Failed Launching of H-ⅡA Rocket #6

Nov. 29th, 2003, Pacific Ocean, Off Tanegashima Island, Kagoshima

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(Summary)

H-ⅡA Rocket #6 was launched from Tanegashima Space Center of NASDA at 13:33 on Nov. 29th, 2003. About 105 seconds after the lift-off, the signal for separation of the two solid rocket boosters was sent from the on board computer. However, the solid rocket booster on the right was not separated. Without the separation, the rocket was not able to gain the height and velocity necessary for launching the payload to the scheduled orbit, so the signal for self-destruction was sent from the ground control center at 13:43:53. As a result, the rocket and payload were lost in the Pacific Ocean.

The Technical Investigation Committee of the Space Development Commission of Japan conducted the investigation into the cause of the accident.

The direct cause of the incomplete separation of the forward brace connecting the solid booster to main rocket was the malfunction of the separation system, which was due to the leak of fuel gas from the nozzle of the solid rock booster into the aft adapter. The cause of the leak of fuel gas was found to be the thickness reduction by local erosion of the nozzle insulator that was made of carbon fiber reinforced plastic (CFRP).

1. Component

Solid Rocket Booster

2. Event

The sequence of the SRB separation is shown in Fig.4. The SRB on the left hand side failed to separate because the forward brace connecting the fuselage and the SRB was not cut.

Figure 3 shows the structure of the nozzle. Thermal protection is to be achieved by the liner aft B2 with the abrasion behavior of the carbonized layer.

The sequence of events leading to the failure is believed to have occurred as follows. (See Figure 5)

○ Because of the difference in the materials used for the nozzle throat and the liner aft, a step emerged along the front edge of the liner aft B2 on the inner side of the SRB-A nozzle during combusting.

○ This step caused a disturbance in the flow of the combustion gas, the heating rate became higher, and a thickness reduction was induced downstream of the flow.

○ Somewhere in this area of reduction in thickness, relatively deep grooves were formed by the deterioration of the binding properties of the carbonized layer.

○ As the grooves grew, the inter-laminate pressure and delamination increased, causing the exfoliation of the CFRP laminates. As a result of this phenomenon, local erosion was accelerated.

○ As a result of the increase of local erosion of the liner-aft B2, the combustion gas reached holder B, resulting the melting of the holder, which led finally to the leakage of the hot gas into the aft adapter.

○ The combustion gas leaked into the aft adapter, heated the cable that carried the electric signals for the separation device causing the cable to fail so that the separation signal of SRB was not transmitted.

3. Course

During the development of the SRB-A, the following combustion tests were carried out.

・Ground combustion test (EM): Heat resistant property test of FRP

・Ground combustion test (PM): Assurance test of design and manufacturing process

・Ground combustion test (QM): Reliability assurance and evaluation of the manufacturing process

Results of the QM tests:

In August 1999, significant erosion was observed at the aft liner B due to the exfoliation of CFRP induced by the delamination that occurred as a result of the thermal resolution of the phenolic resin. In order to minimize this erosion, a design change was made from a separate to a monocock structure, and the thickness and the material were also changed.

In June 2000, an incident occurred where the throat inset dropped into the motor case at the final stage of combustion. In order to avoid this from occurring in the future, a design change was made on the shape of the throat insert and the liner aft B2.

In October 2000, significant erosion was found to have occurred in a local area of the liner aft B2 due to the induced vortices. Additional experiments were performed, but the true mechanism of the local erosion was not discovered. In order to counter the effects of the erosion, the wall thickness was increased and a CFRP outer panel was added.

4. Cause

Factors accelerating the local erosion were examined.

Due to the uneven thickness reduction of the insulator, the delamination and exfoliation of CFRP tends to take place locally. The formation of a carbonized layer also accelerates these phenomena, resulting in the formation of deep grooves.

The higher combustion pressure of SRB-A compared with conventional SRB may also be a factor contributing to the acceleration of the above-mentioned phenomena.

