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# Contribution to Japan's Flagship Launch Vehicle – part 2 -Successful Launch of the first Epsilon Launch Vehicle-


Courtesy of JAXA

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*On September 14, 2013, the first Epsilon Launch Vehicle was launched from (Independent Administrative Institution) Japan Aerospace Exploration Agency (JAXA) Uchinoura Space Center, and succeeded in properly injecting a satellite into orbit. In Epsilon Launch Vehicle development, we participate in the development/manufacture of the second-stage reaction control system(RCS) and modification maintenance of the launcher for the Epsilon launch system. The development/maintenance details and launch results are introduced in this report.*

## 1. Introduction

JAXA started development of the Epsilon Launch Vehicle in 2010, going through the stages of vehicle development, manufacturing, and maintenance of launch-related facilities, until the first Epsilon Launch Vehicle was launched from Uchinoura Space Center in 2013. We contributed to the successful launch of the first Epsilon Launch Vehicle through development of the second-stage reaction control system, which was equipped onto the launch vehicle, and modification maintenance of the launcher. Details of the development/maintenance and the launch results are introduced here.

## 2. Approach to Epsilon Launch Vehicle Development

### 2.1 General

The Epsilon Launch Vehicle is the three-staged solid rocket developed by JAXA since 2010, and is the successor to the M-V launch vehicle technology, which completed operations in 2006, and develops to organize technical application/commonality of the H-IIA launch vehicle.

In addition, the launch complex for the Epsilon Launch Vehicle takes maximized using of the M-V equipments in the JAXA Uchinoura Space Center ; maintenance is undertaken by modifying an existing M series launcher and rocket assembly building.

Of these, we participate in the development of the second-stage reaction contorol system (RCS) of the Epsilon Launch Vehicle, and modification maintenance of the M series launcher in the launch site.

As shown in **Figure 1**, the first Epsilon Launch Vehicle consists of solid motors, from the first stage through to the third stage, and a compact liquid propulsion system (Post Boost Stage: PBS). Two reaction control systems (RCS), which we were in charge of, are installed in the bottom part of the second-stage motor (**Figure 2**). In addition, assembly whole stages of launch vehicle, transportation to launch pad and launching are done by using the M series launcher including a launcher and a mobile service tower which we were in charge of. The overview of the M series launcher in the Mu center of the Uchinoura Space Center is shown in **Figure 3**.

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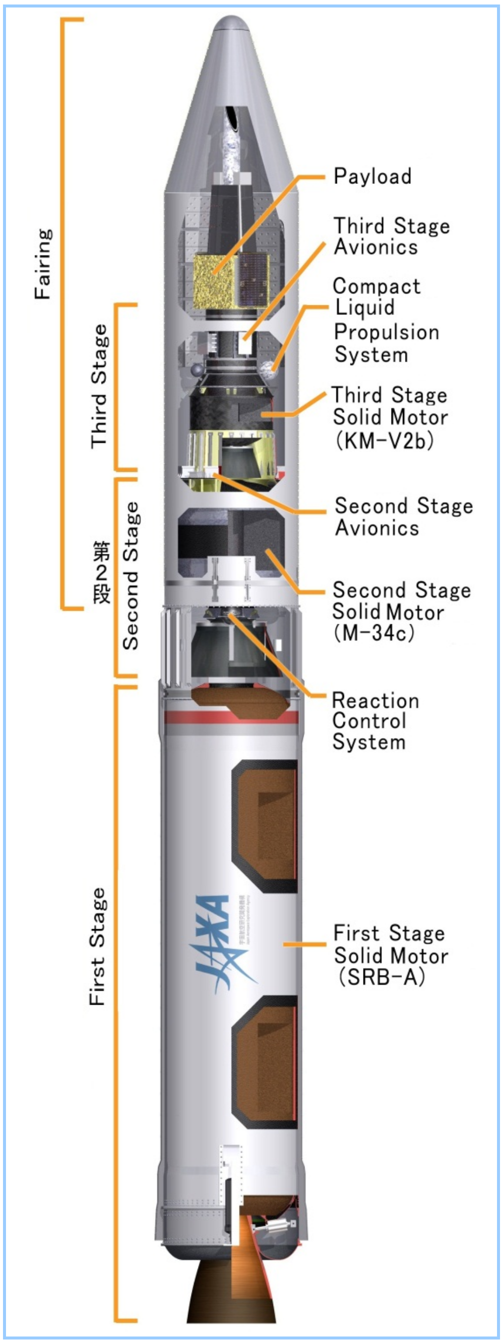


