A Innovative Design Procedure for H-IIA/B Evolution

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Abstract

A design procedure for H-IIA/B Evolution, which is next flagship launch system in Japan, is presented. Aiming drastic cost efficiency and potential for future variation, which include heavy version and human rated variation, H-IIA/B Evolution is targeted to be operational in 2020 with brand-new system, which include launch vehicle and facility. Therefore, the quick system design procedure for given needs with appropriate depth and broadness is important, especially in early study phase.

As introduction, current status and future plan about Japanese space transportation system, especially H-IIA/B Evolution, is explained. After that, with presenting characteristic situation of JAXA's launch range, the research status of the quick system design procedure is explained

1. Introduction

H-IIA/B is Japanese flagship launch vehicle of Japan (Fig. 1). This launcher equips the equivalent capability and cost with world standard of large launchers. Also, only one launch failure (H-IIA-F6) from twenty flights indicates the high reliability 95%. Also, as space transportation system, there are two times successful cargo delivery to ISS using H-II Transfer Vehicle (HTV) and smooth development of "epsilon rocket", which consist of three solid stages, for 2013 operation.

While we continue to operate our flagship launch system to serve national and commercial needs, many discussions of the succeeding launch system have been continued. Main factors are summarized below.

A, Efficient fit with the current needs:

The fact that H-IIA/B's launch capability is not best fit with the needs of customers today. Since the size of satellites that use Sun Synchronous Orbit (SSO) (mainly Earth observation satellites) has become smaller, which are about 2.5ton, after the development of H-IIA launch vehicle, the vehicle is now too powerful, which is over 4ton, for SSO satellites and we need a solution for cost effective launch method of SSO satellite. Furthermore, for Geostationary Orbit (GSO) satellites, the high latitude 30.4degN of our launch range, Tanegashima Space Centre (TNSC), requires an additional delta V for spacecraft to change the orbit inclination. It is time to consider the best family configuration to match the needs of the customers.

B. Potential for future needs (heavy and human rated)

Starting the study of technologies for a human rated launch vehicle was recommended by a government committee. In addition, we are considering starting an upgrade program of HTV to outfit it with return cargo to Earth(HTV-R), eyeing further the possibility of evolving into future human rated capsule. In this context, our next flagship launch system needs to have the potential to be upgraded to human rated system. Also, there are international collaborative heavy interplanetary missions, like potentially USA human mission to Mars as stated by President Barack Obama.

From these situation, we are planning to adopt a step-by-step development approach and keep stage reliability at each step to keep vehicle reliability and to avoid excessive risk and cost for the development. The vehicle upgrade concept is depicted in Figure 2. The first step will be the upgrade of the second stage of H-IIA to enhance its capability without major system design change, which is called "H-IIA Upgrade". It is targeted to launch flight test vehicle in 2013. The second step, which will be presented in section 2, will be the development of the next flagship launch system with a new stage configuration, which is called "H-IIA/B Evolution (hereafter noted as H-X)". It is targeted to start the development at 2013 and be operational in 2020.

As slightly mentioned, this last few years will be important to make out the concept of H-X. This study requires not only watch of government trend and market research of satellite, but also many trade off study in terms of system and subsystem design to confirm system requirement. For this reason, we are studying the quick system design procedure for given needs with appropriate depth and broadness.

Type	H-IIA202	H-IIA204	H-IIB
Payload Capability*	4.0 ton	6.0 ton	8.0ton
Gross Mass	280ton	410ton	550ton
Diameter	4m (1st & 2nd stage)		5.2m (1st stage), 4m (2nd stage)
Number of Solid Rocket Booster	2	4	4
Fairing	4 or 5m diameter		

