Contribution to Japan's Flagship Launch Vehicle-part 1 Continuous Successful Launch of H-IIA and H-IIB launch Service Privatization

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The Flight #4 H-IIB launch vehicle carrying the H-II Transfer Vehicle (HTV4) was launched at 4:48:46 am on 4 August, 2013 from Tanegashima Space Center, and successfully injected the HTV4 into its designated orbit. H-IIA/B launch vehicles have now been successfully launched 20 consecutive times. In addition, the Flight #4 H-IIB was the first launch vehicle to be privatized, and the privatization was accomplished smoothly. This paper introduces one aspect of the activities behind the reliability of the H-IIA/B launch vehicle.

1. Introduction

The past launch record is shown in **Table 1**, and the H-IIA/B launch vehicle family, which is Japan's flagship launch vehicle program, is shown in **Figure 1**.

Table 1 Record of H-IIA/B launch

Success Rate of H-IIA and H-IIB: 96.2%

Type	Flight No.	Launch Date	Mission	Orbit	Note	
H-IIA	TF1	2001.8.29	LRE	GTO	Success	Postponement
H-IIA	TF2	2002.2.4	MDS-1/DASH	GTO	Success	Postponement
H-IIA	F3	2002.9.10	DRTS/USERS	GTO/LEO	Success	On Time
H-IIA	F4	2002.12.14	ADEOS-II/Small Satellites	SSO	Success	On Time
H-IIA	F5	2003.3.28	Classified	-	Success	On Time
H-IIA	F6	2003.11.29	Classified	-	Failed	-
H-IIA	F7	2005.2.26	MTSAT-1R	GTO	Success	On Time
H-IIA	F8	2006.1.24	ALOS	SSO	Success	Postponement
H-IIA	F9	2006.2.18	MTSAT-2	GTO	Success	Postponement
H-IIA	F10	2006.9.11	Classified	-	Success	On Time
H-IIA	F11	2006.12.18	ETS-VIII	GTO	Success	On Time
H-IIA	F12	2007.2.24	Classified	-	Success	On Time
H-IIA	F13	2007.9.14	SELENE	Transfer to Moon	Success	On Time
H-IIA	F14	2008.2.23	WINDS	GTO	Success	On Time
H-IIA	F15	2009.1.23	GOSAT/Small Satellites	SSO	Success	On Time
H-IIB	TF1	2009.9.11	HTV1	ISS	Success	On Time
H-IIA	F16	2009.11.28	Classified	-	Success	On Time
H-IIA	F17	2010.5.21	PLANET-C/IKAROS	Transfer to Venus	Success	On Time
H-IIA	F18	2010.9.11	QZS	Quasi-Zenith Orbit	Success	On Time
H-IIB	F2	2011.1.22	HTV2	ISS	Success	On Time
H-IIA	F19	2011.9.23	Classified	-	Success	Postponement
H-IIA	F20	2011.12.12	Classified	-	Success	On Time
H-IIA	F21	2012.5.18	KOMPSAT-3/GCOM-W1	SSO	Success	On Time
H-IIB	F3	2012.7.21	HTV3	ISS	Success	On Time
H-IIA	F22	2013.1.27	Classified	-	Success	On time
H-IIB	F4	2013.8.4	HTV4	ISS	Success	On Time

GTO: Geostationary Transfer Orbit
SSO: Sun-Synchronous Orbit
LEO: Low Earth Orbit
ISS: HTV Orbit heading to International Space Station