Figure 1 Structure of Epsilon Launch Vehicle

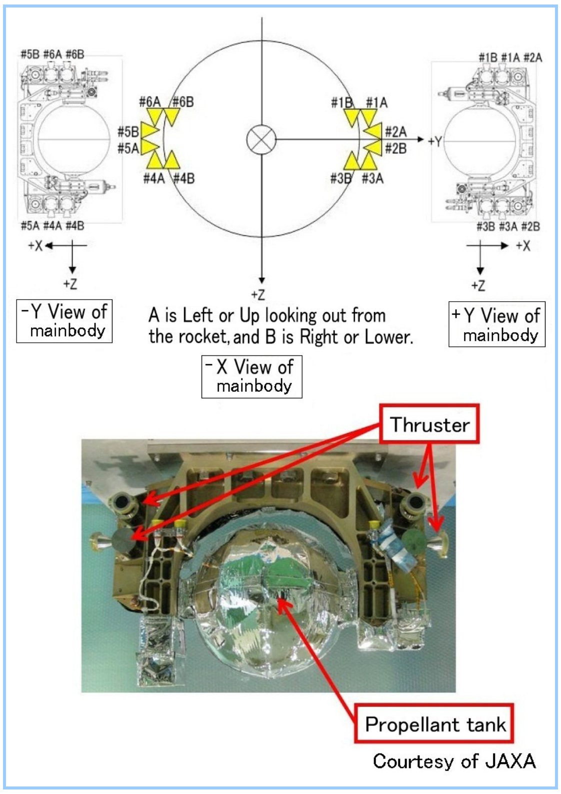


Figure 2 Second-Stage Reaction Control System (RCS)

Courtesy of JAXA

Figure 3 Overview of M series launcher

## 2.2 Development of Second-Stage Reaction Control System (RCS)

(1) Outline of Second-Stage RCS

The second-stage RCS is installed on the rear ring of the second-stage solid motor; it has an attitude control system used to control the attitude in the second-stage flight phase. The RCS has a module configuration that consists of one fuel tank, six (4 for the first launch vehicle) 23N class monopropellant thrusters, pipings, valves, and support structure, and each of them is installed on a "+" and "-" side of the Y-axis (a radial direction) of the second stage. The basic design of the RCS is shown in **Table 1**, and its schematics is shown in **Figure 4**.

**Table 1 Basic design of the second-stage RCS**

| Specification | |
|---|---|
| Type | Hydrazine monopropellant |
| Propellant supply system | Blowdown type |
| Fuel tank configuration | All metal spherical tank |
| Usable fuel | Hydrazine ($N_2H_4$) |
| Thruster structure | Six 23N class thrusters<br>(4 for the first launch vehicle) |
| Mass | About 32 kg |