*) GTO: ha=35976km, hp=250km, inc=28.5deg, ω=179deg

Figure 1: H-IIA/B launch vehicle

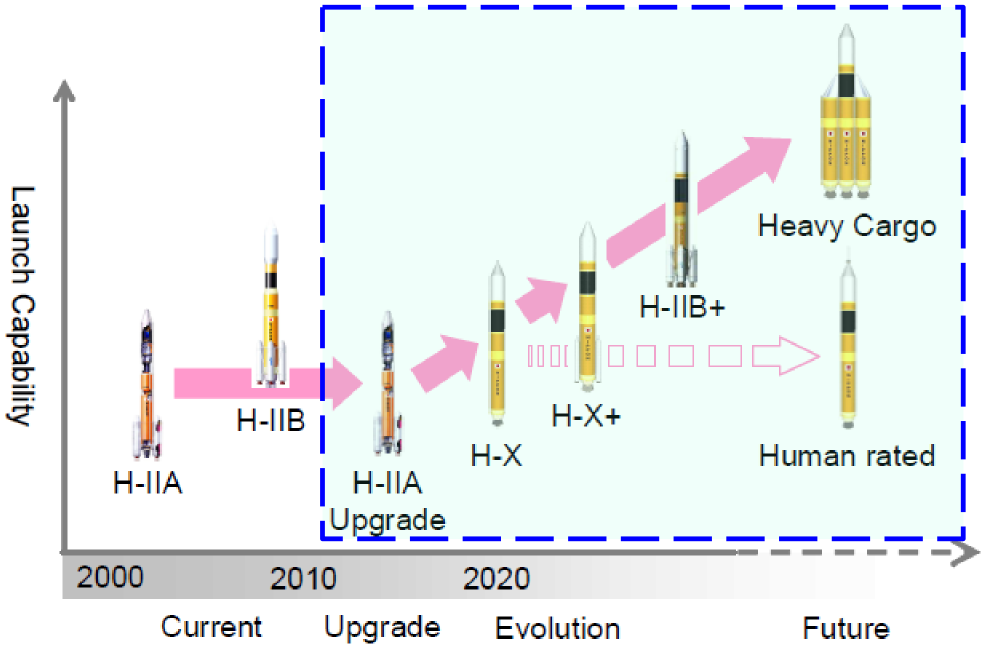

Figure 2: Development approach for next flagship launch vehicle

2. H-IIA/B Evolution – H-X Overview

A family concept of H-X is depicted in Figure 3. This configuration covers SSO 2.5ton class mission, GTO 4ton class mission and manned LEO mission using common stages except for additional redundancies due to human rating requirements. Sales points of this concept are small system with three stages and commonality of each stage. That may be expected to decrease the launch cost and increase the reliability. The optimization of lift off mass is done at GTO 4ton class version with three stages. This version take advantage for debris issue with small 3rd stage, which means the reduction of “Expected casualty (Ec)”, and interplanetary missions with the effect of many stages.

For SSO 2.5ton class version, the configuration is just combination of 1st stage and 3rd stage in GTO 4ton class version. On the other hand, GTO 6ton class version increase the launch capability with four solid rocket booster. For future variation, “man-rated” version simply consist of 1st stage and 2nd stage in GTO 4ton class version, which requires additional redundancies due to human rating requirements. The launch capability of the family variation is set tentatively to cover national and commercial needs. But, as the vehicle and family configuration is now under discussion, the quick system design procedure for given needs with appropriate depth and broadness is important, which will be presented in section 3.

