Failed Launch of H-II Rocket No. 5
February 21, 1998 at the Tanegashima Space Center

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National Space Development Agency of Japan (NASDA) launched COMETS, the Communication and Broadcasting Engineering Test Satellite by its 5th H-II launch vehicle, from the Tanegashima Space Center on February 21, 1998.
The first firing of the second-stage engine following the first-stage main engine completed normally. The second burning time period of the second-stage engine was shorter than scheduled, which was caused by gas leaking from the combustion chamber of the LE-5A second stage, overheating engine parts and damaging the electrical system in the engine control box (ECB), resulting in the engine's premature shutdown.
The H-II launch vehicle released COMETS at the scheduled time, but at a wrong apogee altitude. While the perigee altitude was close enough to the altitude of the planned release point, the apogee altitude was 1,902 km, a lot lower than the planned altitude of 35,976 km. It failed to place the COMETS satellite into the correct orbit

1. Event

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2. Course

NASDA launched COMETS, the Communication and Broadcasting Engineering Test Satellite by its 5th H-II launch vehicle, from the Yoshinobu Launch Site of the Tanegashima Space Center at 16:55 JST on February 21, 1998. It was launched with the azimuth of 92.5 degrees over the Pacific Ocean (with the true north at 0 degrees, 92.5 degrees in the clockwise direction pointing almost to the west).
The weather was rainy with a northeast wind of 8.7m/sec. and temperature of 15 degrees C.
The first-stage main engine and the solid rocket booster fired normally. The solid rocket booster, the satellite fairing and the first-stage rocket were separated at 96 seconds, 243 seconds and 356 seconds respectively after liftoff.

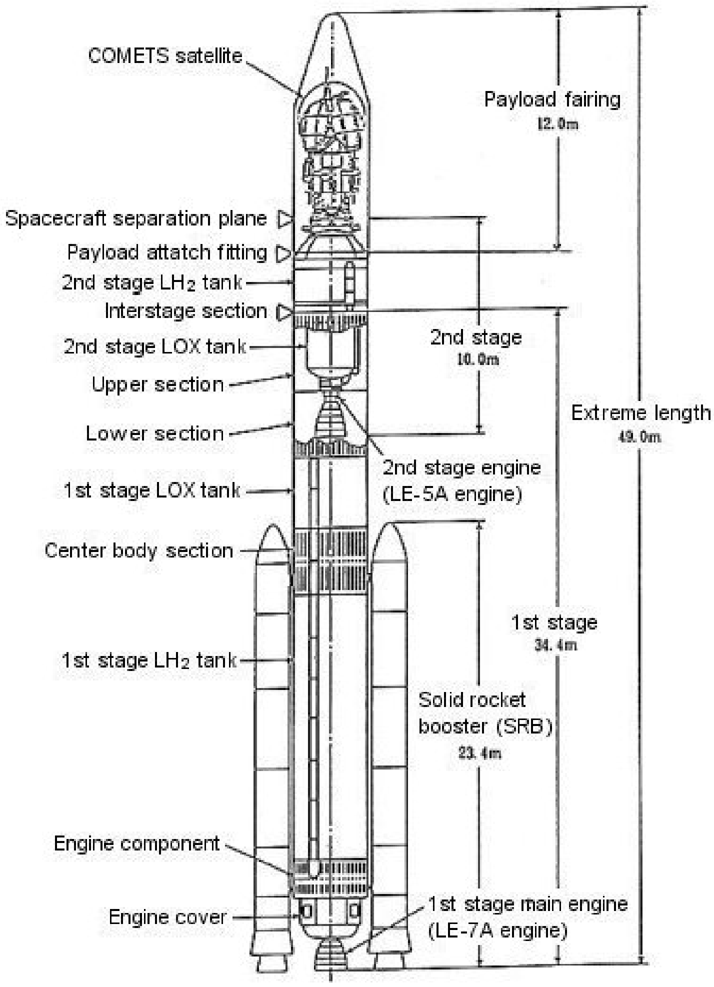

Figure 1. Schematic Diagram of NASDA's H-II Rocket (No. 5) [1]

The first firing of the second stage engine began at 362 seconds after liftoff. All including the guidance control went normally as planned until the first firing of the second stage engine stopped 672 seconds after liftoff.