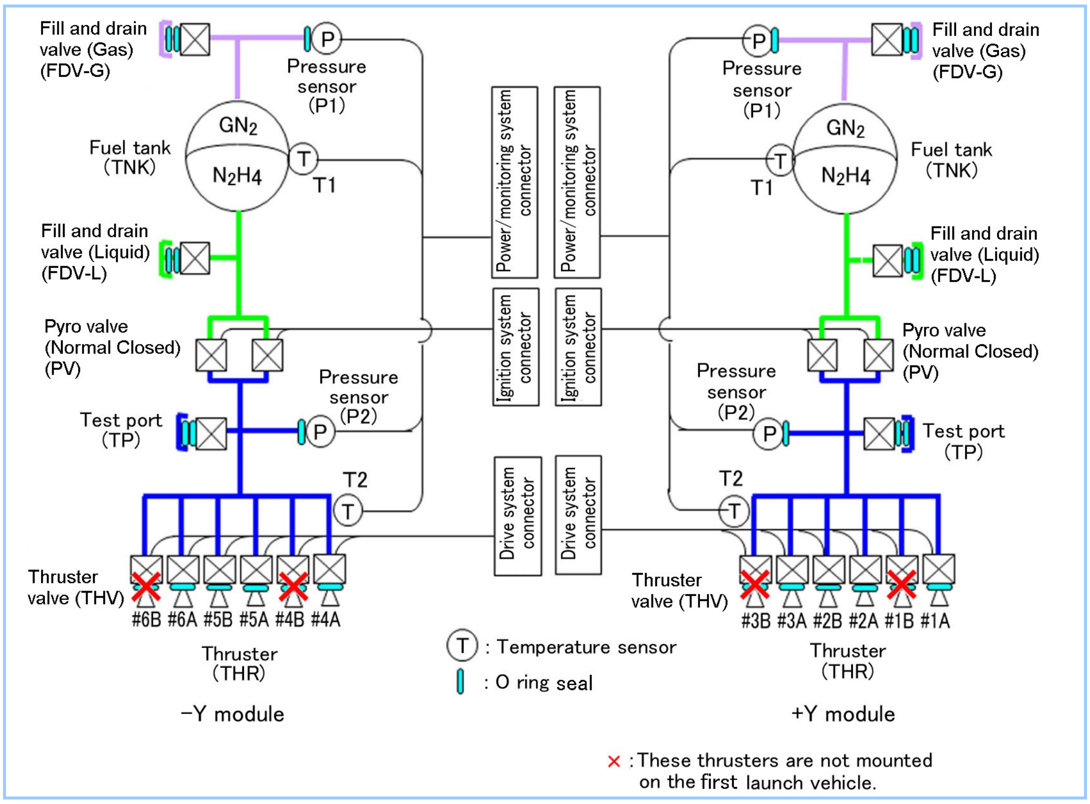


**Figure 4 Schematic diagram of the second-stage RCS**

(2) Development History

We have developed many space craft propulsion systems including the third-stage attitude control system (side jet: SJ) of the M-V launch vehicle. We develop and manufacture the second-stage RCS of the Epsilon Launch Vehicle by using accumulated experience and the following development designs,

(a) Provide an interchangeability in the fuselage and between continuation unit to optimize serviceability as a built-in unit

(b) Secure reliability and reduce the cost by using existing components with a heritage

(c) And introduce domestic products preferentially for equipment that tends to be a bottleneck in procurement

(3) Development Issues and Results

For SJ of the M-V launch vehicle that had been developed, delivery time and cost were the issues through the use of imported propellant valves. Therefore, for the second-stage RCS, it was decided to use domestic propellant valves of a satellite with a design change (change to single seal and interface) for the launch vehicle. As for a new adoption of the domestic propellant valve, an environment test in conditions which utilized a jet motor manufactured by us was executed and confirmed to the design specifications.

(4) Manufacturing Result

As for the manufacture of the flight model, performance/function were evaluated for component level and subsystem level, and the model was carried into the Uchinoura Space Center. After being moved into the launch site, a pressure test and function test was executed; the model was inspected its conformity and it was then delivered to JAXA.

## 2.3 Maintenance of Launcher

(1) Launcher Outline

The M series launcher used for vehicle assembly and launch of the Epsilon Launch Vehicle took full advantage of the M-3S launcher manufactured (in our then Kobe Shipyard) in 1982, which was modified/maintained in 1995 for the M-V launch vehicle. It mainly consists of a service tower, launcher, frame duct, air conditioning system and umbilical system; the preliminary design of the modification was started in July 2011, on-site construction was started in November 2012, and was delivered to JAXA in May 2013.

(2) Service Tower

The service tower was located at the rotating terminal of launcher; it accommodated the launcher, had functions available to assemble the first stage and fairing vertically one by one and to checkout health status of the vehicle on the launcher; it was modified as follows (**Figure 5**):

(a) Newly equipped with an overhead crane that could lift and assemble the first stage and fairing to the vehicle support platform

(b) Reinforced service tower structure accompanied by increased capability of overhead crane

(c) Newly equipped operation floors (third, sixth, seventh and eighth) to correspond with the vehicle access windows on the Epsilon Launch Vehicle, which are used to safely and easily checkout operation

The lifting capabilities of the overhead travelling crane were reinforced to 100 tons from the preexisting 50 tons, in response to the lifting mass increase in comparison with the previous M-V launch vehicle, and the hoisting drive control realizes a lowering rate of 0.83mm/sec during vehicle assembly by adopting the vector control system that used an inverter to generate sufficient torque, even at low speed, and a rate analyzer. Through these, the vehicle assembly operation could achieve to prevent a shock to the first stage and fairing without using a special tool of the precise vertical control (ex. Hydra-Set), and simplified launch operation is achieved.

Finally, at the on-site verification test before the delivery, a dummy rocket was used to simulate the geometry of the Epsilon launch vehicle, the mass, and center of gravity; the lift up and setting of the first stage and fairing were confirmed to be able to operate as we expected.

