Development of CubeSat Deployer for Epsilon Launch Vehicle

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The Epsilon launch vehicle, the latest version of Japan's solid fuel rocket, has extended its capability to deploy multiple satellites: one small satellite up to 200 kg, three micro satellites up to 65 kg and two to six CubeSats in 1U to 3U size (the number depends on the combination). Newly developed systems for the rideshare launch are the ESMS (Epsilon Satellite Mounting Structure), a multi-payload dispenser system, and the E-SSOD (Epsilon Small Satellite Orbital Deployer), a CubeSat deployer. This paper describes one of these new systems, E-SSOD, its interface with CubeSats and the flight results of the latest mission and discusses the future opportunities for small satellites on Epsilon's flights. The improvement plans of the system for the next Epsilon's rideshare mission are also presented.

Key Words: CubeSat, Multi-Satellite Launch System, Epsilon, Subsystem, Structure

1. Introduction

The Epsilon launch vehicle, the latest version of Japan's solid fuel rocket, has extended its capability to deploy multiple satellites: one small satellite up to 200 kg, three micro satellites up to 65 kg and two to six CubeSats in 1U to 3U size (the number depends on the combination). Newly developed systems for the rideshare launch are the ESMS (Epsilon Satellite Mounting Structure), a multi-payload dispenser system, and the E-SSOD (Epsilon Small Satellite Orbital Deployer), a CubeSat deployer. Epsilon's new capability was demonstrated by the successful launch of January 18, 2019, the fourth launch and the first multiple satellites launch mission. All the seven satellites on board were confirmed to be precisely carried into their planned orbits.

The research and development of the Epsilon has been continued to improve the payload environment since the beginning of its development. In the single launch configuration, it achieved the world top level user-friendliness in acoustic, sine-equivalent vibration and shock environments. The recent flight in the multiple launch configuration also confirmed Epsilon's superiority in providing the comfortable environment to small and micro satellites in the rideshare structure ESMS.

In order to ensure compatibility of the mechanical interface with CubeSats, the E-SSOD was developed based on the J-SSOD, Japanese CubeSats deployer currently operated on the International Space Station (ISS), while its entire actuating system was newly designed in consideration of thermal deformation in orbit. With the E-SSOD using non-pyrotechnics to release CubeSats, Epsilon can provide more comfortable conditions than other launchers.

This paper describes one of these new systems, the E-SSOD, its interface with CubeSats and the flight results of the latest mission and discusses the future opportunities for small satellites on Epsilon's flights. The improvement plans of the system for the next Epsilon's rideshare mission are also presented.

2. Vehicle Overview

The Epsilon is a three-staged solid propellant vehicle with a capacity of launching up to 600 kg payload into SSO at 500 km altitude. Epsilon offers a basic configuration and an optional configuration with PBS (Post-Boost Stage), which enhances its orbit injection accuracy. This optional configuration can mount additional structures on the third stage to provide small satellites with a rideshare option. Table 1 shows the difference between the specifications of these configurations and Fig. 1 shows the exploded view of Epsilon's configurations with and without PBS. Fig. 2 shows the details of mounting position of ESMS and E-SSOD for multi launch configuration.

All satellites are released by non-pyrotechnic devices in order to reduce shock to the satellites. Damper made of multi layered structure of rubber and thin metal is located under the satellites to isolate the sinusoidal vibration. Applying these components realized the world top level user-friendliness in sine-equivalent vibration and shock environments.

Table 1. Difference between specifications of Epsilon's configurations.

Device		Basic Configuration (without PBS)	Optional Configuration (with PBS)	
			Single	Multi
Payload Separation system	PAF-937M	1	1	1
	Lightband	−	−	3
	E-SSOD	−	−	2
Damper		●	●	●
PBS		−	●	●