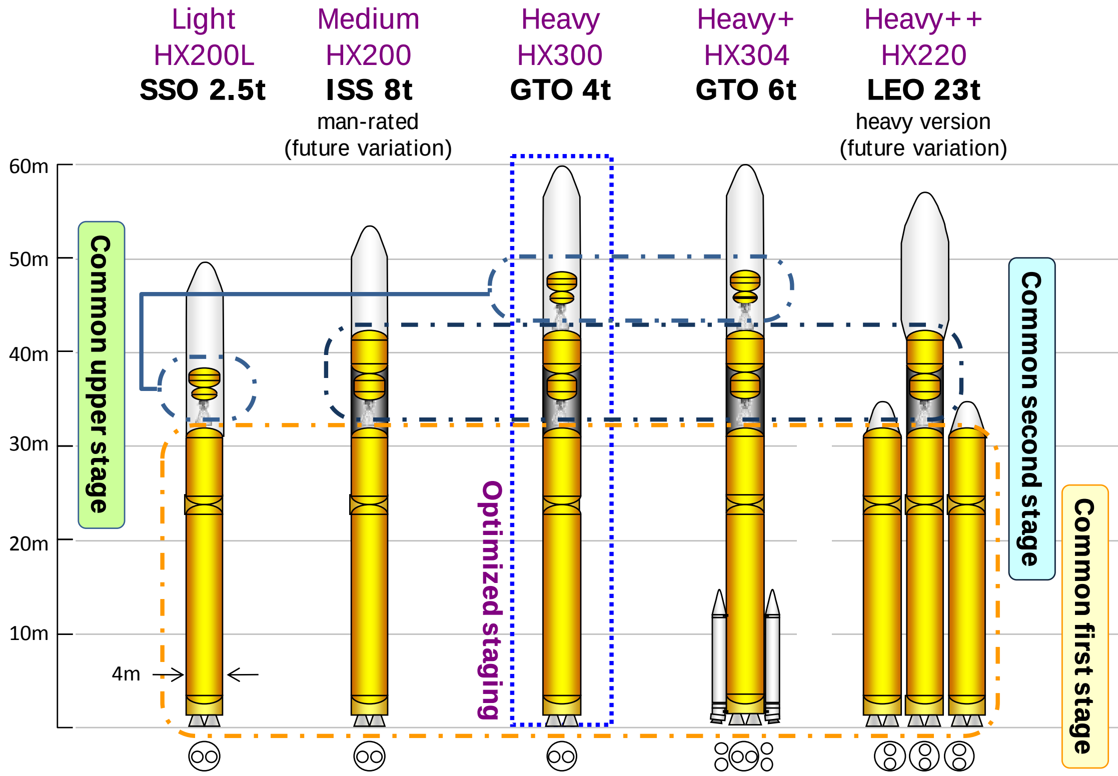

Figure 3: A family concept of H-X

On the other hand, to start the development of H-X, we have to indicate the distinct merit for both Japanese government and industry. For this purpose, detailed understandings of the present situation is the most important matter, which include not only needs of satellite and seeds of technical level, but also problems of today’s launch service industries and national policy. With these consideration, we have to set precise strategy for future to make the space development be sustainable progress and suitable H-X to the strategy. These studies would be continued to take correlation with system concepts.

Other than above, many research and development works about system and subsystem are now ongoing for “H-IIA upgrade” and “H-X” system. Some of these works are introduced below.

Man-rated version

To start the development of man-rated version, “system concept” and “necessary cost and period to realize it” had been studied. A result of the system concept is simple integrated system between launch vehicle and space ship, which carry two persons. The total cost to develop man-rated launch vehicle and space ship is prospected under 4 billion dollars, which is about one sixth of Space Shuttle. Also, if we can start the development at 2013, base vehicle with unmanned will be released at 2018 and man-rated mission will be realized at 2023 with minor update. The study of detailed system, which include launch abort system, and design procedure would be done this year.

Range facility

The concept for range facility is “compact and simple” to reduce the launch and maintenance cost. For example, to boost efficiency of operation, umbilical cable would take away before lift off to avoid the repair after launch and flight control centre will be remote. Minimizing the configuration change at launch day, we plan to choose mobile service tower (MST).

