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Epsilon Launch Vehicle - First Flight and its Evolutions -

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ABSTRACT

The first Epsilon launch vehicle was successfully launched from Uchinoura Space Center (USC) on September 14th, 2013. Epsilon has achieved full mission success by injecting SPRINT-A into planned orbit with high accuracy. Epsilon is now ready to offer launch opportunities for small payloads to the Low Earth Orbit (LEO) and Sun Synchronous Orbit (SSO).

The paper consists of three parts. At first, this paper describes the main features of Epsilon launch vehicle, its mission profile and the brief summary of actual flight data. Secondly, the short-term development plan is presented, as Epsilon has to become more cost effective in order to meet the growing needs for lower cost. Finally a further development plan including design evolutions under study is presented.

1. INTRODUCTION

One purpose of this paper is to present and analyze the result of Epsilon maiden flight qualification analysis. Epsilon launch vehicle is a single-body 3-stage solid propellant rocket suitable for a new age, with higher performance and lower cost to meet the increasing demand for small payloads. The purpose of Epsilon is to provide small satellites with responsive launch opportunities, which means a lower cost, user-friendly and ultimately efficient launch system are focused.

Epsilon development was carried out with initiative by Japan Aerospace Exploration Agency (JAXA) under which IHI Aerospace (IA) functioned as the rocket system integrator. The launch site for Epsilon is JAXA's Uchinoura Space Center (USC).

The USC is located in attractive place in southern part of Kyushu Island, 3-hour flight from Tokyo.

Epsilon is able to carry 1.4 tons into LEO, and 0.6 tons into SSO with optional Post Boost Stage (PBS).

Epsilon has two line-ups; standard and optional configurations. The standard configuration is the low end type without PBS. On the other hand, the optional configuration is the standard configuration plus PBS. The basic configuration is illustrated in Figure 2.

Figure 1: Epsilon Maiden Flight.

The PBS is one of the liquid propulsion systems in Epsilon as the fourth stage which is propelled by conventional hydrazine propulsion, which realizes more accurate orbital injection by 3-axis control of spacecraft. By using this system, a wide variety of orbits, including SSO, that small satellite missions often use, can easily be reached. And the accuracy of trajectory injection can be increased almost the same level as that of the liquid propellant launch vehicles.

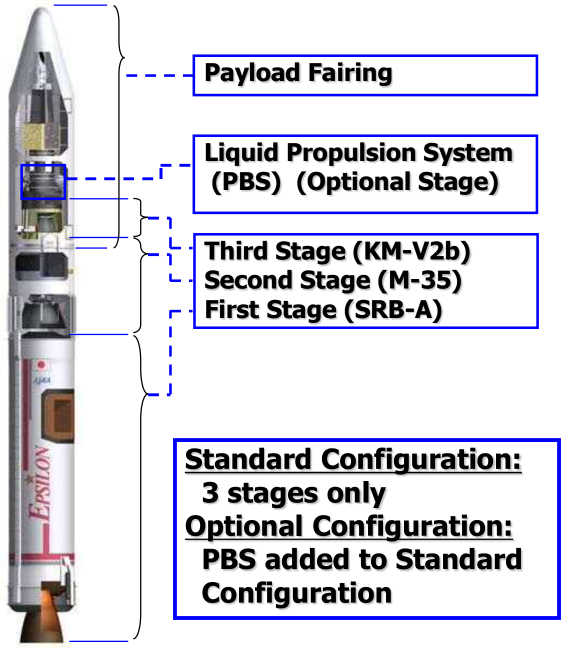


Figure 2: Configuration of Epsilon Vehicle

In order to enhance the comfortable satellite-ride environment, a special Payload Attach Fitting (PAF) is introduced to lower the level of high frequency vibration that is caused by resonant burn of the first stage solid rocket booster (SRB-A). The PAF consists of a multi-layer structure of rubbers and thin metals, having lower axial rigidity, to isolate the high frequency vibration.

The PAF is illustrated in Figure 3.

Epsilon has an autonomous check-system, which can shorten launch campaign period down to 10 days.

The launch check out and operation can be conducted by using a few laptop computers, which is called as “mobile launch system”. The check-system and mobile launch system realized short launch campaign. Thus, the lift-off is executed in less than 10 days after spacecraft mating to launch vehicle.

2. EPSILON LAUNCH VEHICLE

In order to realize low-cost development and high reliability, various flight-proven hardware were

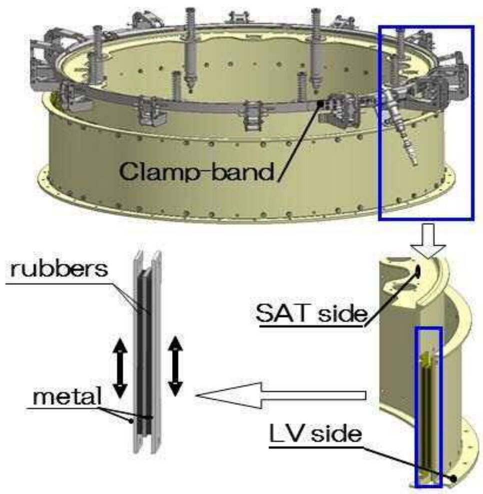


Figure 3: Schematic Diagram of PAF

introduced to Epsilon system with ample and well established heritage from M-V and H-2A launch

vehicle. M-V was a medium payload lifter mainly for scientific payloads for ISAS (Institute of Space and Astronautical Science) with 7 flights performed. H-2A has been a Japan’s flagship heavy lifter for more than 10 years with more than 23 successful flights.

