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Topics

First Launch in Months: Japan's Epsilon Launcher and Its Evolution

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The development of the Epsilon launch vehicle, Japan's next generation solid rocket launcher, has just moved to the final stretch for its first launch scheduled in the summer of 2013 to carry the planetary telescope satellite SPRINT-A. The JAXA appreciates the advantages of combined benefits of the standardized small satellites and the Epsilon's highly efficient launch system in order to increase the level of space activities. The primary purpose of Epsilon is to provide small satellites with a responsive launch that means "*Small, Low cost, Fast and Reliable*". The attention should be directed toward the innovative design concept of *Epsilon*, which aims at developing the next generation technologies such as the highly intelligent autonomous checkout system and the mobile launch control. Now that the full-scale development is about to be finished, the most important is what the next step should be beyond the Epsilon. This paper deals with the significance of the Epsilon launch vehicle and how it contributes to the possible evolution of future space transportation systems.

Key Words: Solid Propulsion, Mobile Launch Control

1. Introduction

The development of the Epsilon launch vehicle, Japan's next generation solid rocket launcher, has just moved to the final stretch for its first launch scheduled in the summer of 2013 carrying the planetary telescope satellite SPRINT-A (Fig. 1). It should be emphasized that the JAXA appreciates the advantages of combined benefits of the standardized small satellites and the Epsilon's highly efficient launch system, both developed by the JAXA. The launch site of the Epsilon rocket is the Uchinoura Space Center (USC), the home of Japan's solid rockets, which has been modified to become more efficient although it is already a highly compact launch complex. The efficient launch vehicle and the compact USC will establish one of the most powerful tools that contributes to small missions (maximum 1.2 ton into LEO and 450kg into SSO as of the first flight). [1-3)]

The purpose of the Epsilon rocket is to provide small satellites with a responsive launch, which means we focus on a low cost, user-friendly and ultimately efficient launch system and to take the most advantage of combined power of small satellites and the efficient launch system. The attention should first be directed toward the innovative design concept of *Epsilon*, which aims at developing the next generation technologies such as the highly intelligent autonomous checkout system. From now on, the launch control can be conducted by using a couple of laptop-class computers, which is called a mobile launch control, and the lift-off will be executed in less than 6 days after the first stage motor stand-on. Such novel ideas will not only make the *Epsilon* rocket far ahead of the world but will also bring transportation technologies to higher level. They will be applied to the H2A/B rockets as well and will eventually become the world standard after the development of *Epsilon*. In addition, the simplification of such a launch control system should be the technology that is indispensable to future reusable rocket systems. In this way, the concept of *Epsilon* is beyond the scope of mere solid-propellant rockets. Rather the *Epsilon* rocket aims at achieving the innovative transportation technologies that can be equally applicable to liquid fuel rockets as well as future space transportation systems.

Another aspect that small satellites will most welcome is more user-friendly character such as an improvement in the acoustic vibration at ignition that will be reduced to the similar level of the liquid launchers. This can be achieved by modifying the current launch facilities and the effectiveness was validated by using a numerical analysis as well as a series of static firing tests with a scale model of the launch facility. The construction has just been finished at USC. Other endeavors involve improvements in the sinusoidal vibration

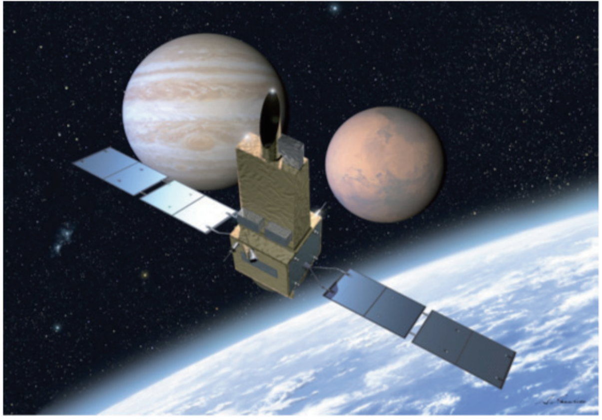

Fig. 1. Artistic view of SPRINT-A, an extreme unltraviolet planetary telescope to be onboard the first flight of Epsilon. It weighs 320 kg.

environment by a newly developed special vibration attenuator; and the orbit injection accuracy by a newly introduced versatile liquid propelled upper stage. In this way, Epsilon will undertake missions to reduce the threshold of access to space for everyone.