As the local erosion at the CFRP nozzle structure is the stochastic phenomenon that is related to the microscopic mechanism, the location and the depth of the erosion cannot be calculated in a deterministic manner. Furthermore, it was pointed out that the present design tools cannot prevent deep erosion that leads to the development of an open hole from occurring. It is difficult to predict the site where the local erosion occurs. However, once the erosion occurs, it will continue to grow at that site.

This phenomenon of local erosion occurred and continued until an open hole in the left SRB-A of H-ⅡA #6 for the first time

5. Immediate Action

Japan Aerospace Exploration Agency (JAXA) conducted a general re-examination of the H-ⅡA rocket development systems. In this examination, which covered the basic designing of the system as well as the countermeasures adopted towards the direct causes of the failures, top priority was placed on the improvement of system reliability.

By establishing the Re-examination Specialist Board on the H-ⅡA rocket, the Space Development Commission watched and discussed the re-examination conducted by JAXA.

6. Countermeasure

The fundamental policies of the design changes of SRB-A were as follows.

- Develop a revised version of SRB-A that minimizes local erosion, at the cost of tentatively reducing the launching payload capability of the rocket.
- In order to regain the launching capability, try to develop a new type of SRB-A with high reliability by establishing sound measures to suppress the occurrence of local erosion.

The following is the draft of design changes of the revised version of the SRB-A nozzle.

○ Re-examination of combustion pattern

A combustion pattern having lower combustion pressure and longer combustion period was adopted.

○ Re-examination of nozzle geometry

A bell-type nozzle with a higher angle at the nozzle mouth was adopted to more effectively prevent the delamination that accelerates the local erosion.

○ Extension of throat insert width

The thickness reduction of the liner-aft made of CFRP was found to be alleviated by extending the throat insert in the downstream direction of the exhaust gas flow.

○ Re-examination of the thickness of the liner-aft

A new design criterion was adopted to establish the reliability of nozzle. In accordance to this criterion, the thickness of the liner-aft was increased.

○ Improvement of manufacturing and inspection

Enforcement of specification management for the raw material and products of CFRP was implemented.

Inspections for flaw detection of the CFRP and 3-D C/C components were also enforced.

The liner-aft thickness was increased by using a double-liner structure formed from two CFRP components that are bonded together. In this context, non-destructive inspections had to be carried out for every process of manufacturing.

Moreover, design changes were proposed to assure system redundancy in wiring of ignition cables and others. Specifically, the ignition cable for SRB separation and other wire cables were installed by two routes - the, main tunnel and a sub tunnel - in order to mitigate the risk of malfunction.

7. Knowledge

(1) The importance of taking an honest attitude towards recognizing what was happened

At the moment when the local erosion was observed during the QM3 ground test, the engineers should have honestly accepted the facts even if those facts did not agree with their past experience, because unknown phenomena are often encountered in development of new systems. The engineers should have examined the difference between the observed phenomenon and ordinary erosion in order to elucidate the mechanisms generating the local erosion. Consultation with outside specialists might have been effective for finding a solution to the local erosion caused by unknown phenomena.

(2) The importance of taking an earnest attitude towards pursuit of all of possibilities

At the moment when the delamination occurred during the QM3 ground test, the engineers should have taken the attitude that the delamination of CFRP must be prevented from occurring in the heating test. In particular, they should have determined the conditions of delamination occurrence and the material characteristics under those conditions.

8. Sequel

The local erosion might recur as the number of launches and tests are increased, if the phenomenon was in fact a probabilistic event and had occurred at the right side of the SRB-A just by chance. To check this possible and to obtain technical data on the local erosion, a combustion test using the same conical nozzle as the #6 rocket engine was conducted on the ground on July 7th, 2004. Using ultrasonic sensor, the tested nozzle was discovered to have developed a hole.

The specific results of the test were: the nozzle fractured at the hole that developed through the thickness reduction by local erosion, and combustion gas started to leak about 50 seconds after the ignition of the engine. Because of the sensor hole for the test, the liner-aft B2 fractured earlier than in the actual case. However, this ground test proved that the hypothesis of the accident cause was correct: local erosion readily occurs with high probability.