● Installed

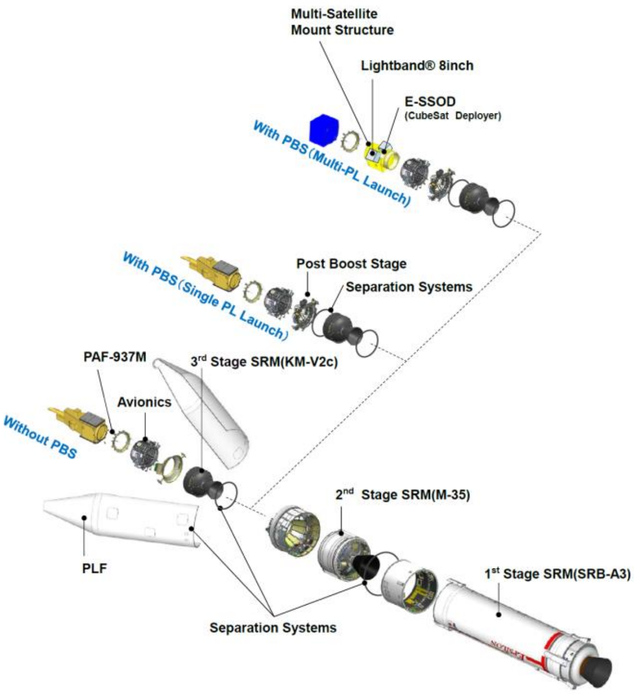


Fig. 1. Epsilon Configurations.

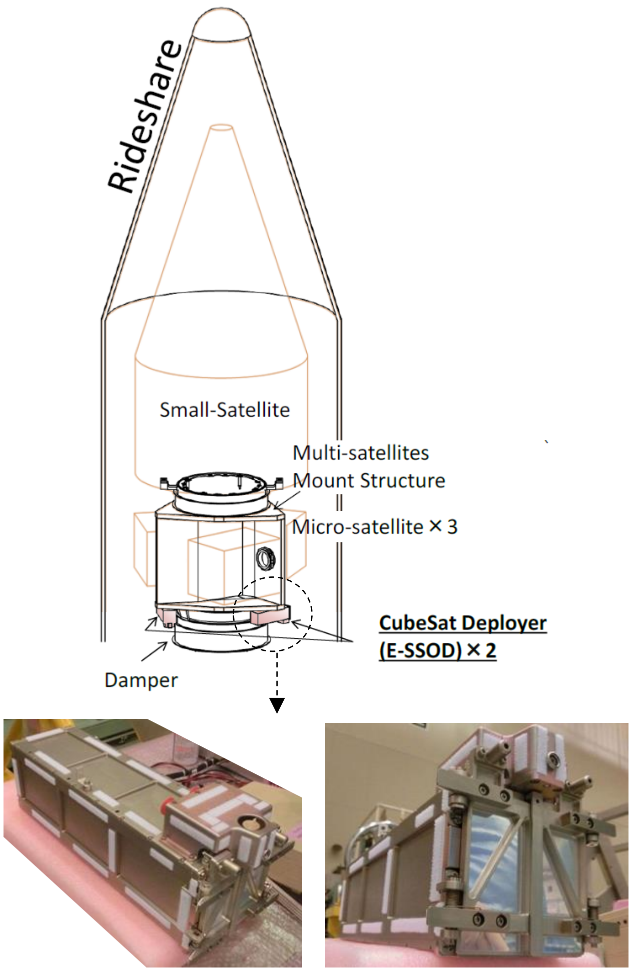


Fig. 2. Details of Mounting Position of ESMS and E-SSOD.

3. Development of E-SSOD

3.1. Overview

E-SSOD is the newly developed CubeSat deployer which can accommodate 1U to 3U size CubeSats. E-SSOD, located at the bottom of ESMS as shown in Fig. 2, recieves the electrical signals from the vehicle and then opens the lock door to deploy CubeSats into orbit. E-SSOD is based on J-SSOD, a proven deployer installed on JEM of the International Space Station. While the mechanical interface of these deployers is completely the same, the actuating system of them is totally different because E-SSOD has to function even after suffering launch load and thermal deformation. The actuating system of E-SSOD is shown in Fig. 3.