LE-X, expander bleed cycle booster engine

In order to expand the possibility of LE-5B engine, booster engine with the same engine cycle, dubbed LE-X, has been studied for several years. Although the cycle, expander bleed (EB), has thrust upper limit for it uses vaporized hydrogen as an energy source for turbo pump, it is safer than gas generator (GG) or staged combustion (SC) cycle engine that uses high pressure and high temperature combustion gas to rotate turbine. In this aspect, EB engine is favourable for a human rated vehicle since it has less catastrophic failure mode than GG or SC engine. Tests of the elements of the engine have been conducted and the Bread Board Model engine firing testis planned.

Al-Li, high specific strength material

As a candidate of propellant tank material, Al-Li alloy has been studied for taking the technical feasibility and effectiveness for H-X. For technical feasibility, some mechanical material tests and shaping process test have been done. The effectiveness of cost and mass for H-X has been calculated quantitatively with rough system design. Up to now, the result of this research indicate effectiveness of low cost and good feasibility. The study of structural type would be done this year.

3. Research on System Design Procedure

A final image of this procedure is depicted in Figure 4. For the given conditions, which indicate “INPUT” in this figure, quick design and evaluation of feasibility, which are “Vehicle Design” and “Rough Check” in this figure, with appropriate depth and broadness is possible especially at the early study phase. With this procedure, we can quickly compare variety of configurations in terms of system, which mean cost, capability and reliability. Also these procedure is necessary to check the system impact of design change.

At first, “INPUT” parameters include “Launch probability” other than normal parameters. The unique reason for the launch range would be explained below. At “Vehicle Design” module, the sizing calculation with necessary ideal velocity would be done. But the velocity is mainly depend on T/W at lift off and flight safety. Also, structural efficiency ratio must be set to take sizing calculation. But the ratio is mainly depend on T/W at lift off, flight safety and vehicle diameter. So, the data base to connect these parameters is important. That result in the vehicle size, which means outline, mass, thrust and specific impulse. At “Rough Check” module, launch capability is confirmed with rough flight trajectory. The flight safety is evaluated with rough analysis. The flight load would be checked with Q*alpha, which is multiplication of dynamic pressure and attack angle. Finally, If the vehicle doesn’t match to input or constraints, the process would be back to vehicle design with updated ideal velocity. But the degree of depth and broadness for this “Data base” and “Rough analysis” is correlated each other and being studied with various try and error.

As the first step of this procedure, the coupled method of flight safety and structural design, which is big impact to launch capability and vehicle design, will be explained in section 3.2 and 3.3. Especially, flight trajectory near launch pad is bent for flight safety to avoid the interference between “envelop drag impact area (EDIA)” in case of flight termination and “impact limit line (ILL)”, which is set about 3km away from launch pad, like Figure 5. Thus, if the winds aloft at the launch day have possibility to take the interference, we can’t launch it. So, considering the narrow launch range, the flight azimuth and height near launch pad of flight trajectory is limited to rise the launch possibility. But these constraint decrease the launch capability of H-IIA/B, and require the extra thrust level of booster engine and vehicle size of H-X, which lead to the extra cost of development H-X. In this research, we try to balance between the vehicle design and the launch possibility. Other than this unique matter, constraints of flight safety for TNSC is introduced in section 3.1.