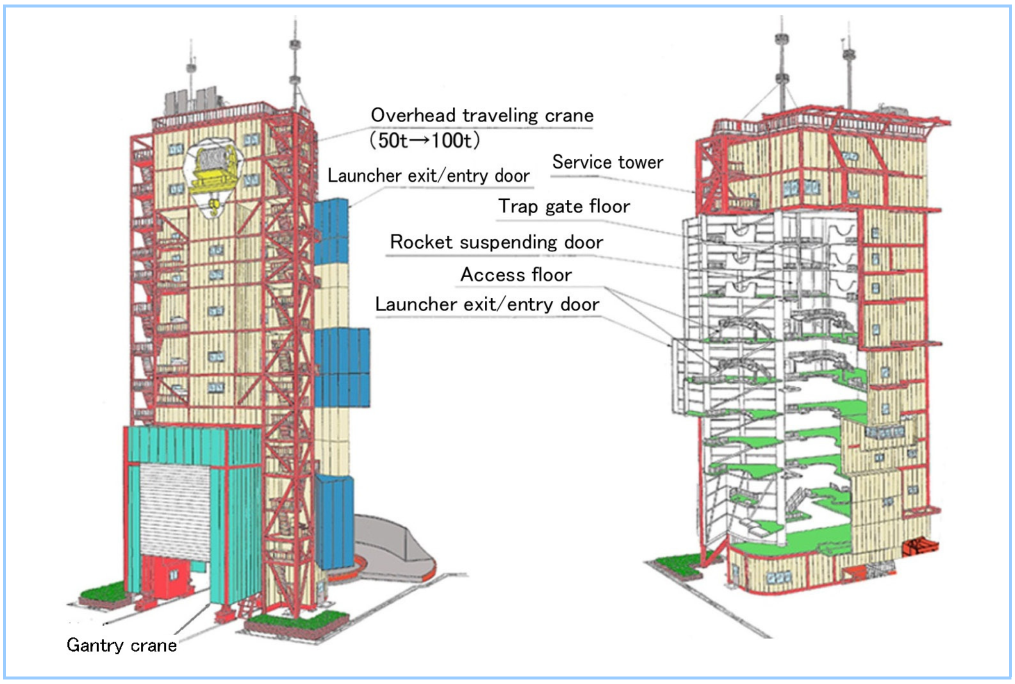


**Figure 5 Overview of service tower**

(3) Launcher

The launcher is a structure independent from the service tower, which has the function of rotating the launch vehicle while it is moving to the launch pad from the service tower, and consists of a dolly, rocket support platform, and boom (umbilical mast). (**Figure 6**)

The rocket support platform to directly install the launch vehicle supporting the entire load of the Epsilon Launch Vehicle, and installed to the preexisting dolly as steel framework which has sufficient strength to reduce a drift area at the lift off.

The existing link structure was modified, because the boom, which had the air conditioning system between the ground facility and the launch vehicle and the function of power/signal interface, stood vertically before launch but it was necessary to move to a non-interfering position where beyond the vehicle drift area (opposite direction of the launch vehicle) after launch.