Now that the full-scale development is about to be finished, the most important is what the next step should be beyond the Epsilon. JAXA has already proposed the follow-on development to upgrade *Epsilon* and the target of the next innovation is cost reduction with the goal of lowering it significantly. The tentative plan is to launch the low cost version *Epsilon* (E1) in 2017 based on the studies on the radically low cost technologies, primarily in avionics and structural systems, that are already underway in parallel with the *Epsilon* development. [4-7]

These studies will evolve the Epsilon rocket and enhance the space transportation technologies in the larger scale. Once the mobile launch control is implemented in the initial version of Epsilon using an intelligent check-out system, it will be considered natural that the intelligence of the rocket should be further enhanced by making even the flight safety control autonomous, which will eliminate those expensive tracking facilities and make the tracking control system highly compact and mobile. Our attention should then be directed toward a revolution of manufacture that will convert the current large-scale and inefficient manufacturing processes to a much smaller scale and higher utilization frequency. This is the dimension that we hardly considered seriously until now, but it cannot be avoided to achieve lower-cost and more frequent space activities. The targeted launch cost is set at below ¥3 billion (~US$ 30M based on current exchange rate of US$1≈¥100) to be competitive in the world market. Note that the strategy taken to lower the cost will be mainly based on using lighter and lower cost materials, thus it leads to higher performance as well.

In order to minimize the level of technical risks, the JAXA plans to take a step by step approach to improve the cost and performance. As a development strategy, the key technologies required for E1 will be demonstrated well in advance. As such, we are planning to upgrade the second flight of Epsilon that will carry a geospace satellite ERG in 2015. As already stated, this endeavor will lead to an enhanced launch capacity that is estimated to be 550 kg into SSO – an 22% increase in the launch capacity.

This paper provides the details of the final phase of the Epsilon development and reveals its evolution plan.

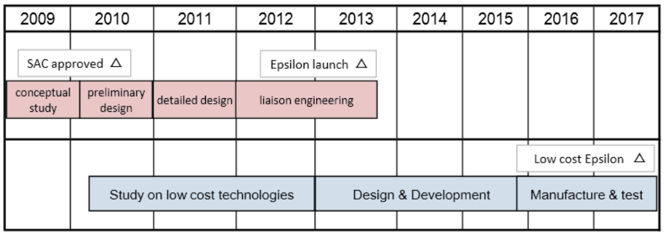

Fig. 2. Two step development plan of the Epsilon rocket.

2. Two-step Development Plan of the Epsilon Rocket

The final goal of the *Epsilon* rocket program is to provide small satellites with a highly cost effective launch, which involves ultimately efficient launch system, including the efficient launch operations and the compact ground facilities. This attempt will contribute equally to the possible evolution of the liquid rockets as well as future space transportation systems. To realize this highest vision in a steady way, JAXA takes a two-step development plan of the *Epsilon* program: in the first step of development, the target is to achieve the next generation technologies such as the rocket intelligence and the mobile launch control while minimizing the development cost and period (Fig. 2). The total development cost is just ¥20.9 billion (~US$209M). To achieve that, almost all the onboard avionics are taken to be the same as H2A except for the newly developed equipment related to the mobile launch control and the autonomous checkout system. In the same way, the SRB-A, the side booster of H2A, will be used for the first stage motor. In exchange of this highly efficient way of development, the launch cost of the initial version *Epsilon* (sometimes called EX) remains relatively high at approximately ¥3.8 billion (~US$38M, Table 1).

The launch site of *Epsilon* is the Uchinoura Space Center (USC) that has been acting as the home of Japanese solid propellant rockets since Japan's first satellite launched in 1970. The launch site development has been finished by making the most use of the existing facilities of USC to reduce the associated development cost. This will not deteriorate the entire design concept of *Epsilon* because the launch site design of USC is already highly compact.