・Privatization by MHI
H-IIA: from F13
H-IIB: from F4

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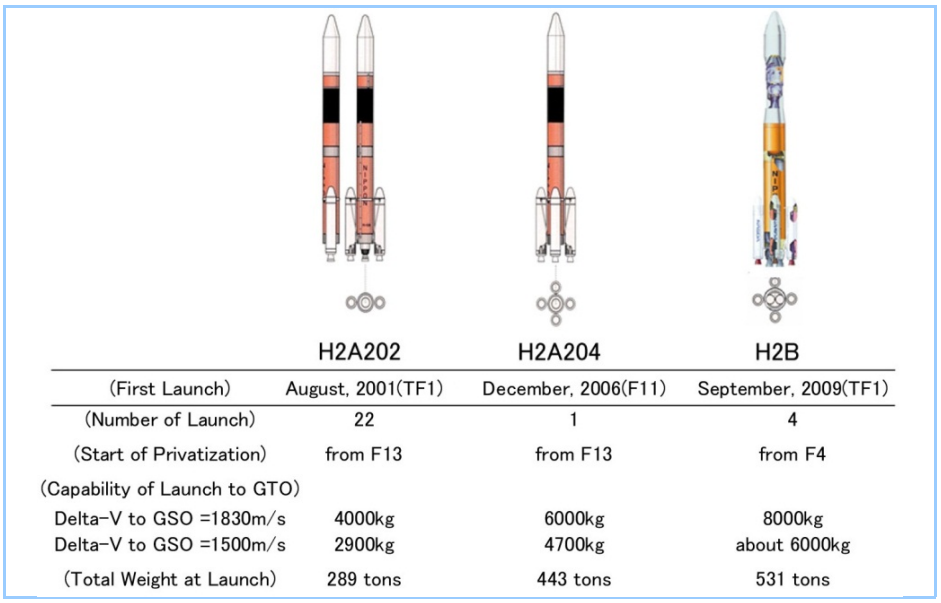

	H2A202	H2A204	H2B
(First Launch)	August, 2001(TF1)	December, 2006(F11)	September, 2009(TF1)
(Number of Launch)	22	1	4
(Start of Privatization)	from F13	from F13	from F4
(Capability of Launch to GTO)			
Delta-V to GSO =1830m/s	4000kg	6000kg	8000kg
Delta-V to GSO =1500m/s	2900kg	4700kg	about 6000kg
(Total Weight at Launch)	289 tons	443 tons	531 tons

Figure1 H-IIA/B Launch Vehicle Family

H-IIA launch vehicles have succeeded 25 times; the only failure was Flight #6. The results compared with the success rate of the flagship rockets of other nations are shown in **Figure 2**. The success rate of the H-IIA launch vehicle reached 95.5%, the world's top level. In addition, the trend of the on-time launchratio, representing the ratio launched on the date it was originally planned, is shown in **Figure 3**. It has a high ratio of 92% for the last 4 years and has continued to increase from 2000.