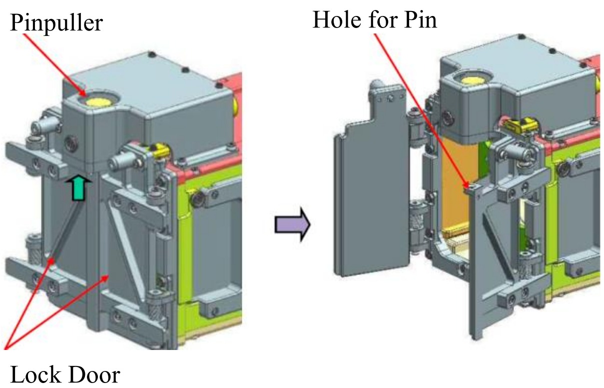
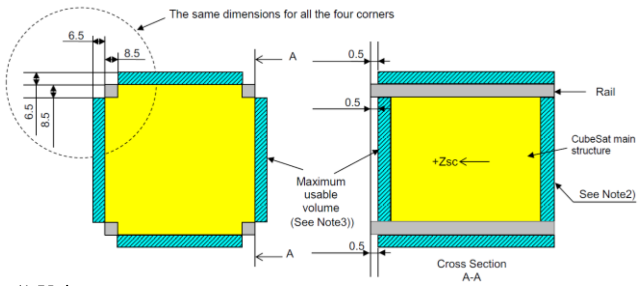


Fig. 3. Actuating System of E-SSOD.

3.2. Mechanical Interface

The mechanical interface of E-SSOD was designed to store the world standard CubeSats. The usable volume of a CubeSat is shown in Fig. 4 and allowable sizes of CubeSats are shown in Table 2. Each CubeSat should hold its deployable components within its usable volume without using any structure of E-SSOD, such as the rail guides and walls.



1) Unit : mm
2) Any component should be stored within the rail end surface line.
3) Any protrusion should be held within the maximum usable volume.

Fig. 4. Allowable Usable Volume of E-SSOD.

Table 2. Allowable Sizes of CubeSats.

	Exterior Dimensions of CubeSat main structure (including rails) [mm]			Rail Dimensions
	Xsc	Ysc	Zsc	
1U	100 ± 0.1	100 ± 0.1	113.5 ± 0.1	at least 8.5 mm square
2U			227.0 ± 0.1	
3U			340.5 ± 0.3	

3.3. Development Tests

Development tests of E-SSOD were conducted to verify the capability of withstanding expected maximum flight environments of Epsilon. Figure 5 shows the whole flow of development tests.

The most technically difficult point in the development was to reduce the random vibration on the pinpuller, which is commercially available in the space industry. Since E-SSOD is mounted at the bottom of ESMS as shown in Fig. 2, the random vibration level of the mounting point is directly measured, and then reduced by using data of ground acoustic test on ESMS with dummy satellites.

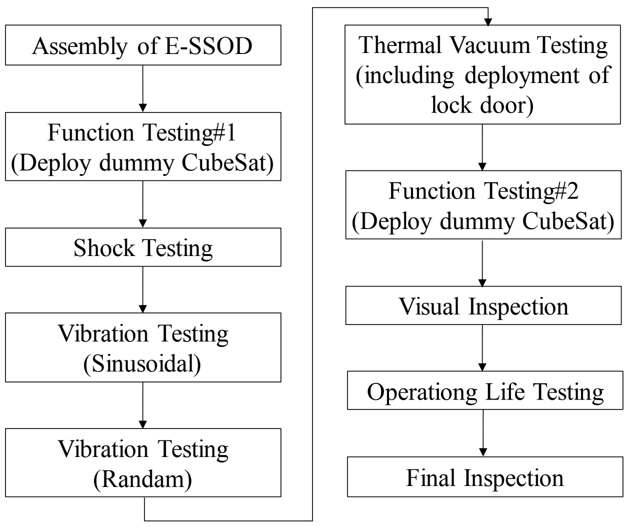


Fig. 5. Development Tests Flow of E-SSOD.

3.4. Environment Conditions

During launch, CubeSats are exposed to various frequency ranges of mechanical environments such as quasi-static acceleration, sinusoidal vibration, random vibration and shock. These environmental conditions are shown in Tables 3 to 6 and Figs. 6 and 7. Since these conditions are acceptance level, the qualification factors should be considered at CubeSat design.

Table 3. Quasi-Static Acceleration.

		Longitudinal	Lateral
On Ground		-9.8±19.6 [m/s^2]	±9.8 [m/s^2]
In Flight	1st stage	22.4±11.2 [m/s^2]	24.5 [m/s^2]
	2nd stage	88.3[m/s^2]	9.8 [m/s^2]
	3rd stage	98.1 [m/s^2]	9.8 [m/s^2] Spin Rate (on the roll axis) to 360 [deg/s]
	Spin up	-	Spin Rate: to 360 [deg/s] Spin Rate Acceleration: to 90 [deg/s2]

Table 4. Sinusoidal Vibration.