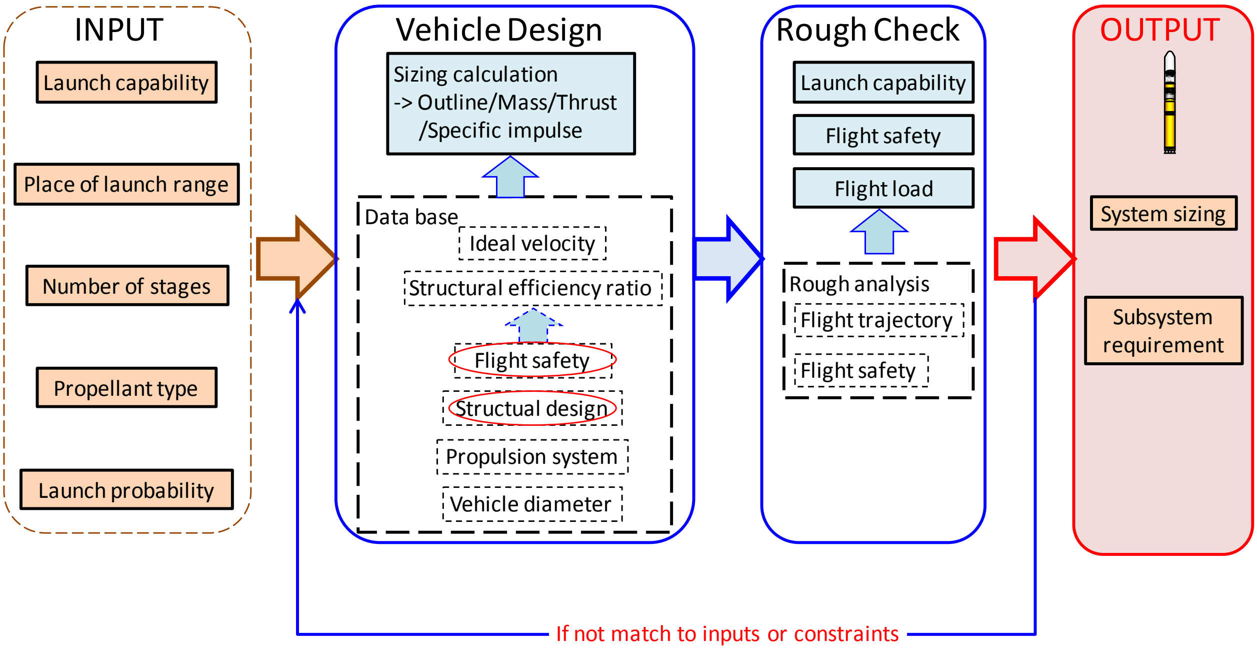

Figure 4: A final image of this procedure

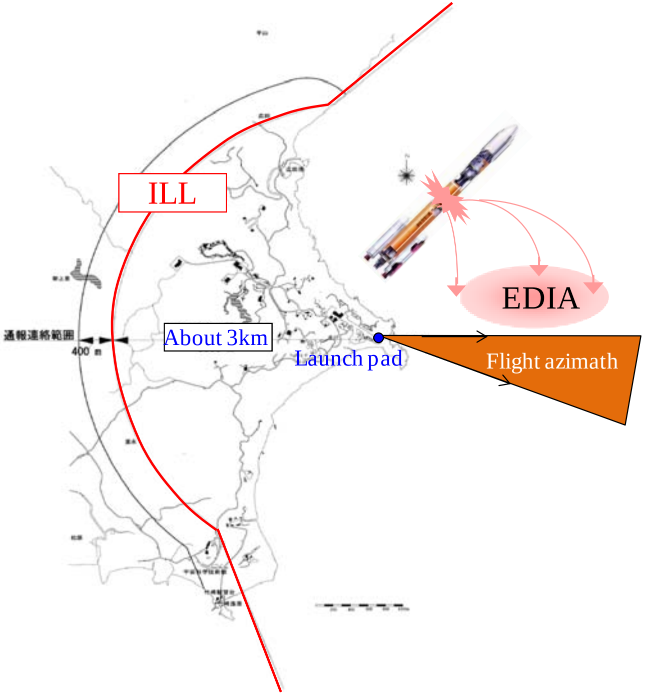

Figure 5: Image of the interference between EDIA and ILL near launch pad

3.1 JAXA’s Launch Range

For typical missions like GTO, SSO and HTV, instantaneous impact points (IIP) with rough sketch of dropped area are indicated at Fig. 6. TNSC is located at latitude of approximately 30 degrees north in the Pacific. As the influence for rotation of the earth, this is basically disadvantage for launch capability of GTO mission compared with main launch range of other countries like “Kourou” of CNES and “Sriharikota” of ISRO.