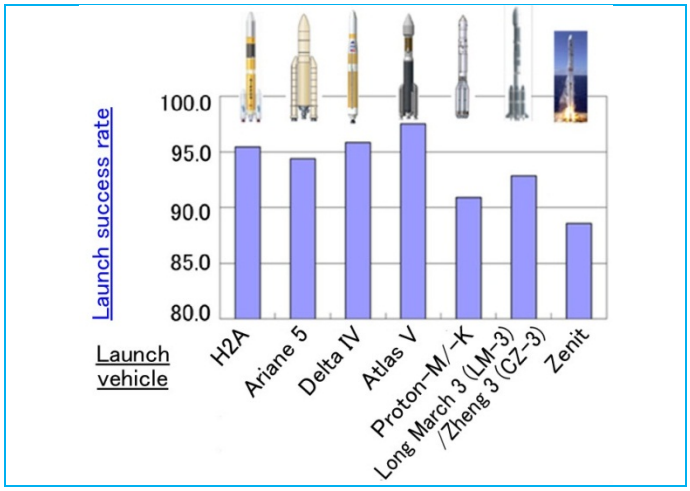

Figure 2 Comparison of Launch Success Rate

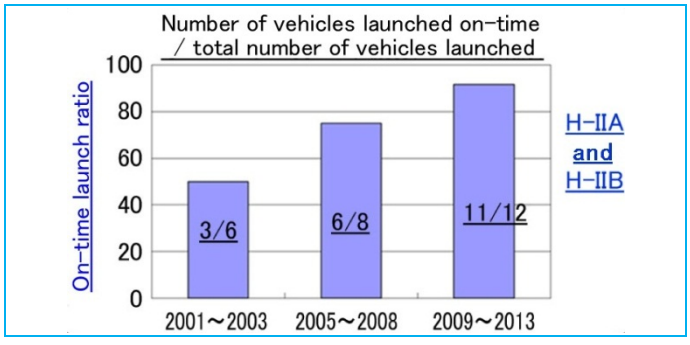

Figure 3 On-Time Launch Ratio

Furthermore, the number of defects that occurred at the Tanegashima Launch Site is shown in **Figure 4**. It is understood that as the quality of the product improves, the number of defects decreases. Here, we introduce the activities that support the high reliability of the H-IIA/B launch vehicle.

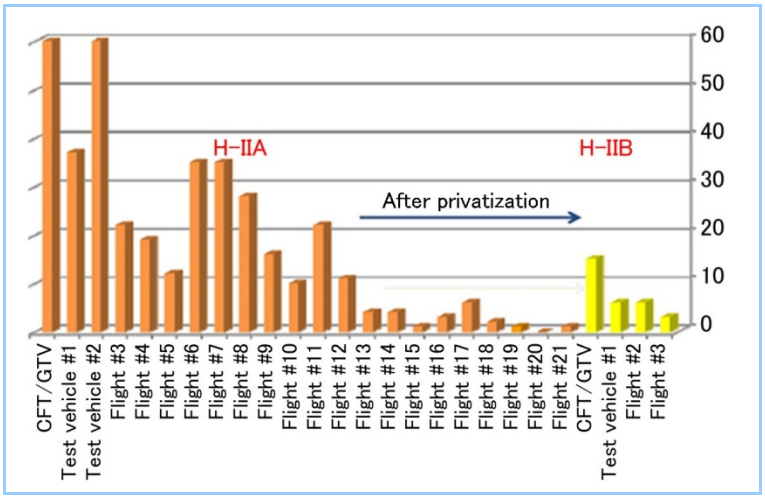

Figure 4 Number of defects at Tanegashima Launch Site

2. Activities to Support the Reliability of the Product

When we consider the reliability of the product , there are two activities we regard as important: data trend evaluation activity (2σ evaluation) and quality evaluation activity.

2.1 Data Trend Evaluation Activity

The outline of the data trend evaluation activity is shown in **Figure 5**. The activity is to arrange the functional test data, etc. in time series from the equipment manufacturer, MHI Nagoya Oye plant to Tanegashima Launch Site and to evaluate whether the data are within the range [dispersion of average value +-2σ of the past record value]. In general, the value of the [dispersion of average value +-2 σ] is less than the specified value (SPEC value). Through this activity, when the value deviates from [dispersion of average value +-2 σ] even if it meets the specified value, it is assumed that some changes are produced in the process and the cause and impact are investigated thoroughly. And we evaluate the dispersion between the data of the same test of each vehicle, It is assumed that continuing this activity steadily leads to the early detection of the sign of defect.