In sharp contrast, in the second step, the research and development will be conducted to realize a low cost and higher performance version *Epsilon* (E1). The tentative plan is to launch E1 in 2017 based on the studies on the radically low cost technologies, primarily in avionics and structural systems that are already underway in parallel with the *Epsilon* development. The targeted launch cost is set at below ¥3 billion (~US$30M). Once again, the attempts to lower the cost include higher performance as well.

To minimize the level of technical risks in developing E1, JAXA plans to take a step by step approach to improve the cost and performance of the launch system. In accordance with the idea, the second flight will be conducted as a revised version in 2015 with the enhanced launch capacity of more than 550 kg into SSO. Such evolution will include: a conversion of the metallic rocket structures to integrated CFRP; and a replacement of mechanical relays by semiconductor driven ones (power MOSFET).

3. Design of Vehicle and Ground Facilities

3.1. Vehicle configuration of epsilon

As a next generation launch vehicle, the *Epsilon* rocket has unique emphasis in development on: the optimization of the

Table 1. Representative specifications of *Epsilon*. Note that E1 denotes the low cost version Epsilon.

Items	**Specifications**
Configuration	3-stage solid propellant launcher with optional PBS (Post-Boost Stage)* * see Section III.III
Length/Diameter	24 m/ 2.5 m
Lift-off mass	92 ton
Launch Capacity	LEO (250×500 km): 1.2 ton SSO (500 km): 450 kg (550 kg for E1)
Cost per launch	¥3.8 billion (US$38M**) < ¥3.0 billion for E1 (US$30M**)
Next Generation Technologies	Autonomous Checkout System Mobile Launch Control
Development Cost	¥20.9 billion (US$209M**)
First Flight	in 2013 (E1 in 2017)
Launch Site	Uchinoura Space Center（USC)

** based on current exchange rate of US$1≈¥100

Fig. 4. Qualification Tests (QT) of the Epsilon's second stage motor: the mechanical test conducted at ISAS/JAXA Sagamihara campus (left) and the pressure test at Tomioka factory of IHI Aerocpace Co. Ltd. (right) both executed in the first quarter of 2012.

rocket configuration for better cost and performance, the reform of the launch system for more efficient launch, and the enhancement of user friendliness. The configuration of the Epsilon rocket is a three-staged solid propellant vehicle, having a 1.2-ton payload capacity into a low earth orbit (LEO) with a lift-off weight of 92 ton, 24 m in total length, and 2.5 m in maximum diameter (Table 1). Each of the first and the second stages has 3-axis attitude control capability: the pitch and yaw in the powered flight can be controlled through a mobile nozzle thrust vector control (MNTVC) that are driven by a pair of electro-mechanical servo-motors. The first stage servo-motor is powered by a special high power thermal battery and the second through an integration of commercial lithium batteries. On the other hand, the roll in the powered phase and the 3-axis attitude in the coasting phase can be stabilized by reaction jets. The first stage reaction jet, solid motor side jet (SMSJ), is generated by a solid propellant gas generator (GG) while the one for the second stage, reaction control system (RCS) by conventional hydrazine engines. Contrary to the M-V, the third stage is just spin-stabilized for more simplicity. To compensate for the residual orbit error caused by the spin-stabilized third stage, an optional tiny upper stage, post-boost stage (PBS) can be installed onboard, which will be propelled by conventional hydrazine engines (see Section 3.3). This is for better orbital accuracy and maneuverability to increase the user friendliness. To further enhance the user-friendly characteristics, a special payload attachment fitting (PAF) is introduced to lower the level of high frequency vibration (about 50 Hz) that is caused by the combustion vibration of the first stage solid rocket booster (SRB-A). The fundamental configuration of the vehicle is illustrated in Fig. 3.

One of the keys to success in lower cost and better performance is the idea of sensitivity to the launch capacity. Usually the first stage motor is relatively high cost but low sensitivity. As such, it is reasonable to utilize the low cost but medium-performance SRB-A, a side booster of the H-2A. On the other hand, at the second and third stage motors, their characters are usually the reverse: low cost and high sensitivity. Hence, the already high-performance third and kicking stage motors of the M-V rocket are utilized. In addition, their cost and performance are further enhanced by making the filament wounded motor case lighter with latest materials and converting the manufacturing process to simpler one: from a complicated autoclave to a mere oven. As a result, the combined performance of the second and the third stage motors of *Epsilon* is expected to exceed that of the M-V and it will produce as high payload ratio as the M-V rocket despite utilizing a sub-optimal first stage motor (1.33 for *Epsilon*; 1.32 for M-V). The full-scale test model was utilized for the qualification test (QT) such as the pressure and the mechanical tests (Fig. 4) showing results well within the scope of expectation. It should also be noted that one of the challenges for the next generation *Epsilon* (E1), is to make the motor case much lighter by introducing simpler insulation structures.