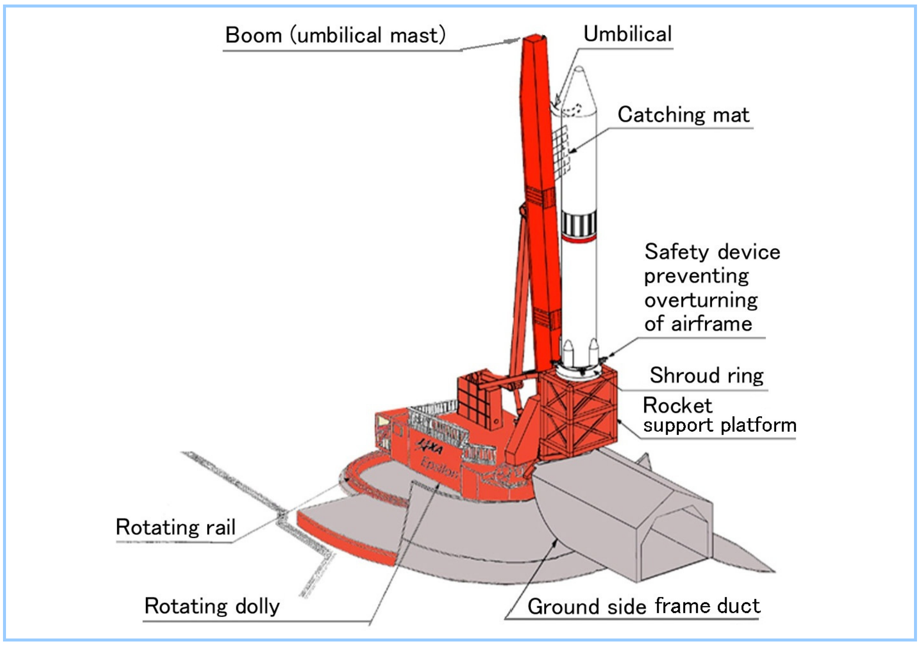


**Figure 6 Overview of launcher/frame duct** （図中も frame duct へ修正済み）

The launcher, including the launch vehicle, was modeled for structural analysis, and the strength/rigidity and impact of the launch vehicle were examined by the following analysis (**Figure 7**). In addition, a structural analysis model was simulated based on the results of the modal survey after modification of the launcher

(a) Static analysis ... Evaluate rigidity and strength of the launcher
(b) Natural frequency analysis ... Evaluate natural frequency of each mode
(c) Earthquake analysis ... Evaluate strength of components, displacement, and response acceleration in case of an earthquake
(d) Wind resistant characteristics ...
  ① Evaluate strength of components and displacement by static response analysis with a steady wind
  ② Evaluate resonance wind velocity by the Karman vortex

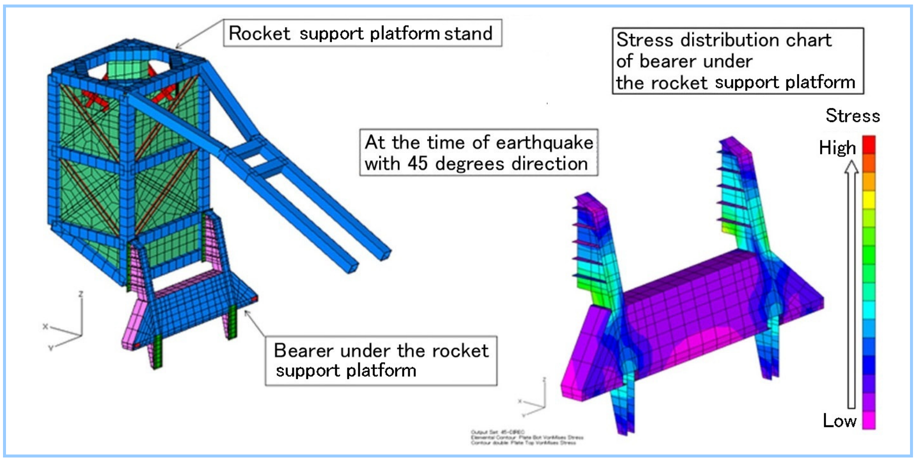


**Figure 7 Rocket Suport Platform stress contour diagram**
An example of FEM analysis results for rocket support platform is shown.

The earthquake analysis results indicated that the vehicle overturned at the maximum presumed seismic intensity in some cases. Therefore a vehicle overturning prevention unit was installed on the upper part of the launch vehicle support stand.

The vehicle overturning prevention unit is a structure securing the launch vehicle's bottom end, and is left open just before launch. The launcher and the vehicle overturning prevention unit was modified for a remote control system so that it had manipulability while being remote from the launch control center if the launch vehicle was sent back to the service tower during an emergency such as a lightning detect, and the remote control operation monitor station (touch panel) was placed in the launch control center.

Finally, at the on-site verification test before the delivery, the dummy rocket that simulated the geometry, mass, and center of gravity of the Epsilon launch vehicle was loaded onto the launcher, and confirmed that the series of turning and returning operations was able to operate on schedule.

(4) Frame duct

The frame duct, which deflects and drains the combustion gas at the lift off, is installed for the purpose of reducing the impact to the radio waves link by the smoke and to the satellite and launch vehicle equipped instruments by the acoustic environment, and it consists of a launcher side frame duct and ground side one. The frame duct is designed to endure plume pressure (temperature) and over pressure from the launch vehicle; the launcher side frame duct has a structure with an installed steel plate squared to surround the inside of the vehicle support platform frame and rotate with launcher to arrange at launch pad. The ground side frame duct is arranged at the launch pad; it is a reinforced concrete structure in the form of a tunnel to prevent acoustic diffusion based on acoustic analysis and acoustic test results from a scale model by JAXA. The launcher side frame duct, which rotates with the launcher, overlaps the ground side frame duct in the launch pad, and forms an integrated flue configuration from the bottom of the vehicle to the exhaust slot (Figure 6 and **Figure 8**).