The second firing of the second-stage engine started 1,410 seconds after liftoff. It was designed to continue firing until 1,598 seconds after liftoff; however, a series of malfunctions occurred at about 1,450 seconds after liftoff (40 seconds after the start of the second firing). The second firing of the second-stage engine stopped 1,457 seconds after liftoff (47 seconds after the start of the second firing).

The H-II launch vehicle stayed coasting by inertia for the remaining firing duration, then released COMETS near the scheduled time of 1,638 seconds after liftoff.

The COMETS satellite was released at the perigee altitude of 246.2km, which was close to the planned altitude of 250km, however, at the apogee altitude of 1,902 km, which was a lot lower than the planned altitude of 35,976 km. Despite a successful separation from the rocket, COMETS failed to enter the geostationary transfer orbit.

3. Cause

Figure 2 shows the combustion chamber of the second stage LE-5A engine, and Figure 3 its cross section.

(1) Loss of engine thrust

Hot combustion gas penetrated the weight-saving windows on the LE-5 engine's nozzle skirt (Figure 2). This gas cut the electrical power wiring to the engine control box (ECB) located near the weight-saving windows on the engine nozzle skirt. The loss of electrical power closed the mail valve to shutdown the engine.

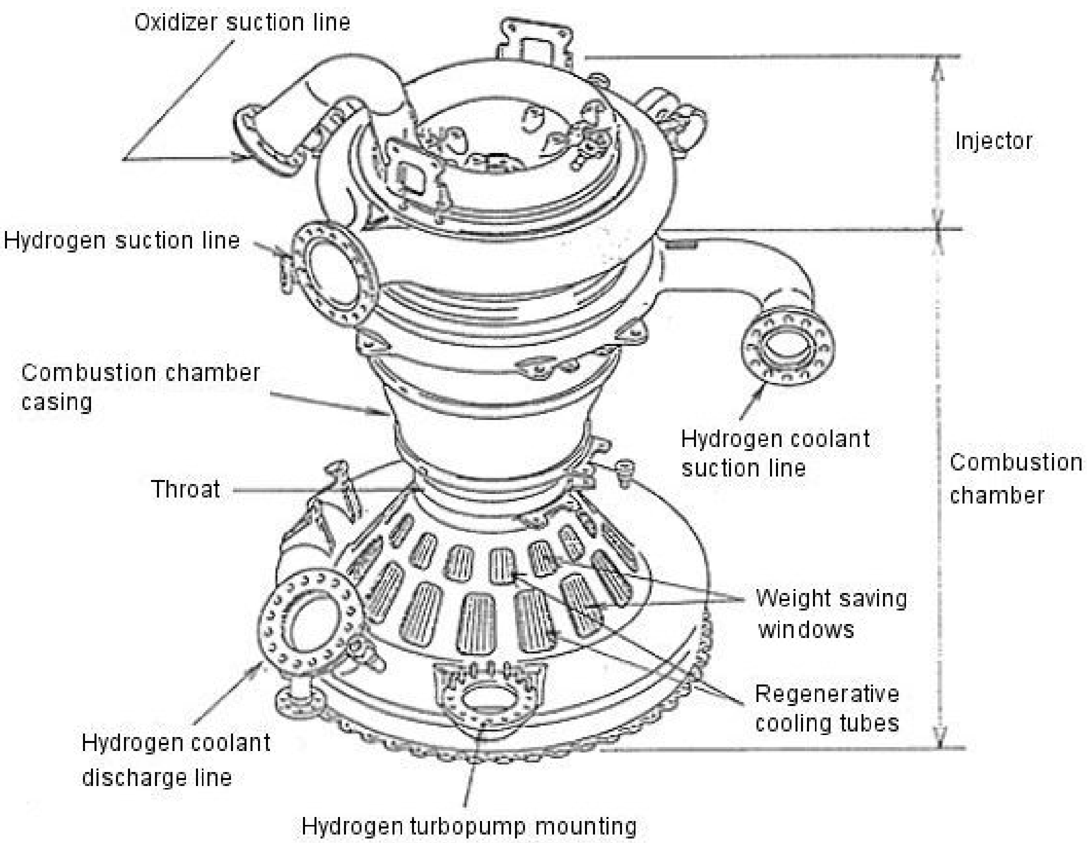

Figure 2. LE-5A Engine (Exterior) [1]

(2) Combustion gas leakage

At about 41 seconds into the second firing of the second-stage engine, a crack in the brazing caused hot combustion gas to heat up cooling tubes in the lowest part of the combustion chamber. One second later, the overheated tubes buckled, allowing a large amount of combustion gas to escape through gaps between the brazed tubes (0.17kg/sec through a 5cm^2 area). As the combustion pressure decreased, liquid hydrogen leaked from the damaged cooling tubes of the cooling system (0.04kg/sec). These gases heated the ECB electrical power wiring to above 1,500 degrees C. The electrical power supply was cut off at 46 seconds into the second firing of the second-stage engine.