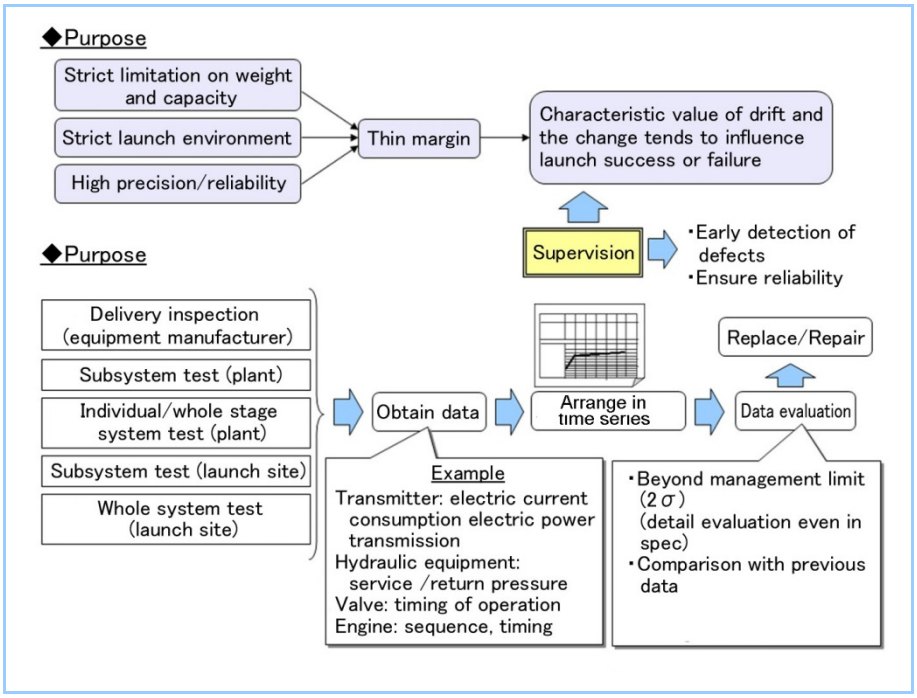

Figure 5 Outline of Data Trend Evaluation Activities (2σEvaluation)

In the H-IIA launch vehicle, about 5,000 data points are evaluated. As a result of having an investigation into a cause beyond the dispersion of 2σ by the trend evaluation, there were 8 or more cases of defects detected regarding design or manufacture. Two of those examples are introduced here.

The first example is shown in **Figure 6**. During the propulsion functional test of the second stage, the pressure drop rate in one enclosed space exceeded the value of the [average value +2σ dispersion of the previous unit]even though the value was within the SPEC value.

As a result of the investigation, the cause of the large drop in pressure rate was discovered to be a contamination lied between the sealed section of the check valve in the system, so the gas of the enclosed space was able to leak out. And the cause of contamination was design defect of the manual valve in the system.The design modification of the manual valve was started immediately, and a countermeasure product was manufactured and replaced before the launch.

The second example is shown in **Figure 7**. We discovered that about 3% nitrogen gas got mixed in the helium gas for driving engine valves supplied from the facility to the launch vehicle, which was after the investigation into a 5% delay in the engine valve operation time.