Courtesy of JAXA

**Figure 8 Overview of frame duct**
Overview photo of frame duct is shown.


Courtesy of JAXA

**Figure 9 Overview of No. 2 movable air conditioning vehicle for fairing**
Overview of No. 2 movable air conditioning vehicle for fairing is shown.

(5) Air Conditioning System

There are two air conditioning systems to maintain the launch opereation and satellite/instrument environment. One is for the service tower and the other is for the satellite in the nose fairing and the instrument which are installed in the first stage engine area.

For the service tower air conditioning facility, the preexisting facility could be operated and we decided it could be reused after maintenance. The source of the air conditioning supply for the first stage and nose fairing air conditioning system could not be adapted to the vehicle interface of the existing air conditioning unit of the vehicle, and it was decided to reuse and operate the No.2 movable air conditioning vehicle, which was assigned from the Tanegashima Space Center (**Figure 9**).

When the fairing was transported between the rocket assembly building and service tower, the No.2 movable air conditioning vehicle ran by itself and maintain satellite environment by sending conditioned air. After the fairing was installed, the fairing air conditioning transfer vehicle No. 2 was arranged and fixed at the west side of the service tower; the system passed through the first stage and the nose fairing duct and umbilical duct, constructed along with the boom, which ran through the center of the rotating dolly; the facility is to maintain the environment by sending conditioned air to the first stage and fairing until the lift off.

In addition, the first stage/nose fairing air conditioning system was modified to enable remote checking of supply humidity/temperature and flow rate and changing the setting from the monitor station (touch panel) placed in the launch control center at a distance from the launch pad.

Before the delivery, we confirmed that the function of the systems are according to its design by sending conditioned air under the operational launch conditions.

(6) Umbilical System

The umbilical system is the equipment to connect electricity and fluid between the vehicle and the facility during launch operation, and to disconnect and evacuate according to vehicle ascent after lift off. The Epsilon Launch Vehicle differs from the conventional existing M-V launch vehicle which uses inclined launch system, and adopts a vertical launch system the same as the H-IIA/B launch vehicle. Therefore, the umbilical system for the Epsilon Launch Vehicle takes full advantage of the FLY-AWAY system using in the H-IIA/B launch vehicle; development was realized at low cost and over a short term. The outline of the FLY-AWAY system is shown in **Figure 10**. The umbilical system for the Epsilon Launch Vehicle was developed following technical challenges owing to the restrictions of the preexisting facility.

(a) Because the evacuation distance after the umbilical system had separated from the vehicle was short, the acceptable bounce range was small after evacuation.

(b) When the umbilical system was evacuated, the capturable range was limited.

Regarding this matter, we newly developed a compulsion retracting system and verified system operation for defective behavior, evacuated the location and bounce area by a verification test using a dummy rocket, which went according to plan (**Figure 11**).

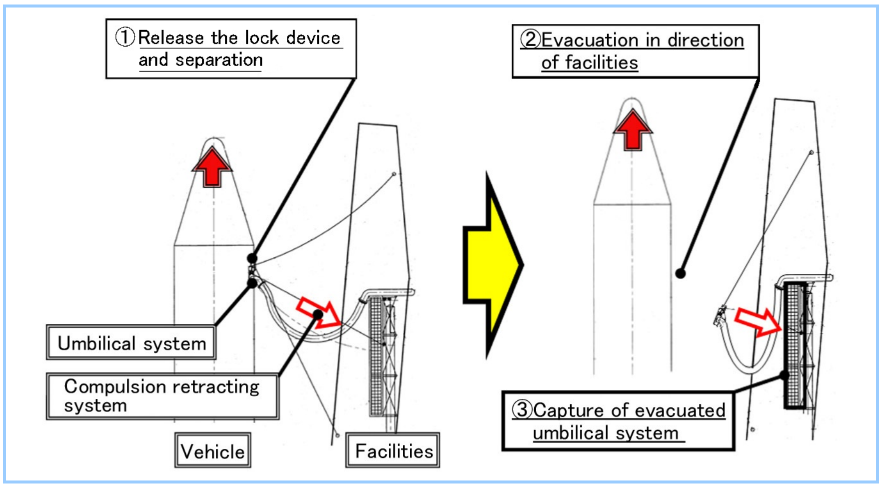


**Figure 10 Outline of umbilical system for FLY-AWAY system**
Umbilical system are separated from launch vehicle and evacuated in direction of facilities accompanied with vehicle ascent