Other than above, the launch capability is restricted mainly by flight safety constraint. The flight safety limits mostly the flight azimuth around TNSC, the dropped area of fairing and the first stage, and the over-all flight trajectory for radio frequency (RF) link from ground station (GS) and for expectation casualty (Ec). The flight azimuth is confined within about 90deg to 115deg, from the north to keep the safety of inhabitant near TNSC, by the narrow launch range of TNSC. There are many island and island chains near IIP like Mariana, Carolyn, Marshall, Palau, New Guinea, Australia and New Zealand for the South-East of TNSC. For the restricted flight azimuth and to avoid the interference with islands, the flight trajectory is bent especially at high inclination mission, such as in SSO missions. Therefore, loss of capability would be exhibited if compared with potential capability of H-IIA/B configuration. On the other hand, at the design of H-X, the thrust level of booster engine and vehicle size would be increased depend on the necessary launch capability. Then, the coupled design procedure with these flight safety constraint is necessary for H-X.

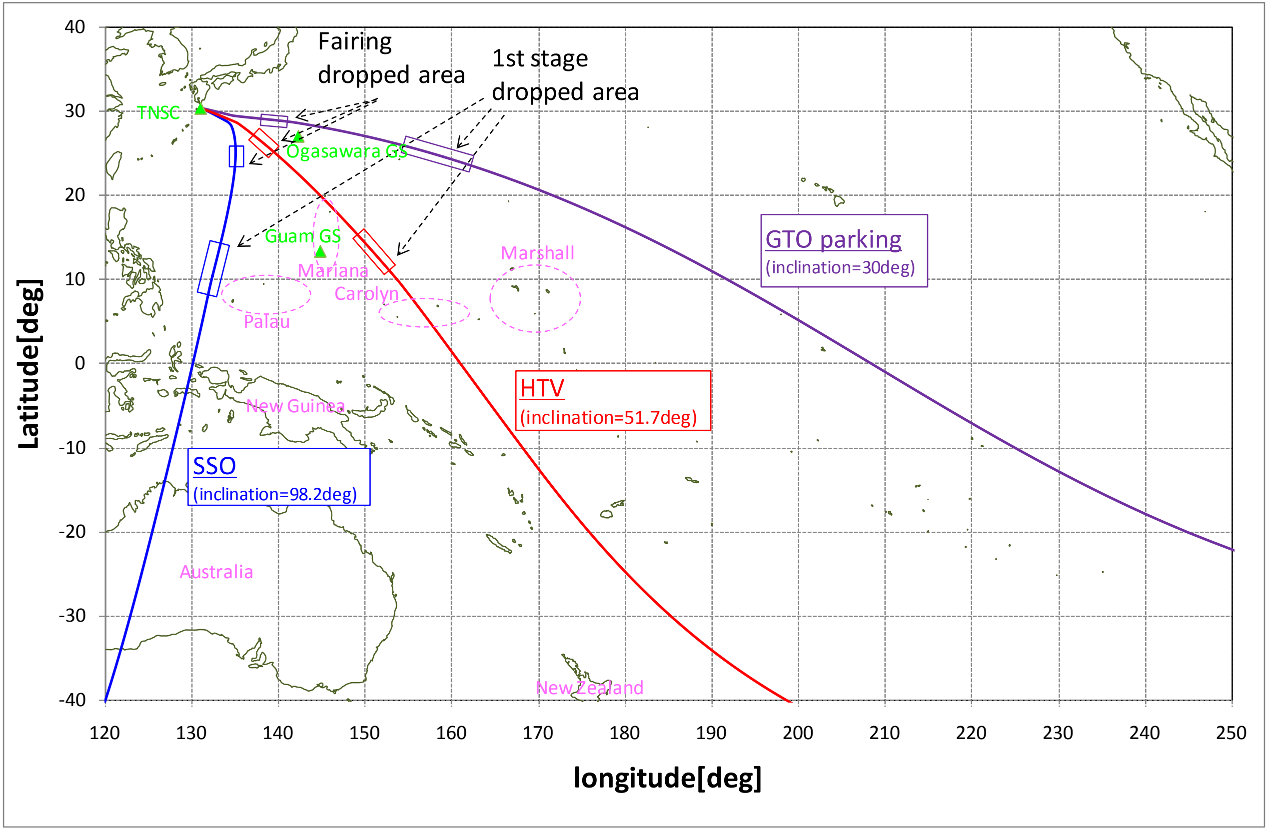

Figure 6: IIP with rough sketch of dropped area for typical missions

3.2 Coupled with Flight Safety Design

Explained above, flight safety give big effect on vehicle design. If normal “INPUT” like launch capability and flight safety constraints are fixed, the vehicle design is not settled because of unique input “launch probability”, which is interference between EDIA and ILL. In case of H-IIA/B, for simplification, the flight trajectory near launch range is limited with height and flight azimuth to maintain high launch probability. But these design lead to the loss of launch capability. On the other hand, if the necessary capability is fixed and similar design would be done, extra cost would be taken to increase the