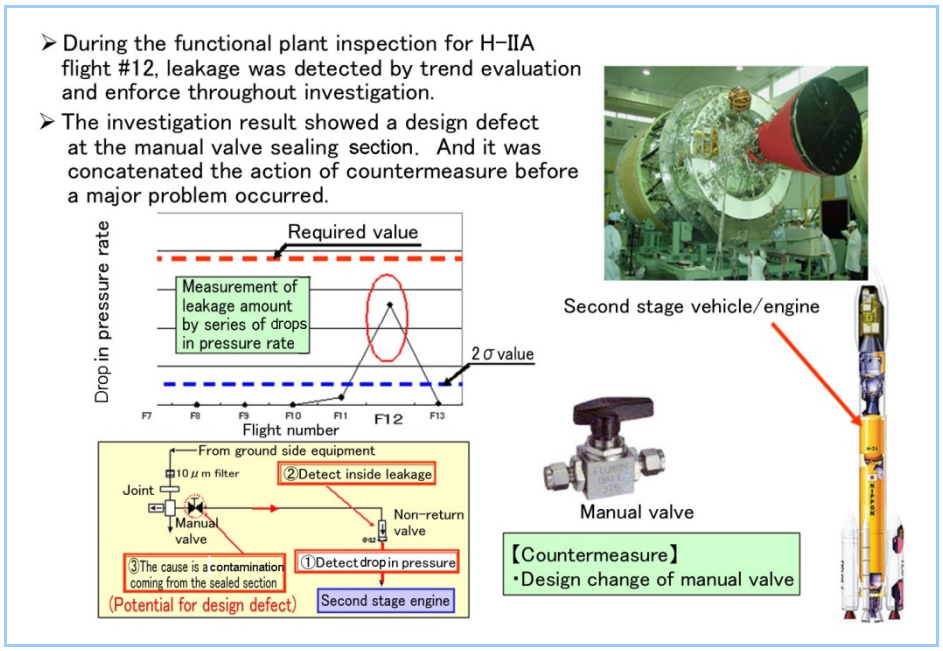

Figure 6 Data Trend Evaluation Activities – Example of Performance (1)

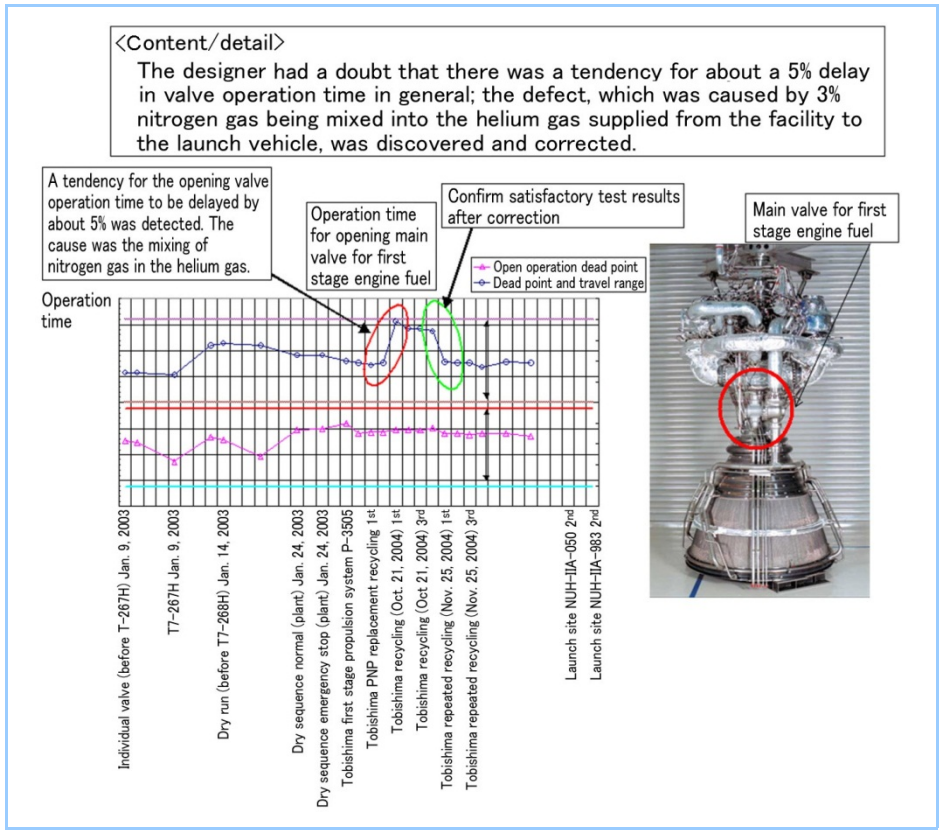

Figure 7 Data Trend Evaluation Activity – Example of Performance (2)

2.2 Quality Evaluation Activity

The outline of the quality evaluation activity is shown in **Figure 8**. In general, the quality of a product is based on a drawing/SPEC, which is decided by a engineering department, and it is certified by manufacture/inspection of the manufacture/quality assurance department. This process is similar for launch vehicles.