Epsilon launch vehicle is 24 m tall, 2.5m in diameter and lift off mass 91 tons.

The first stage motor is applied from the side booster (SRB-A) of the H-2A. The second and third stage motors are applied from M-V’s third and fourth stage motors respectively. These two motors are with very high performance due to the light-weight, stiff filament wounding motor case and expansion nozzle.

In addition, the on-board avionics is also applied from well flight-proven H-2A’s ones.

3. MAIDEN FLIGHT MISSION

The Maiden flight mission is to inject the extreme ultra-violet planetary telescope satellite (SPRINT-A) into the LEO: 950km-1150km @29.7 degrees. The SPRINT-A configuration is that the mass is almost 350kg and the size is 1m x 1m x 4m at the launch mode.

The Table 1 shows essential specifications of Epsilon of maiden flight.

Table 2 shows the fundamental sequence of events of maiden flight.

Table 1: Epsilon's Essential Specifications For Maiden Flight.

Stage	Specification	
1st	Dry Mass [ton]	8.9
	Propellant Mass [ton]	65
	Burn Time [s]	116
	Isp (Vac) [s]	284
2nd	Dry Mass [ton]	1.7
	Propellant Mass [ton]	10.7
	Burn Time [s]	105
	Isp (Vac) [s]	299
3rd	Dry Mass [ton]	0.68
	Propellant Mass [ton]	2.5
	Burn Time [s]	90
	Isp (Vac) [s]	301
PBS	Propellant Mass [kg]	103
	Isp (Vac) [s]	230

At the 3rd stage motor burned-out, the launch vehicle reached to the perigee point of transfer orbit. After the solid propulsion phase, the PBS firing was conducted twice, which is designated as Phase-A, over the Hawaiian Islands, and Phase-B, over the South-America, both approximately 5 minute firing of 50N thrusters x 4 on PBS. The purpose of Phase-A and Phase-B are for orbit raise up the altitude of planned perigee and apogee, respectively.

Table 2: Outline of sequence of events

No	Event	Time
1	Lift-off	X+0s
2	Initial turn	X+2s
3	1st motor burn-out	X+116s
4	Fairing separation	X+150s
5	1/2 Separation	X+161s
6	2nd motor ignition	X+165s
7	2nd motor burn-out	X+270s
8	Spin motor Ignition	X+604s
9	2/3 Separation	X+624s
10	3rd motor ignition	X+628s
11	3rd motor burn-out	X+718s
12	3rd motor/PBS separation	X+1008s
13	PBS phase-A start	X+1287s
14	PBS phase-B start	X+3264s
15	Satellite separation	X+3700s
16	CCAM start	X+4269s

After the satellite separation (satellite separation and following the time delay needed to provide a safe distance between PBS and spacecraft), the launch vehicle performs the Collision and Contamination Avoidance Maneuver (CCAM) into the lower orbit.

4. MAIDEN FLIGHT RESULTS

Epsilon's first flight was successfully conducted with SPRINT-A from Uchinoura Space Center (USC) on September 14th, 2013. After the orbit insertion, SPTINT-A was named as "HISAKI".

The maiden flight was excellent. All events were in accordance with planned sequence of event without any anomalies. All basic and additional engineering data that we planned were collected. The post flight analyses have confirmed that all of propulsion performance, navigation, control, mechanical thermal environment, separation conditions and so on, were all normal, as designed and as planned as shown below.

<Trajectory>

Figure 4 shows the trajectory of maiden flight compared to the nominal prediction which shows a good matching each other.

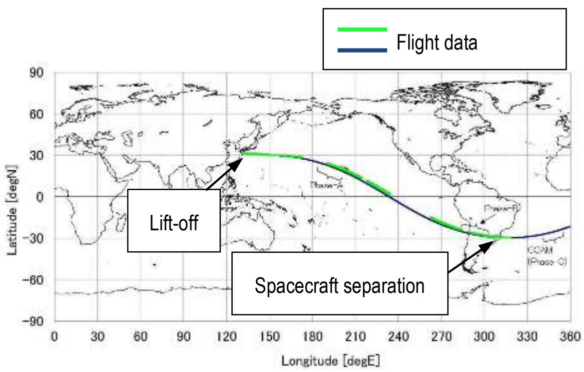


Figure 4: Present Position Indicate (PPI) Predicted v.s. Maiden Flight Result

<Separation condition>

The Spacecraft was inserted precisely to the expected trajectory over the South-America. Table 3 shows the injection result compared to the requirement.

The result indicates the high accuracy orbit insertion by Epsilon.