thrust level of booster engine and vehicle size. So, for the design of H-X, the direct correlation method between launch probability and vehicle design would be researched in consideration of flight safety. If the method is possible, for each launch probability, we could directly compare extra design cost to keep a launch probability with operation cost to take launch delay. At that time, optimised launch probability and vehicle design would be calculated in terms of life cycle cost.

For this purpose, we firstly try to make the balance graph which image is depicted in Figure 7. Making process of this graph is follows for each “thrust by weight (T/W)” at L/O.

1.Design the vehicle to satisfy the necessary launch capability with sizing calculation
2.Make flight trajectory with no constraint near launch pad
3.Calculate launch probability not to interfere between EDIA and ILL
4.Limit the height near launch pad or flight azimuth, and repeat the above 1~3 (3~5cases)
5.Plot the left side graph of Figure 7
6. Plot the right side graph of Figure 7

Some results of this procedure are depicted in Figure 8. This is designed with three stages for GTO which configuration is centre of Figure 3, and correspond to left side graph of Figure 7. In case of “T/W=1.3”,the vehicle design to take high launch probability cannot match the assumed load constraint, which is Q*alpha=20kPa deg. So, to complete the graph like Figure 7 , the coupled method with structural design is necessary. Also, SSO mission is more difficult because of many flight safety constraints mentioned section 3.1. These will be done this year.

With these graph and consideration of necessary cost and technical feasibility to develop it, the requirement for vehicle size and 1st stage engine will be settled. Other than above, the extend of ILL would be considered. The distinct position near TNSC to effect the launch probability or vehicle design is also studied.