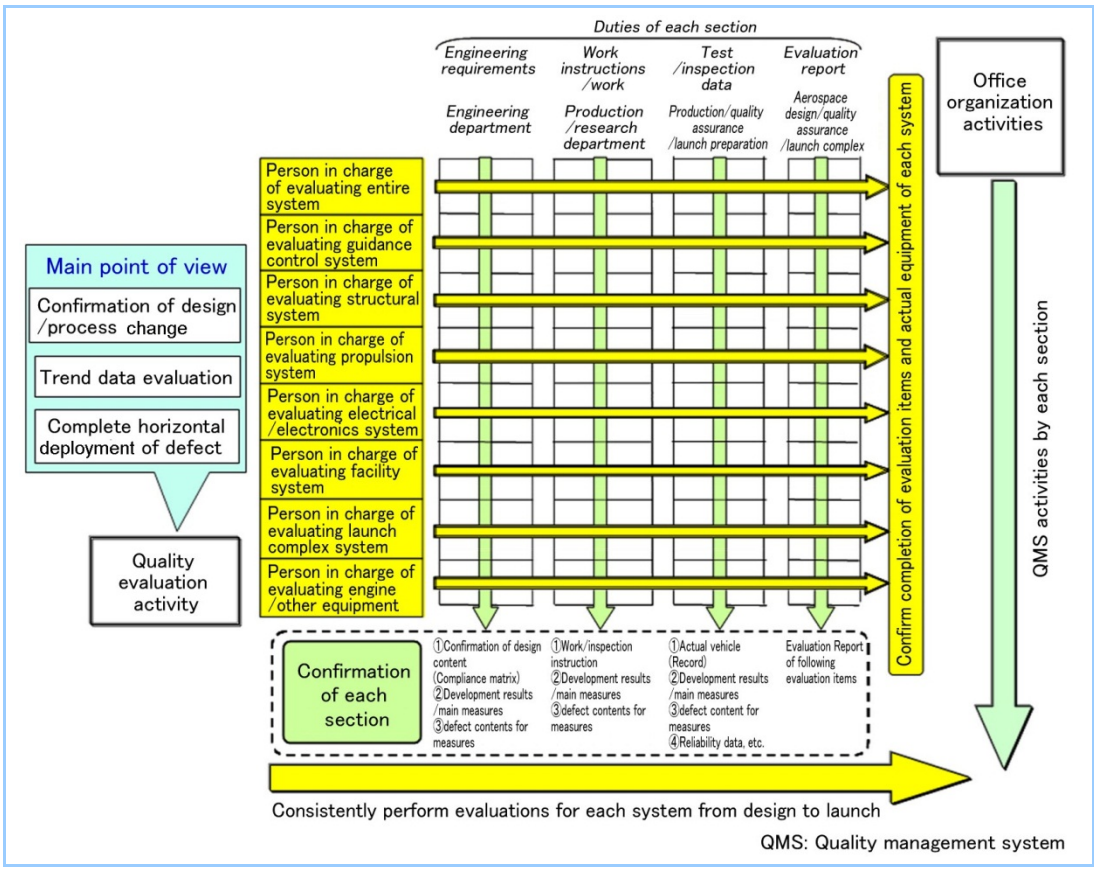

Figure 8 Outline of quality evaluation activities

In addition to this general process, for the H-IIA/B launch vehicle, after the failure of the H-IIA launch vehicle #6, the engineering department took a leading part in quality evaluation activity. It has continued to be performed until now. And this activity is undertaken by the persons in charge of each system. They reevaluate the quality of the launch vehicle regarding design contents, manufacturing condition, inspection result and launch separately from the regular process mentioned above. The main points of view for the evaluation are the following 3:

(1) Confirmation of design/process change
(2) Confirmation of trend changes in data(trend evaluation)
(3) Confirmation of the horizontal deployment status about the defects occurred recently

We have often experienced the cause of defects was the some change. So we pay most attention to evaluating various changes; the following is an introduction to the above point of view of (1).

Twenty-two H-IIA launch vehicles and 4 H-IIB launch vehicles have been launched. It has given the impressions that the H-IIA/B launch vehicle has already been refined regarding design, and manufacture with same design and launch indifferently. However, actually, there have been the following changes, even with the most recently launched H-IIA launch vehicle #22 and H-IIB launch vehicle #4. (The total number includes minor changes.)