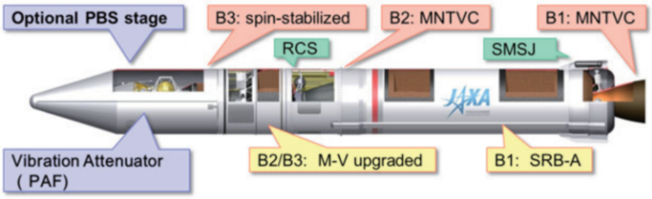

Fig. 3. Configuration of the Epsilon launch vehicle.

Fig. 5. Payload fairing of Epsilon in the final process of manufacturing.

Fig. 6. Artistic image of the mobile launch control.

Fig. 7. Picture taken at the scene of demonstration tests of the autonomous check-out system for the mobile launch control.

The development of the payload fairing has just finished following its deployment test conducted on 7 April, 2013 (Fig. 5). Although the fundamental design of the Epsilon's fairing is virtually the same as those of H2A/B, the novel concept is implemented on Epsilon. This is one integrated structure of the half shell formation consists of a half cone and a half cylinder. They used to be combined together with bolts that required lots of labor and long time resulting in its high cost. Now they are designed to be solidly constructed together into one large component. This seems like a small step but may lead to a big leap to reform the current manufacturing process to a much more efficient one.

3.2. Evolution of launch system and intelligent launch control

A more important aspect of the *Epsilon* development is an evolution of the launch system, which is intended to dramatically increase the availability of the rocket and to reform the current launch system into a responsive launch by improving the operation performance to the highest standard of the next-generation. The key to success is an innovation of the onboard avionics system8). First of all, it is designed to be connected by a high-speed network with the ground support facilities such as the launch control at USC and the range safety control at TNSC (Tanegashima Space Center), and technical support at the associated manufacturing factories. Due to this communication architecture, *Epsilon* will become the first launcher in Japan that is controlled from outside the restricted area, resulting in safer and more comfortable launch operations.

Far beyond this endeavor, it is designed to be highly intelligent so that the vehicle performs checks onboard by itself, which can reduce the associated time and labor required for operations on the ground and make the ground facilities absolutely compact9). The intelligent checkout system consists of two different functions: *automatic* checkout for judgment by threshold; and *autonomous* checkout for evaluation of dynamic data, and fault detection, isolation and recovery. The automatic function of *Epsilon* will make it possible to reduce the number of *operators* and the time for the entire procedure. On the other hand, the autonomous character will make it possible to reduce the number of *engineers* involved and the time required for the evaluation of data. In this study, an artificial intelligence technology, the Mahalanobis-Taguchi method (MT method), was utilized for dynamic diagnosis. The technique uses the Mahalanobis distance for diagnosis, which is equal to the distance from the correlation surface that the normal data would have. This will reduce the possibility of wrong diagnosis as compared to a judgment based on mere combinations of thresholds.

Owing to this endeavor, the check-out of *Epsilon* will be performed remotely, safely, and instantaneously, including even the checkout of onboard ignition system. Ultimately, combined with the high-speed network, it will be possible to conduct launch control anytime and anywhere in the world simply by using a single laptop-class computer[8]. This is called the *Mobile Launch Control*, absolutely the next generation technology or you can say, a realization of the science fiction to the science fact. (Fig. 6). A real model of the mobile launch control and the intelligent checkout system has already been established, indicating no significant technical challenges remaining (Fig. 7). Consequently, the time needed for the ground operation is dramatically reduced and it takes only 6 days to launch starting with the first stage on stand.