After this experiment, the Re-examination Specialist Board on the H-ⅡA rocket issued the report on September 2nd, 2004. Design changes of the revised version of SRB-A were made in accordance to the recommendations in the report.

The insulation and thermal protection characteristics of the revised nozzle were evaluated in three ground tests as follows:

- The maximum and average values of the thickness reduction of the revised liner-aft showed similar values in all ground combustion tests, and the reductions were almost a half those of the conventional nozzle. The thickness reduction values also showed good characteristics of reproducibility.
- In the new bell type nozzle, the angle between the laminated and the heated face was greater than the designated value, and hence no delamination was observed.

On February 26th, 2005, 15 months after the accident, H-ⅡA rocket #7 was launched successfully from Tanegashima Space Center.

9. On the Side

(1) The objective of H-ⅡA rocket #6

The objective of H-ⅡA rocket #6 was to launch the Intelligence Satellite #2 into its designated orbit. The Intelligence Satellite #1 was successfully launched on March 28th, 2003 by H-ⅡA rocket #5. The objective of these satellites was to collect data necessary for assuring the security of Japan. Because of the nature of their specific mission, the launching was not opened to the public. Because of its mission, the self-destruct signal was sent quickly. However, the mission of the Intelligence Satellite can not be achieved by only a single satellite, and so the security of our country can not be assured until the successful launch of H-ⅡA rocket #7.

(2) H- ⅡA rocket engine and Solid Rocket Booster

H-ⅡA is a two stage rocket having the capacity to launch a four-ton payload into orbit. The rocket consists of first and second stage engines and sub-rockets (a solid rocket booster and a solid sub-booster).

・ The first stage engine (LE-7) is a large-scale LOx/LH_2 engine with two combustion cycles.

・ The second stage engine (LE-5) is also a LOx/LH_2 engine

・ The solid rocket booster (SRB-A) is a large-scale engine with a poly-butadiene related propellant. H-ⅡA rocket is equipped with two SRB-A.

・ The solid sub-booster (SSB) is an engine with a poly-butadiene related propellant. H-ⅡA rocket is equipped with either two or four SSB depending on its mission.

(3) Erosion/Corrosion

On August 9th, 2004, steam eruption from a pipe of an atomic power plant occurred at Mihama, Fukui Prefecture. The cause of the burst was a local reduction of the pipe thickness due to erosion and corrosion.

This phenomenon was the same as that of CFRP in the case of the launching failure of H-ⅡA rocket #6. The local erosion of CFRP occurred through the combination of chemical corrosion by the combustion gas and mechanical erosion.

Therefore, it can be concluded that local thickness reduction occurs both in metallic materials and CFRP by erosion and corrosion. The prediction of the thickness reduction rate is not easy, and a poorly predicted thickness reduction can be the cause of leakage.

10. Information Source

(1) On the Investigation of Failure of H-ⅡA #6 Rocket Launching and the Countermeasures for Future, Space Development Commission of Japan (June 9th, 2004).

(2) Report of Specialist Board on Revision of H-ⅡA Rocket, Investigation Group on Revision of H-ⅡA Rocket, Investigation Board of Space Development Commission of Japan(September 2nd, 2004).