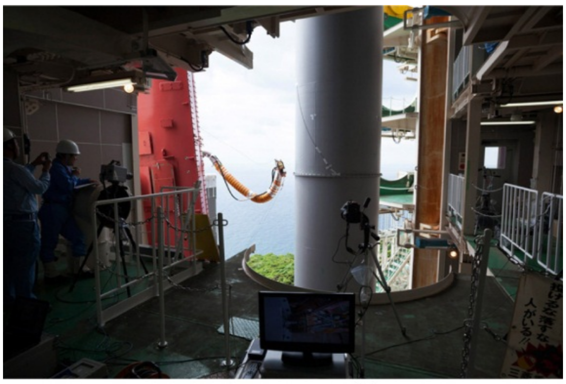

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**Figure 11 Condition of confirmation test for umbilical system separation**

## 3. First Vehicle Launch Result

The first Epsilon Launch Vehicle was launched from JAXA Uchinoura Space Center at 14:00 on September 14, 2013, and it successfully injected a satellite into its predetermined orbit.

On the occasion of the launch, the electric power and air conditioning was supplied to the vehicle and vehicle support until lift-off and during the rotating move to the launch pad; attitude control to attempt stability of the vehicle attitude was correctly carried out by the RCS at the second-flight phase after launch.

### 3.1 The Second-Stage Reaction Control System (RCS)

Through the flight data of the first Epsilon Launch Vehicle, the operating results of the second-stage RCS was followed, and it could be evaluated that the operation worked correctly.

(a) The transition of the pressure and temperature range was predetermined before launch until the second and third stage separation after the end of the operation.

(b) By pressure transition and operating condition of the thruster, the propellant valve was operated normally, and the attitude control in the second-flight phase of the launch vehicle was normal.

### 3.2 Launcher Operation

In operation of the launcher, procedures for the combination of the first stage /nose fairing facility operation (fairing transport) and the launch operation (Y-5 to Y+1) were maintained, and each two teams for launcher and umbilical executed operation respectively. The launcher team was in charge of operations related to the service tower, launcher, the first stage/nose fairing air conditioning and electric facility, and the umbilical team was in charge of operations related to the first stage system and umbilical facility of the fairing system.

Launch operation contents were according to **Figure 12**; since twice of the postponement and the rehearses execution, Y-0 operation on the launch day were attended with familiarize conditions.

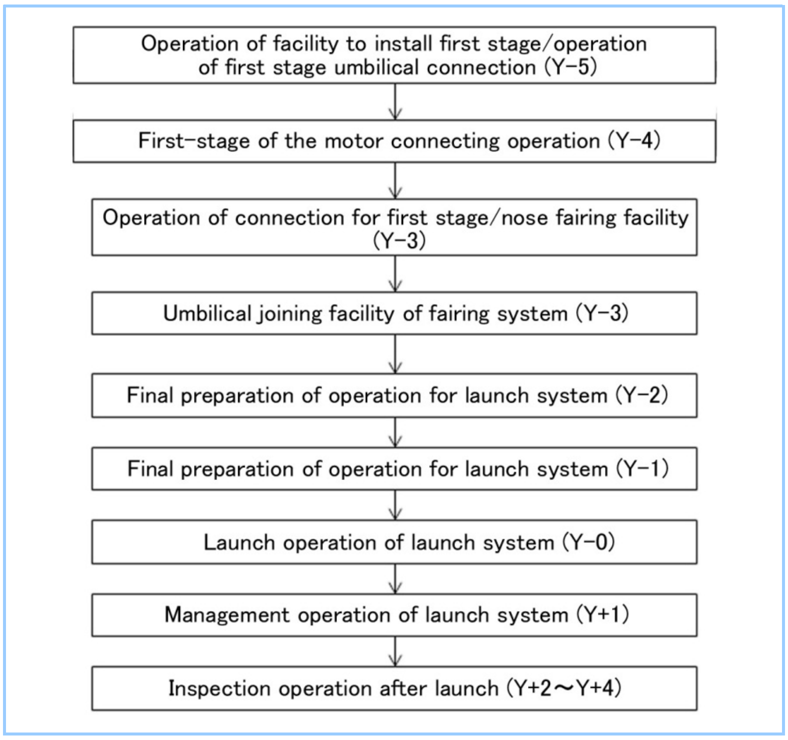


**Figure 12 Operational flowchart**
The figure shows the operational flowchart from first-stage installation through inspection after launch