The onboard autonomous check-out system is called ROSE (Responsive Operation Support Equipment) consists of: ROSE-M (master) aboard the second stage; and ROSE-S (slave) on each of the three stages. The primary function of the ROSE-M is to conduct autonomous check-out based on the data obtained through ROSE-S and to send the associated information to the ground-based mobile launch control system. The main task of the ROSE-S is to gather the necessary data from the onboard components and to send it to ROSE-M. It

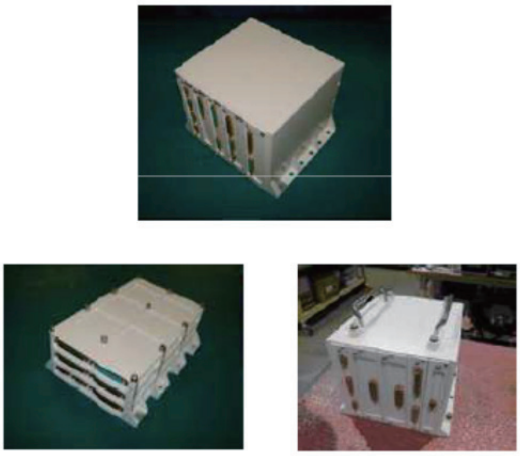

Fig. 8. Intelligent ROSE-M onboard the second stage (top), data gathering ROSE-S installed on each stage (left) and MOC for an ordnance check.

will also control charging of the onboard batteries. In addition, there is an additional equipment that is called MOC (Miniature Ordnance Circuit Checker) set on each stage. They will support ROSE by getting the information on the ignition circuits (Fig. 8).

3.3. Enhanced user friendly character

The last topic is associated with the user friendliness that is of the world leading level as well. Beyond the high performance M-V launch vehicle, more versatile orbital maneuverability and more accurate orbital injection will be achieved by an optional tiny post-boost stage (PBS) that can be installed atop the third stage rocket motor and will act as the fourth stage rocket[10]. It utilizes tiny 50 N hydrazine engines, similar to the M-V attitude control engines. The representative characteristics of the PBS can be evaluated in Table 2. By using this option, a wide variety of orbits, including solar synchronous orbit, that small satellites usually require, can easily be reached. In addition, the accuracy of trajectory can be increased to as high as that of the liquid propellant rockets (Table 3). The QT tests of the flight model of the PBS were already conducted at the Sagamihara campus of ISAS (Fig. 9).

Table 2. Representative characteristics of the Post Boost Stage (PBS), the optional upper stage of the Epsilon launch vehicle.

Properties	Design
Total Mass	<280 kg including onboard avionic
Engine	Hydrazine (mono propellant) A class of M-V side jet
Pressure System	N2 regulated
Container	Cartridge
Thrust	50 N (25NX2) / 200 N combined for orbit control
Isp	> 215 s
Fuel	approx. 95 kg (ΔV =300m/s @ 400 kg satellite)

Table 3. Orbital injection accuracy of the *Epsilon* launch vehicle.

Accuracy in SSO@500km	**Configuration**	
	Standard	PBS onboard
Perigee height (km)	±25	±20
Apogee height (km)	±100	±20
Inclination (degrees)	±0.6	±0.2

To further enhance the user-friendly characteristics, a special payload attachment fitting (PAF) is introduced to lower the level of high frequency vibration (around 50 Hz) that is caused by the combustion vibration of the first stage solid rocket booster (SRB-A). The mechanism consists of a multi-layered structure of rubbers and thin metals, having lower axial rigidity, to isolate the high frequency vibration. The structure also causes a reduction in the lateral rigidity of PAF, resulting in lower bending frequency of the entire vehicle. This is absolutely a new challenge for the robust attitude control algorithm design because the rigid mode dynamics and the first order bending oscillation will be so close. The M-V's H_∞ robust control logic is utilized as modified to tackle with the issue[11-13]. The PAF is installed atop the PBS for the optional configuration (Fig. 9) while attached at the top of the third stage motor for the basic configuration.