11. Primary Scenario

01. Unknown Cause

02. Occurrence of Unknown Phenomenon

03. Insufficient Analysis or Research

04. Insufficient Prior Research

05. Usage

06. Operation/Use

07. Rocket launching

08. Bad Event

09. Thermo-Fluid Event

10. Combustion gas

11. Failure

12. Abrasion

13. Erosion

14. Secondary Damage

15. External Damage

16. Leaks

17. Fires

18. Malfunction

19. Poor Hardware

20.Mmalfunction of control system

21. Fail of SRB separation

22. Failure

23. Large-Scale Damage

24. Crashes

25. Fail of rocket launching

26. Loss to Organization

27. Social Loss

28. Damage to Society

29. Social Systems Failure

30. Damage to social security

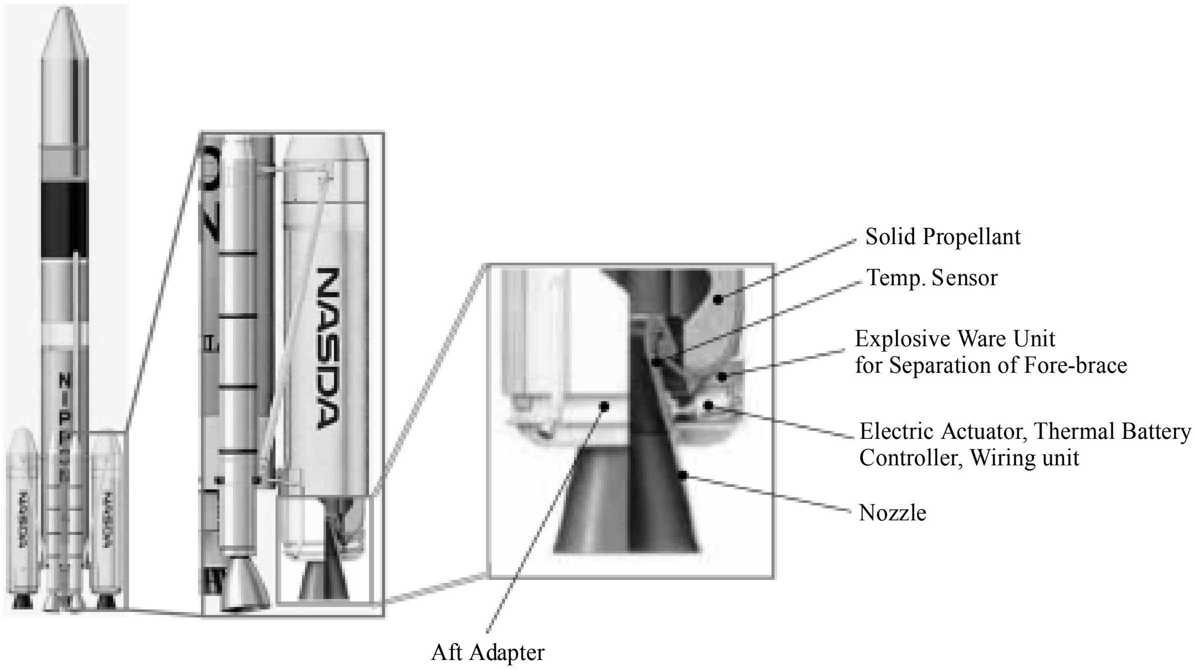


Fig. 1 H-ⅡA Rocket and SRB-A.