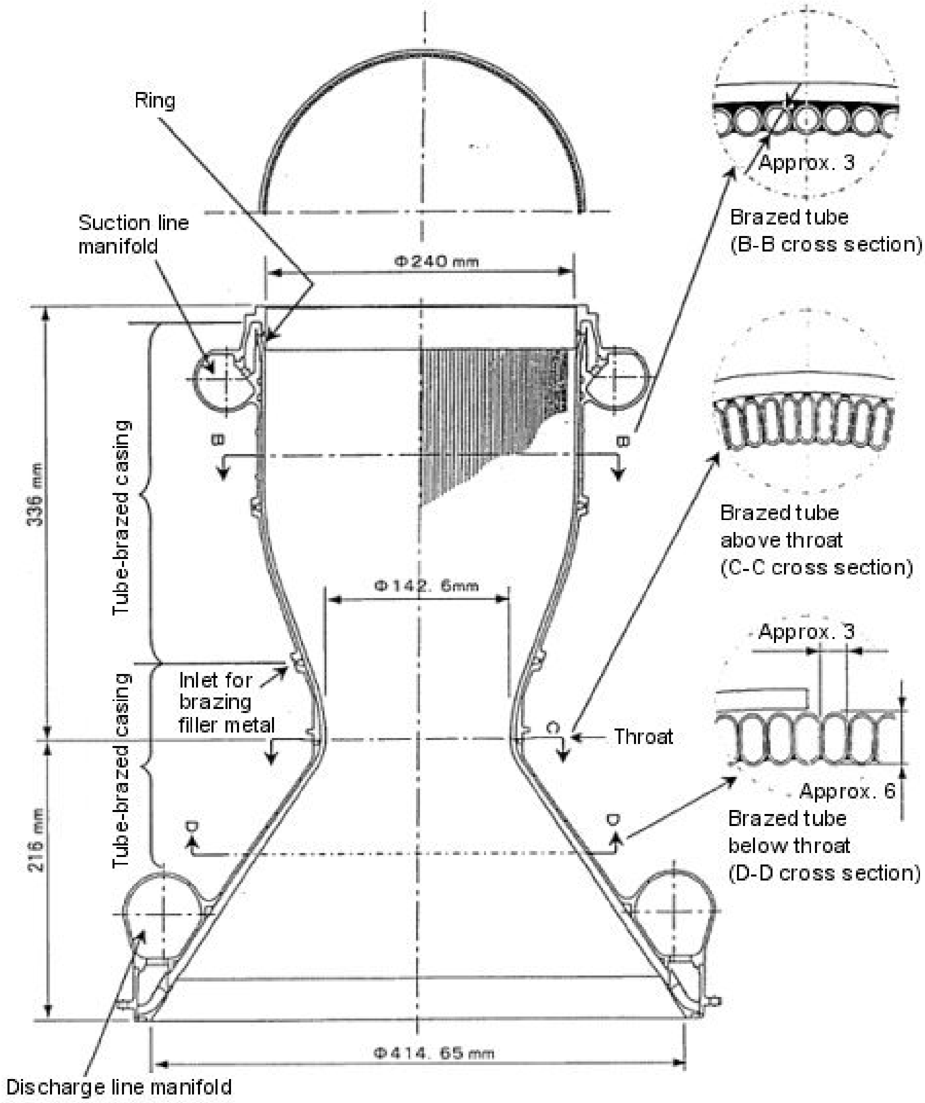

Figure 3. LE-5A Engine Diagram [1]

(3) There are two possible explanations to how the brazing failed.

a. The brazing of the tubes was relatively weak at the center of weight-saving windows where brazed metal was only present on the inside. In the second captive firing test of the LE-5A engine, cracks started from the outside and which then developed into openings at the end of the first firing of the second-stage engine. Liquid hydrogen started leaking and grew bigger during the second firing of the second-stage engine. (Probable cause I)

b. Shape irregularity increased at the center of weight-saving windows where cooling tubes were not brazed to the casing. The structure could not withstand multiple firings, and the overheated tubes buckled during the second firing of the second-stage engine, allowing a large amount of combustion gas to leak through gaps between brazed tubes. (Probable cause II)

In either case, variations (voids and fillets) in the brazing material and the brazing metal brittleness at the temperature of 500 degrees C also contributed to the failure.