Another aspect that small satellites will most welcome is a reduction in the mechanical environment, especially in the acoustic environment. Note that the acoustic vibration caused by solid propellant rockets is relatively severe as compared to that by liquid propellant vehicles due to its higher thrust at ignition. For the *Epsilon* launcher, the acoustic environment will be lowered by modifying the configuration of ground facilities in a special way. This can be achieved by a combination of two independent approaches: elevating the vertical location of the launch pad by as much as 10m to increase the distance from the ground; and making a slope underneath the launch pad to deflect the direction of the exhaust flow by 90º (Fig. 10). The effectiveness was validated by a refined method of numerical analysis[14] as well as a series of static firing tests using a scale model of the launch facility.

4. Next Step and Beyond

The primary purpose of *Epsilon* is to reform the current rocket launch system to a significantly higher efficiency scale by integrating the next generation technologies such as the innovative intelligent launch control. This idea is aligned with our long term goal to realize a more compact and significantly lower cost launch system beyond *Epsilon* and to pave the way to the future space transportation systems.

4.1. Radically low cost technologies

As already stated, the study is intensively underway for the post-*Epsilon* development to realize the radically low cost technologies, mainly in avionics and structural systems. The second generation *Epsilon* (E1), loaded with such low cost technologies, is expected to be launched as early as in 2017. One of the keys to success of the post *Epsilon* development is the innovative architecture of the onboard avionics systems. Although the avionics systems of the H2A rocket are used for

Fig. 9. Vibration test of the PBS that was conducted at ISAS/JAXA Sagamihara campus in 2012. Note, PAF is installed atop the PBS.

Fig. 10. The modified launch facility to lower the level of acoustic environment at launch.

the first generation *Epsilon* (EX) in order to minimize the associated development cost, inexpensive avionics should be developed for the second generation *Epsilon* (E1). The idea is to utilize commercial parts: those latest components having smaller, lighter and inexpensive characteristics. Note, the same trend is already observed in some satellite development. Of course, special consideration is necessary for rocket applications with respect to parts reliability because of the limited redundancy of rocket guidance and control subsystem. Over the past year, the methods for quality assurance of launcher systems have been studied.

Another key to success of the next generation *Epsilon* development is to convert the metallic rocket structures to integrated ones made of CFRP. In other words, the CFRP structures will be molded into almost the final shape: *the near-net shape method.* By this effort, the assembly and inspection process can be minimized. They could cut cost of structures by as much as 50%. Over the past few years, a series of trial maufacture tests were conducted in a Small Medium Enterprise (SME) company specializing in CFRP. Figure 11 shows the main structure of PBS that will be converted to an integrated CFRP structure, an example of the step-by-step technologies demonstration for E1.

4.2. Mobile Tracking Control

Beyond the mobile launch control of the first generation Epsilon, the intelligence of rockets can be further enhanced for the next generation *Epsilon*. The final goal can be autonomous flight safety control, which means the rockets are designed to detect their own trajectories and conduct safety operations by themselves if necessary. This will eliminate the expensive tracking radars and their associated facilities, thus making the entire launch complex as simple as only a mobile telemetry station: an extreme mobility of the launch system. Such a high level of autonomous character will lead to a diversity of launch systems because it doesn't need a gigantic launch complex any more. To realize this revolutionary concept of the mobile tracking control, a step-by-step approach is planned to be taken (Table 4). That is, the telemetry data of onboard GPS/IMU (inertial sensor) will substitute the tracking radar as well. Now the integrated GPS/INS package is under development and will be onboard at the second launch of *Epsilon* in 2015.

4.3. Next-generation solid propellants

Finally, our attention is directed toward a revolution of manufacture, which is aimed at more compact manufacture facilities and more efficient production processes. One of the key factors pushing up the price of the rockets is the inefficient large scale manufacturing process. This is the motivation for the novel propellant which is now under study: it is known as *Low melting temperature Thermoplastic Propellant (LTP).*[15-17] Due to its special nature: the two-way thermal elasticity, LTP can be mixed in a continuous process with smaller equipment, stored like chocolate blocks and melted again when needed for casting. The conventional manufacturing process of solid rocket propellants requires the propellant to be made in a big batch, using gigantic equipment that is utilized only occasionally. The current practical model of LTP can be considered well within the scope of expectation as it is compatible in performance with BP-204J that is Epsilon's current upper stage propellant (Table 5).