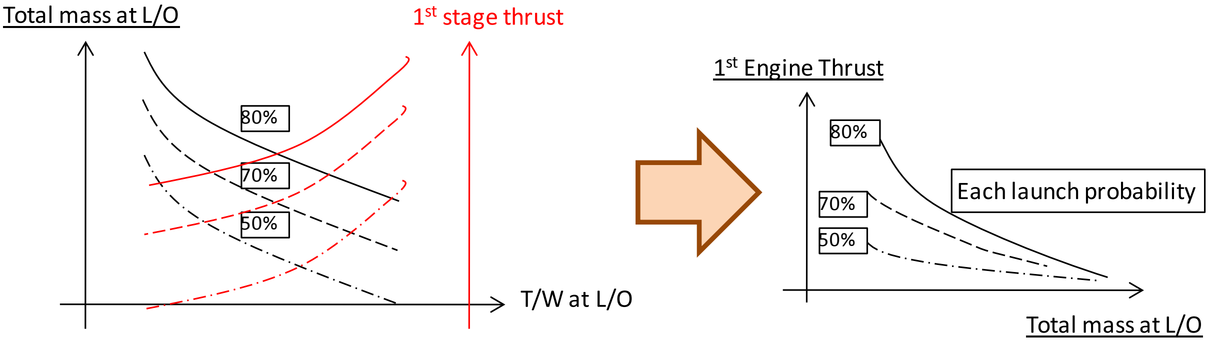

Figure 7: Output image of coupled procedure with Flight Safety Design

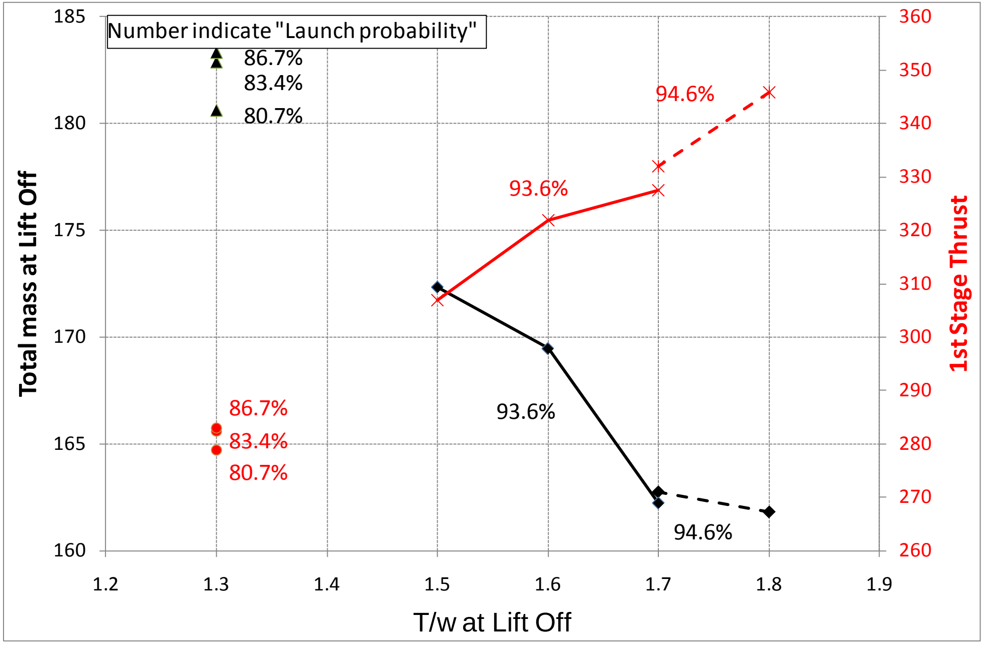

Figure 8: Results of coupled procedure with Flight Safety Design

3.3 Coupled with Structural Design

Structural design also gives big effect on vehicle design. But it has deep correlation with over all vehicle design and flight trajectory. For example, if the flight load is high because of high dynamic pressure or big attack angle, the mass of structure would be heavy to resist the flight load. So, a interface parameter related to overall system is Q*alpha, which is multiplication of dynamic pressure and attack angle. Also, the pressure of propellant tank would effect the mass of tank.

Other than above, structural efficiency ratio have to be modelled with all of dry mass, which include tank, engine, avionics and other structure. These study would be done this year.

4. Conclusion

A innovative design procedure of H-X is presented. Aiming drastic cost efficiency and potential for future variation, H-X is targeted to be operational in 2020 with brand-new system, which include launch vehicle and facility. The quick system design procedure for given needs with appropriate depth and broadness is explained.

References

[1] Takashi Nakamura, et.al., “EVOLVING PLAN OF JAPANESE PRIMARY LAUNCH SYSTEM”, Proceedings 61st International Astronautical Congress,, IAC-10-D2.4.3..

[2] Saito, Y., Kawakatsu, Y. and Yamamoto, M.: Research on Launch Vehicle Interface for Interplanetary Mission, Proceedings of the 22nd International Symposium on Space Flight Dynamics, 2011