by using vented hydrogen

During long-duration coasting, upper stages generally have used reaction control thrusters to resettle the tank contents. The H-IIA launch vehicle uses hydrazine thrusters for the propellant settling, which incurs weight penalties. A new subsystem for propellant settling during coasting phase using hydrogen vent gas from LH2 tank will be applied to reduce the consumption of the hydrazine propellant of the reaction control thrusters. Figure 9 shows schematic of our gaseous hydrogen (GH2) vent settling system. Vaporized gaseous hydrogen in the LH2 tank is vented backward through the two settling nozzles and generates the settling thrust instead of the conventional hydrazine thrusters.

We picked up some risks for the vent settling system development and are mitigating these risks step-by-step. First risk is freeze of vented hydrogen in the settling nozzle during expansion. This would be avoided by applying proper aerodynamic design of the nozzle. Second is prediction error of vaporization of the LH2 during coast phase. Because the accuracy of the prediction affects the thrust level for the settling, now we are tackling the improvement of the two-phase flow simulation model with fundamental experiments [3]. In this experimental campaign, we successfully visualized hydrogen motion and vaporization phenomena as shown in Fig. 10 and obtained various two-phase flow data of cryogenics. Finally, undesirable cooling of equipments (avionics, pressure vessels, etc.) around the settling nozzle by the plume impingement and heat conduction must be concerned. Flow simulation considering rarefied effect, DMSC simulation of the plume, and ground experiments are now undergoing to mitigate of these risks.

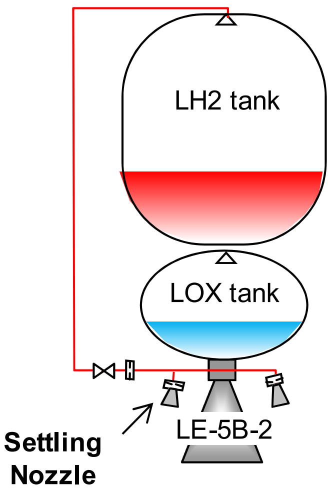

Figure 9: Schematic of GH2 vent settling system.

Figure 10: LH2 vaporisation and visualization experiment.

4. Summary

JAXA is now developing the H-IIA upgrade, in which the 2nd stage of H-IIA launch vehicle is improved to be adopted to the long-duration coasting and multi-time ignition of main engine, LE-5B-2, with several levels of throttling. These operations of the upper stage will realize more effective GTO and SSO missions. We picked up four propulsion system technologies so as to achieve them.
The throttling capabilities, 3 %, 30 % and 60 %, of LE-5B-2 engine were successfully demonstrated in the HATS. The 30 % and 60 % throttling modes accomplished the same specific impulse of 100 % rated power level, approximately 450 s. The low liquid level ignition technique and devices for sloshing suppression now under development through CFD and scaled experiments. Regarding the improvement of LOX chill-down procedure during coast phase, we are now comparing two methods, i.e., recirculation chill-down system and trickle chill-down system. EM model fabrication and test campaign of the recirculation pump was successfully finished and the trickle chill-down system was demonstrated with the engine firing test at HATS. The GH2 vent settling system is now being developed for reduction of hydrazine consumption for propellant settling during coast phase. We are making efforts to improve the simulation accuracy for the risk mitigation. These propulsion system technologies could be developed in a short term with lower cost and will succeed to the next generation propulsion technologies and the next primary launch system.

References

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