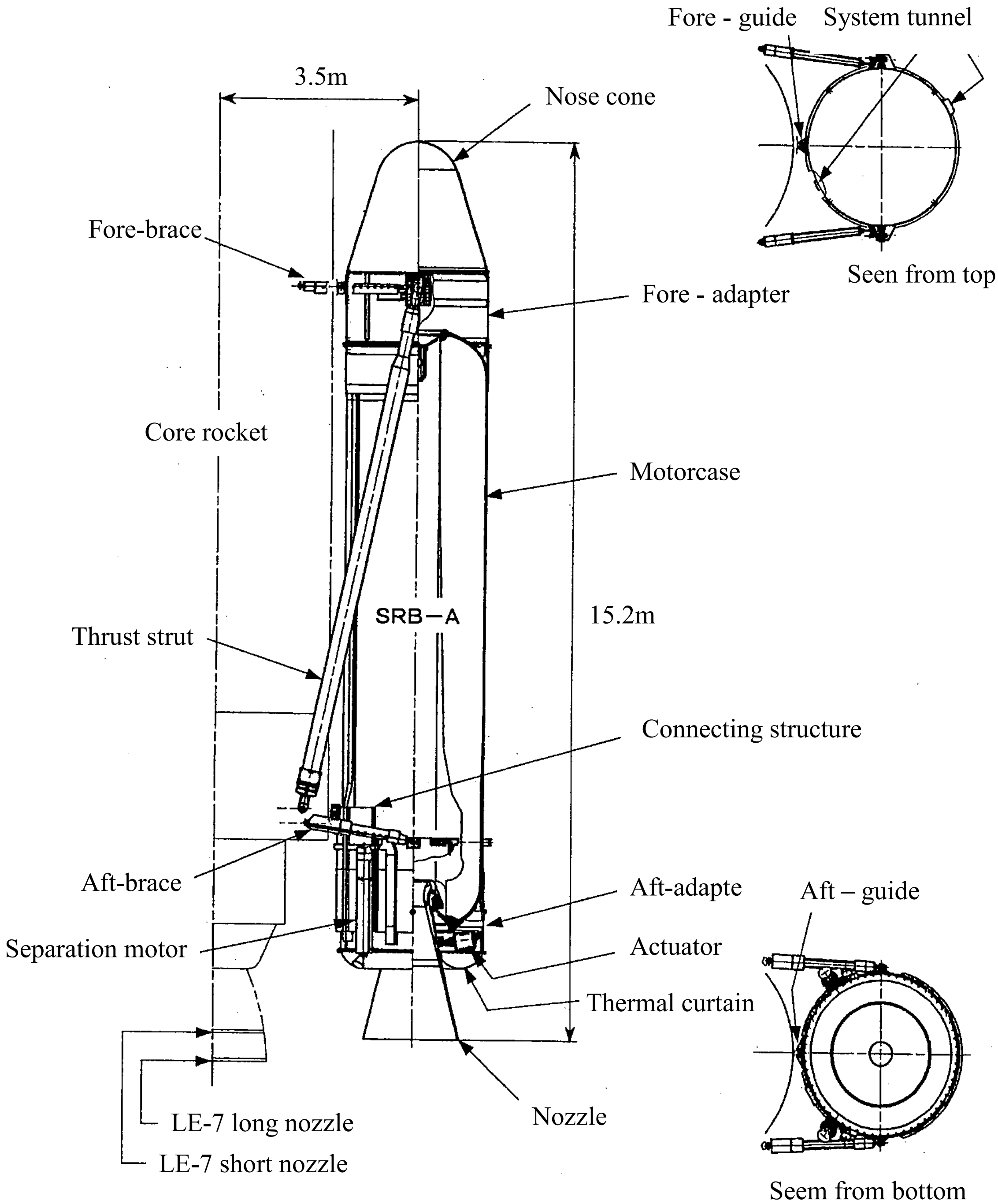
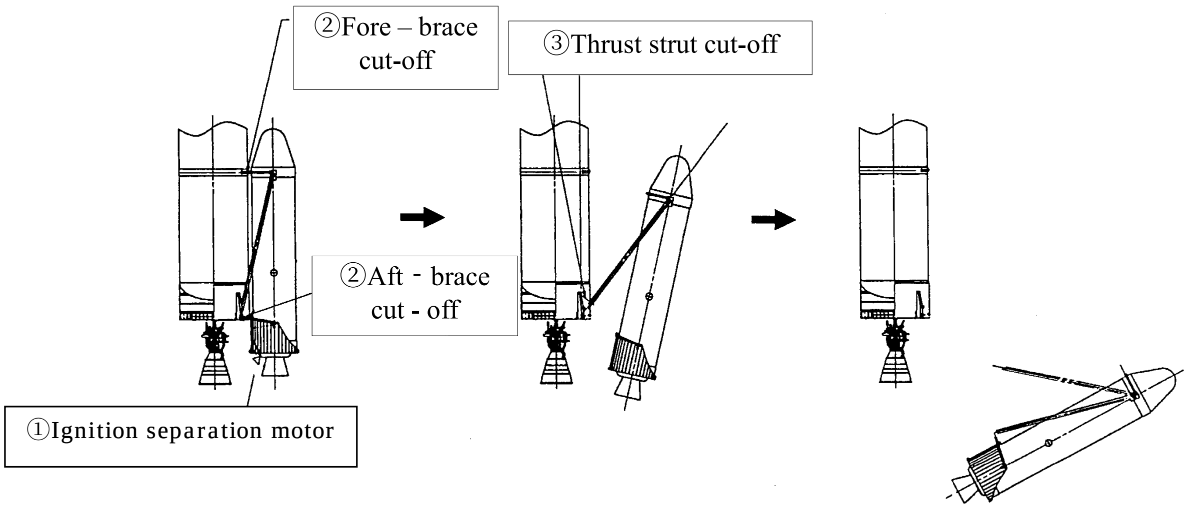


Fig. 2 Structure of SRB-A.