Table 3: Separation Conditions

Item	Target	Result
Alt-Apogee [km]	950±50	954
Alt-Perigee [km]	1150±50	1157
Inclination [deg]	29.7(+2.3/-1.7)	29.7

After the spacecraft separation, the launch vehicle got into CCAM phase, and after CCAM, discharged all residual liquid fuel, which reserved in a PBS fuel tank for CCAM sequence.

After the CCAM phase, these operation data was transmitted to grand station for record.

＜Mechanical Environment＞
In order to enhance the comfortable satellite-ride environment, the PAF is introduced to lower the level of high frequency vibration that is caused by the resonant burn of SRB-A.
The PAF is constructed with a satellite mount and a vibration suppression unit, which consists of a dual-cylinder formation. The PAF is located at the bottom side of satellite-mount.
Figure 5 shows the dynamic longitudinal acceleration.

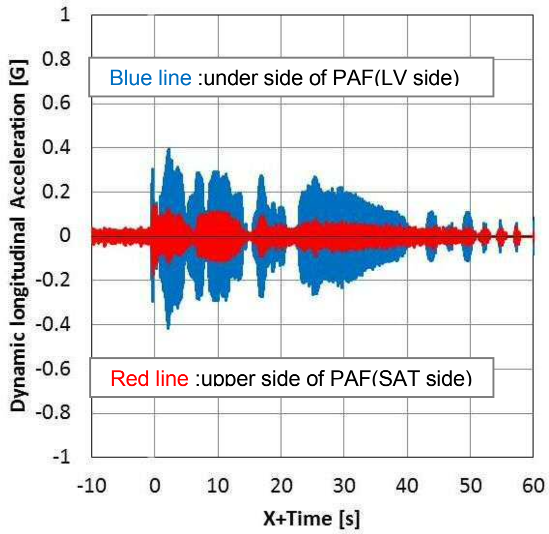


Figure 5: Dynamic Longitudinal Acceleration under the First Stage Firing Phase

(this data is filtered by 40-60 Hz band-pass filter to flight data in order to reduce noise.)

At the under side of suppression unit (launch vehicle side), the dynamic acceleration was lower than 0.5G.

At the upper side of vibration suppression unit (satellite side), the dynamic acceleration was lower than 0.2G, which is low enough to meet the interface requirement of SPRINT-A.

This result is indicated that Epsilon's mechanical environment is at the highest level in the world.

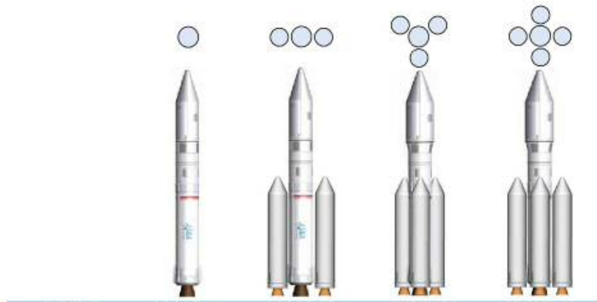
5. NEXT CHALLENGE

After the successful maiden flight, we are conducting Epsilon upgrade program. In order to minimize the technical risks in realizing the lower cost Epsilon, a step by step approach has just started to demonstrate the associated technologies needed to improve the cost goal of launch vehicle.
As next challenge, Epsilon will be improved in some subsystems.
At first, the second stage motor will be replaced by lower cost propellant and non-expansion nozzle. In addition, second motor's propellant mass will be increased for recovering ISP loss due to exchange the nozzle. Secondly, some electric components will be made smaller and lighter. The current mechanical relays of PSDB (Power Supply Distribution Box) onboard the upper stage will be replaced by semiconductor relays.

Further Evolution
IA is studying the lineup expansion in order to apply to launches for more various payloads that customers in the world want. In the satellite market, a demand of 300kg up to 2tons satellite is increasing, and IA aims to capture this market. The current Epsilon launch vehicle is able to carry 1.4 tons and 0.6tons of payload into LEO and SSO respectively.
By 2020, We intend to extend Epsilon's capabilities to 2 tons from current 0.6 tons into SSO with more cost reduction.

In Japan, a development of new generation heavy lifter so called H3 is planned, which capability is more than 2 tons. So if the future Epsilon's capability is extended to 2 tons, the Japan launch systems will be able to cover any payload's range seamlessly.

Figure 6 shows the Epsilon family under study. To expand the Epsilon capability with higher reliability and lower cost, more powerful lineups are to be added on 1st stage boosters, and with more powerful PBS.



TYPE	TYPE-A	TYPE-B	TYPE-C	TYPE-D
Capability (SSO-500km)	600kg	1000kg	1500kg	2000kg

Figure 6: Epsilon Family

6. CONCLUSION

Epsilon's first flight was excellent. All events were in accordance with planned sequence of event without any anomalies.

In addition, the short-term perspective and the further evolution plan were presented to enhance the capability to meet the growing needs for small and middle class satellite launches. Epsilons will certain have a promising future for assured access to space.

7. REFERENCES

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