At the launch day(Y-0), launcher turning and preparation, boom evacuation, vehicle overturning prevention unit release, and umbilical system carrier evacuation at the launch was satisfactory, and we contributed to the successful launch of the first Epsilon Launch Vehicle with the operation time according to plan proceeding without problems (**Figure 13**). In addition, around the launch pad, an acoustic measurement is performed by JAXA; there was no problematic influence about acoustic environment on the interface of the loaded satellite at the advance predicted level, and the constructed frame duct was confirmed to function well (**Figure 14**).

Each piece of equipment of the launcher was inspected after blastsoff, and the facility was checked regarding its damage status. There was some damage that was beyond the level of prediction at the design, but it was considered in detail for the next launch to repair, remodify, and improve the design base on the first launch.

In addition, extracted improvement/refinement of reliability, operability, safety, and serviceability of instruments through the operation will be reflected in the next launch, and we are planning to work so the customer has increased satisfaction.

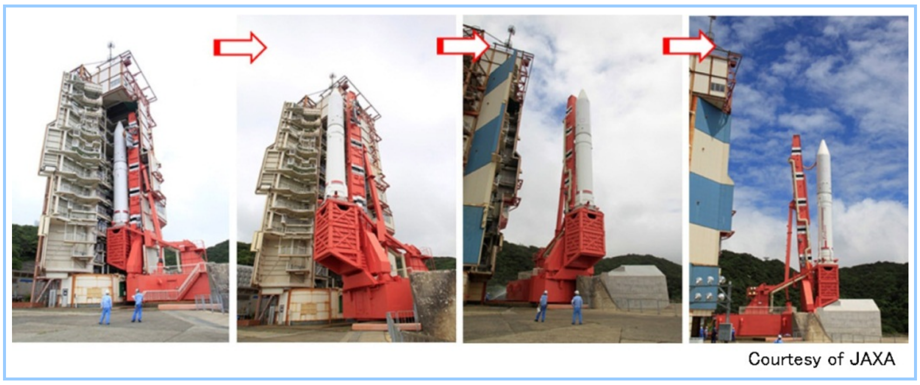


**Figure 13　Figure of launcher rotating situation**
The picture shows the process of rotating the launcher at Y-0

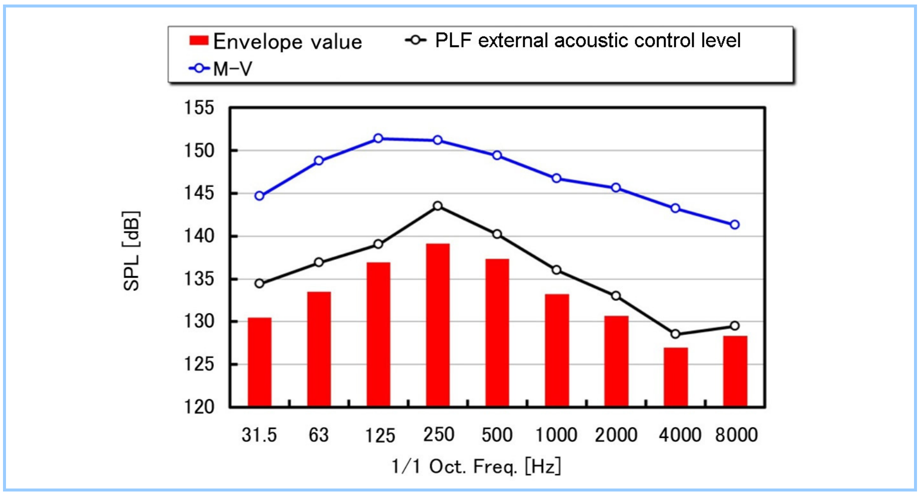


**Figure 14　Result of external acoustic measurement at the first　launch**
The chart shows measurement results (envelope value) against external acoustic control level.

## 4. Conclusion

Development of the second-stage RCS in the Epsilon Launch Vehicle and maintenance contents of the launcher were introduced. For the first launch vehicle operation, there were no serious problems in either of the above, and we were able to contribute to the successful launch in spite of the first Epsilon Launch Vehicle. The reflection and improvement subject provided through the operation was discussed for the next launch, and we continuously support the innovation of the space transportation system of our country including Epsilon Launch Vehicle.