All axes	
Frequency [Hz]	Amplitude [(m/s^2)$_{0\text{-}p}$] at installation plane on E-SSOD
43 – 53	9.8
53 – 57	4.9
Sweep Rate : 0.2 [oct/min]	

Table 5. Random Vibration Environment of CubeSat.

All axes	
Frequency [Hz]	Random Vibration (Acceptance level)
20 – 100	0.0908 [(m/s^2) ^{2}/Hz]
100 – 300	11.1 [dB/oct]
300 – 500	5.21 [(m/s^2) ^{2}/Hz]
500 – 2000	-9.5 [dB/oct]
30 [sec] O.A	50.0 [(m/s^2) rms] (5.1 [Grms])

Table 6. Shock Environment.

All axes	
Frequency [Hz]	Shock Environment (Acceptance level)
100 – 1000	8.28 [dB/oct]
1000 – 4000	4067 [m/s^2] (415 [G])

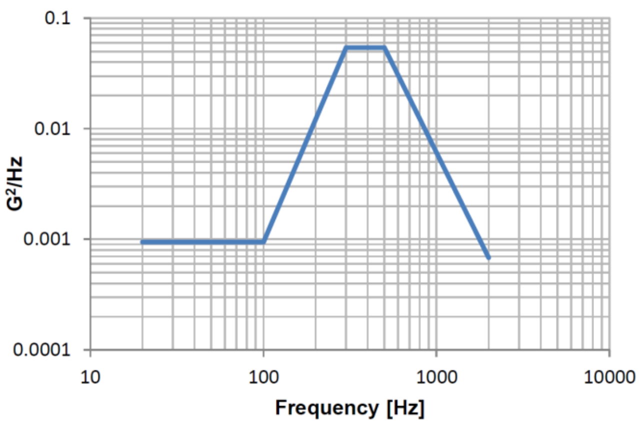


Fig. 6. Random Vibration Environment of CubeSat.

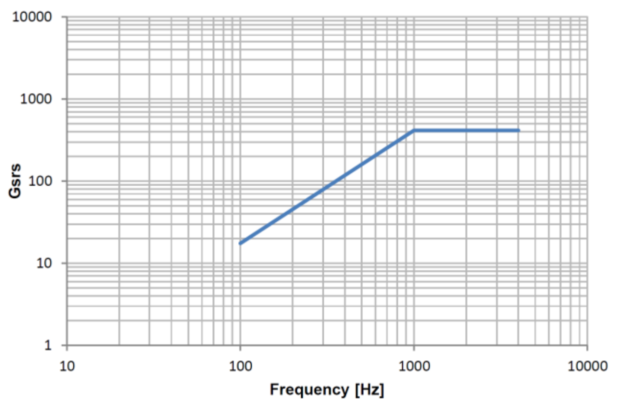


Fig. 7. Shock Environment of CubeSat.

3.5. Tools for CubeSat Verification Test

Two assistant tools for CubeSat verification test were prepared in this development. A vibration test case simulating an E-SSOD as shown in Fig. 8 is used for the vibration test of a CubeSat. When multiple CubeSats are mounted in a single E-SSOD, such CubeSats are recommended to carry out the test using the mass dummy attached to the vibration test case.

A fit-check case shown in Fig. 9 is used for fit-check between a CubeSat and an E-SSOD. Its internal dimensions are 100.2 ± 0.1 mm in height and width while those of an actual E-SSOD are 100.5 ± 0.2 mm.

These two tools can be provided to CubeSat developers for their development tests.

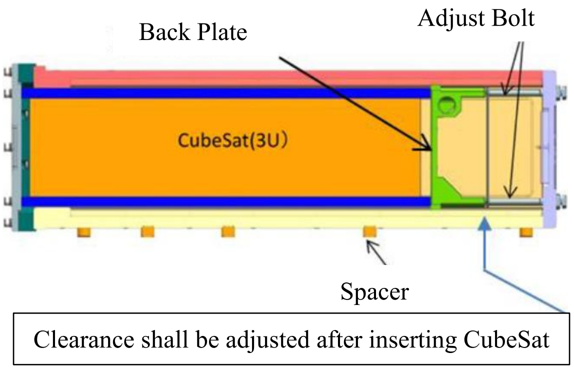


Fig. 8. Vibration Test Case.