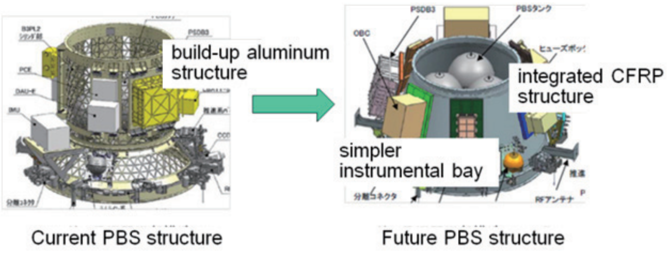

Fig. 11. The main structure of PBS that will be converted to an integrated CFRP structure as an example of the step-by-step technologies demonstration for E1.

Table 5. Representative characteristics of the LTP practical model as compared with the current upper stage propellant of *Epsilon*.

Properties	**LTP practical model: d-2**	**BP-204J: Epsilon's upper stage**
Theoretical Isp (s)	256	260
Burning rate (mm/s)	5.9	9.2
Pressure index	0.37	0.38
Mechanical & Manufacturing properties	good	good

In parallel to continuous endeavors to lower the cost of the launchers and their components, a wide spectrum of researches on future solid propellant is underway beyond Epsilon.[16] Some of which can be considered as “green propellant” because their objective is to convert the current propellants to ones with more green characteristics. A combination of AP and GAP (Glycidyl Azide polymer) is a candidate for the condensed product free composite propellant to control the space debris from the rocket exhaust. According to the theoretical analysis, Isp of the propellant is only 8% lower than the conventional propellant. The high energy density materials (HEDMs) are also intensively studied as the next generation solid propellant. Ammonium Dinitramide (ADN) is a candidate for the chlorine free oxidizer and ADN based composite solid propellant is estimated to enhance Isp of the rocket motor because of its high enthalpy of formation. AP that is the current standard oxidizer for the solid rocket will be replaced with HEDMs and these materials will make the new composition of the propellants with a cleaner combustion for the environment.

4.4. Epsilon’s second flight: front loading step to E1

In order to minimize the level of technical risks in realizing the low cost version Epsilon (E1), JAXA plans to take a step by step approach to demonstrate the associated technologies needed to improve the cost and performance of the launch system and to launch a revised version Epsilon as the second flight in 2015. Note that this process can be considered a front loading step for the E1 program and will include demonstrations of the key technologies such as: a conversion of the metallic rocket structures to integrated ones of CFRP; and a replacement of the current large, heavy and expensive electric parts by small, light and inexpensive ones although the scope of their applications is limited at this stage. In this mini development, the target component that will be converted to integrated CFRP is the main structure of the third stage components bay (B3PL). The electric component that will be made smaller and lighter is the power supply distribution box (PSDB) onboard the B3PL and their current mechanical relays will be replaced by power MOSFET. Note that the strategy taken here is mainly based on using lighter and more inexpensive parts and materials, thus it will result in higher performance as well. As a result, the second flight is expected to have the enhanced launch capacity of more than 550kg into SSO (100 kg increase).

5. Conclusion

The development of the Epsilon launch vehicle, Japan’s next generation solid rocket launcher, has just moved to the final stretch for its first launch scheduled in the summer of 2013 carrying the planetary telescope satellite SPRINT-A. The novel concept of the *Epsilon* launch vehicle is loaded with the next generation technologies: the highly intelligent autonomous check-out system and the mobile launch control. Such innovative design will greatly contribute to increase the level of the space transportation technologies significantly. However, this is not the final destination. Now that the full-scale development is about to be finished, the most important is what the next step should be beyond the Epsilon. JAXA has already announced the post Epsilon development to launch the low cost version Epsilon (E1) in 2017. This paper provided the details of the final phase of the Epsilon development and revealed its evolution plan.

Table 4. An idea of a step-by-step evolution of the autonomous flight safety control.

	Configuration	
	Semi-autonomous	Full autonomous
Year for Demonstration	2013	2017
Ground facilities		
Tracking radar	－	－
Command system	○	－
Range safety computer	○	－
Telemetry system	○	○
Onboard systems		
Navigation sensor	○	○
Telemetry system	○	○
Command decoder	○	－
Onboard computer	－	○
Note: ○: Required －: Not required		

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