- Number of changes in design/process/procedure: H-IIA launch vehicle #22 137
  H-IIB launch vehicle #4 207
- Number of changes of manufacture jigs H-IIA launch vehicle #22 87
  H-IIB launch vehicle #4 118

These changes are evaluated not only about their validities but also are evaluated carefully and quantitatively about their impact to the other system and are judged the impact for launch.

3. Activity that Develops/Maintains Human Capabilities

The activity that supported the reliability of the product was explained in section 2. On the other hand, it is important to educate/maintain human capabilities to preserve the reliability of the entire launch program. For example, human capabilities have a considerable effect on the on-time launch rate introduced in section 1. The various defects related to the vehicles and facilities occur for every vehicle on the day of the launch. The collection of defect-related data, cause analysis and actions must be completed in a short time to launch on-time. If the cause of a problem does not become completely clear, it is still necessary to decide upon the launch in a short time as the defect may not have a harmful effect on the mission of the launch. We consider that to develop and maintain engineers with these capabilities is important.

We perform "launch service operation rehearsal" in Tanegashima and "simulated problem training" in Nagoya Aerospace Systems Oye plant as part of the activity stated above.

The launch service operation rehearsal is a practical rehearsal when the personnel responsible for the launch gather at the Tanegashima launch site and execute training under the assumption the day is the day of launch. Personnel who evaluate the data at the time of launch enter the control room and start the rehearsal. Carefully prepared "simulated problems" are shown to the personnel. The training is a troubleshoot for these simulated problems and to propose answers and report on causes and actions for the launch in a limited time. Through this training, the necessary capabilities to make an appropriate decision in a short time are cultivated. Troubleshooting during an actual rehearsal is shown in **Figure 9**. The rehearsal is performed once for each vehicle. Since it is insufficient to develop and maintain capabilities only through this training, we also execute similar training called "simulated problem training" in Nagoya Oye plant. This serves as part of the education for young engineers.

Figure 9 Troubleshooting in the control room during exercise rehearsal

The development of the recent H-IIB launch vehicle was completed 4 years ago (2009). The development of the H-IIA launch vehicle was completed in 2001. H-IIA/B launch vehicle is an improved product of H-II launch vehicle that was completed in 1994. H-II is the last vehicle we have developed from the beginning. The capability to make adequate judgments in the short time stated above has been taught to young engineers through this H-II launch vehicle development test experience; however, there is no situation for young engineers to develop from the beginning and to experience tense situations that require quick decision making. On the other hand, due to the H-IIA/B launch vehicle being placed in an environment where launch failure is never acceptable, experienced engineers are mostly expected to make on-the-spot decisions just before the launch while young engineers have less opportunity to make major decisions. Therefore, for the purpose of having many decision experiences for young engineers, education and training programs are practiced to judge "simulated problems" in conditions that are the same as the actual launch in Tanegashima. Through the training, young engineers can recognize their current capabilities and work with the incentive that they are going to learn by themselves; also skill levels of individual personnel can be understood to help place them in the right position.

Steadily continuing such activity and educating/maintaining the judgment of personnel, including younger personnel, enables quick judgment and decision making for defect occurred on the launch day and as a result, it is assumed, this will lead to on-time launch rate improvement.

4. Conclusions

One aspect of the activity supporting reliability represented by the launch success rate and on-time launch rate was introduced as a product and a human point of view. These activities were designed for continuous success by senior and veteran personnel directly concerned in launch vehicle development and launch. The H-IIA/B launch vehicle is a vehicle that can continue operating for at least seven years, and we are proceeding with the construction of the structure to continue effective performance without lowering quality. The development of a new flagship launch vehicle, which is to be the successor of the H-IIA/B launch vehicle, is discussed and the space transportation vehicle demanded is one of low cost but high reliability. The next challenge we have to try is to design launch vehicle to be able to simplify the evaluations we currently utilize.