Ignition separation motor/ Brace cut-off

【Thrust strut cut-off】

SRB - A separation complete

Event T	ime lag(sec.)
Ignition separation motor	-0.1
Fore/Aft Brace cut-off	0
Thrust strut cut-off	1.4

Fig. 4　Separation Concept of SRB-A.

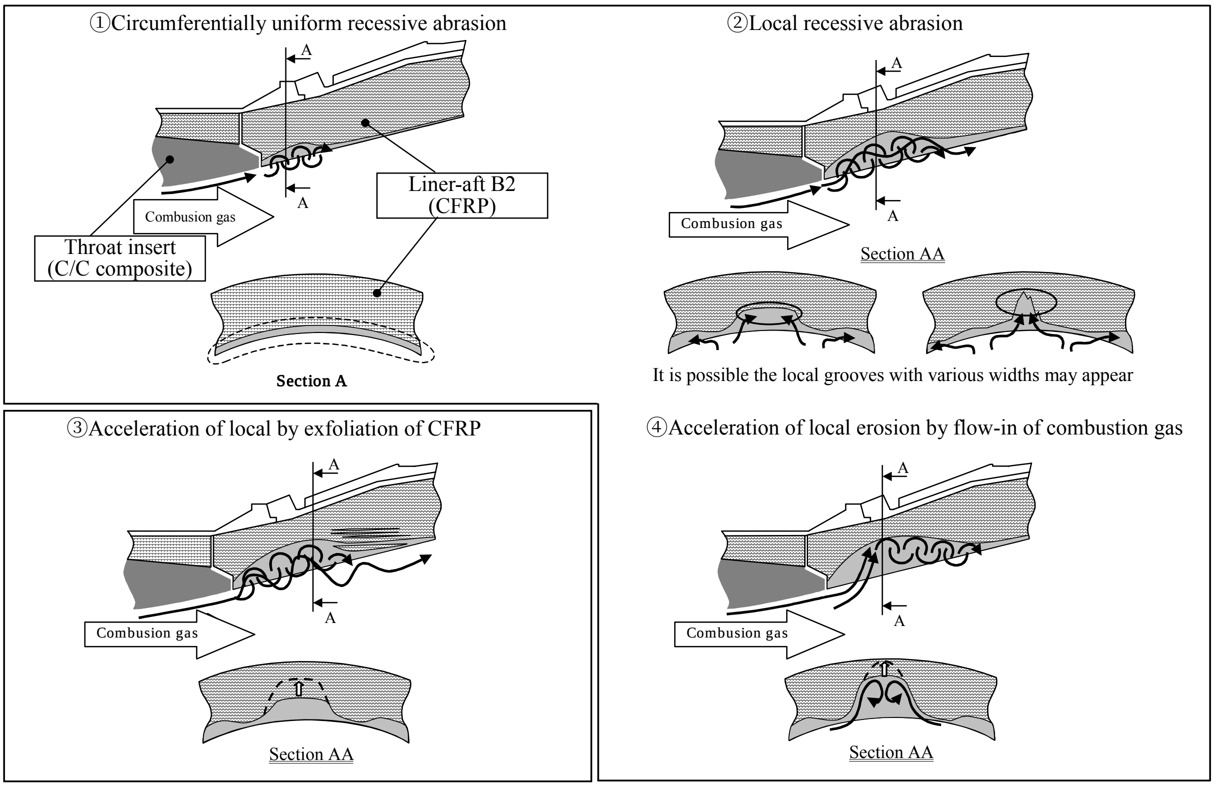


Fig. 5 Acceleration Process of Local Erosion.