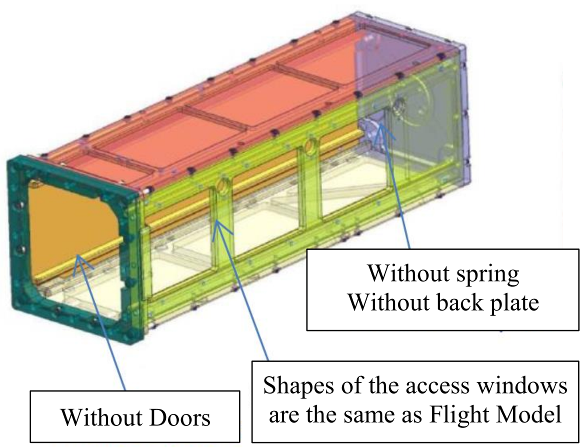


Fig. 9. Fit Check Case.

4. Flight results

Epsilon's first rideshare mission was launched on January 18, 2019 and all seven satellites including three CubeSats separated from the launch vehicle successfully. Table 7 shows the compatibility between the interface specification with CubeSats and the actual flight results. All data indicated the newly developed system for rideshare launch such as ESMS, E-SSOD, and flight software were perfectly functioned as designed.

Table 7. Flight results.

		Specification		Flight
Acceleration	1st stage	lat: 22.4±11.2 [m/s²] lon: 24.5 [m/s²]	●	lat: 33.2 [m/s²] lon: 3.7 [m/s²]
	2nd stage	lat: 88.3[m/s²] lon: 9.8 [m/s²]	●	lat: 52.6 [m/s²] lon: 1.9 [m/s²]
	3rd stage	lat: 98.1 [m/s²] lon: 9.8 [m/s²]	●	lat: 66.3 [m/s²] lon: 1.0 [m/s²]
	Spin up	360 [deg/s] 90 [deg/s2]	●	173.4[deg/s] 37.1 [deg/s2]
Acoustic		138.6 dB O.A SPL	●*	*Estimated from external acoustic
Randam vibration		Shown in Table. 5.	●*	*Estimated from external acoustic
Shock		Shown in Table. 6.	●*	*Estimated from development test

● Complied

5. Future Plan

Unlike J-SSOD, E-SSOD has a clearance adjustment of up to about 0.3 mm between a CubeSat in deployment direction, because E-SSOD suffers the thermal deformation in orbit as shown in Fig. 10. This clearance generates impactive loads during sinusoidal and random vibration tests. Although these loads are evaluated below the level of shock environment shown in Fig. 7, it could be excessively severe test conditions for CubeSats verification. Therefore, the mechanism for actuating the lock door will be changed to remove the clearance between E-SSOD and CubeSats. This design change will make it possible to provide much better environmental conditions and reduce development risks to CubeSats.

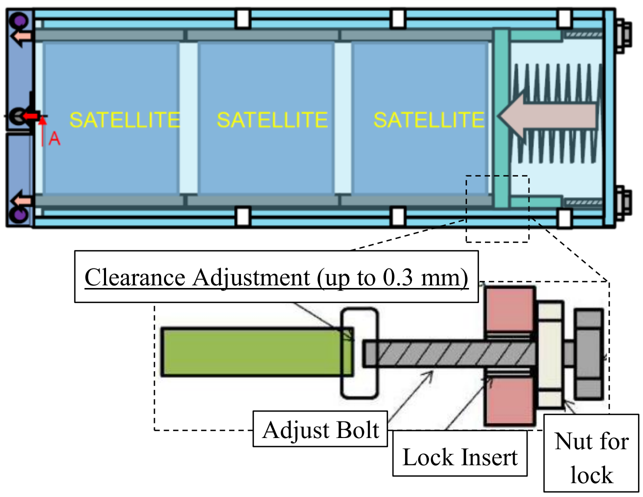


Fig. 10. Clearance Adjustment of E-SSOD.

6. Conclusion

This paper described the newly developed CubeSat deployer, E-SSOD, its interface with CubeSats, the flight results of Epsilon's rideshare launch, and the future improvement plans. One of the top concepts of Epsilon is user-friendliness in terms of payload environment. Based on this concept, we continue working on the research and development to realize a better satellite environment.

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