4. Immediate Action

NASDA performed telemeter data analysis, fault tree analysis and confirmation tests to find the cause of the engine's premature shutdown. Their findings were as follows:

(1) Propellant leak from the combustion chamber caused the engine's premature shutdown.
(2) Propellant leaked from the damaged cooling system of the combustion chamber.
(3) Propellant penetrated brazing between the nozzle skirts cooling tubes located in the lowest part of the combustion chamber.

NASDA then performed the following tests to reevaluate brazing in the combustion chamber of the engine installed on its 7th H-II launch vehicle, which was scheduled to be launched the next.

- X-ray inspection
- Visual inspection: Fillet brazing of cooling tubes in the interior of the combustion chamber casing
- Visual inspection: Fillet brazing of cooling tubes around the windows on the nozzle skirt in the exterior of the combustion chamber casing
- X-ray CT inspection of the combustion chamber

Inspections did not find faulty brazing that might have caused propellant leak.

5. Countermeasure

Improvement and through inspections were made to the brazing and the nozzle structure of the LE-7A engines of the 7th H-II launch vehicle and the LE-5A engines of the H-IIA launch vehicles (the successor aircraft to the H-II launch vehicle) to ensure the higher reliability of the engines.
A low-pressure firing was reported during the second captive firing test of the LE engine; however, it was due to a leak detector jig left in the engine. Turbine propellant was unable to flow into the engine through the valve, which was taken up by the jig. It was only the tank pressure that fed propellant to the engine, which resulted in low-pressure combustion. The testing procedures were modified to enforce the placement of a red tag on an engine that has a leak detector installed. A red tag is to be always stored with a leak detector.

6. Summary

The H-II launch vehicle is a two-stage rocket powered by liquid-hydrogen/liquid-oxygen engines, capable of launching a 4-ton class satellite into geostationary transfer orbit. It is equipped with two huge solid rocket boosters (SRB), which along with the vehicle's main engine provide jump in thrust during the first stage thrust.

The 1st stage LE-7 engine is a large two-burning cycle engine that burns liquid oxygen and liquid hydrogen. It was developed based on the LE-5 technology.

The 2nd stage LE-5A engine is an improved LE-5 engine whose propellants are liquid hydrogen and liquid oxygen. It offers higher performance and reliability than the LE-5 engine. The LE-5A engine can reignite so that the H-II launch vehicle makes a two-step journey to geosynchronous transfer orbit.

The advanced SRBs are polybutadiene composite solid propellant boosters. Unlike the solid strap-on boosters (SSB) equipped by the predecessor aircrafts such as the H-I launch vehicle, SRBs have hydraulically steerable nozzles that enable guidance and control of the first stage.

Five earlier H-II launches and missions were all successful. The firings of the 2nd stage LE-5 and LE-5A engines were completed as scheduled during the past 14 launches of the H-I and the H-II launch vehicles. The H-II launch failure in 1998 occurred after number of successful launches. Engineers may have been too confident about their technology. A good example is the careless mistake during the captive firing test.

The second captive firing test of the LE-5A engine was aborted 22.4 seconds after the engine started firing, because the combustion pressure did not reach the maximum.

Engineers later found that the low-pressure firing was due to a leak detector still connected to the waist intake valve of the engine by mistake. Turbine propellant was unable to flow into the engine through the valve. It was only the tank pressure that fed propellant to the engine, resulting in low-pressure combustion. It was a simple mistake that held up the firing test and ultimately caused the firing failure of the engine during the mission. Officials later explained that a leak detector was used to make sure that the combustion chamber and the nozzle skirt was cooled down after the firing test.

Unevenness (voids and fillets) of the brazing occurred during the engine manufacturing may have also contributed to the brazing failure.

7. Knowledge

(1) Compared to machining, brazing process is likely to produce unevenness in fillet size and braze joints. It is necessary to properly design requirements and parts for brazing to maintain an acceptable quality. The same applies to welding.

(2) A performance test must be performed with an accurate test method and without oversight to avoid producing an inaccurate result. An inadvertent oversight caused the failure of the firing test in this case. Inaccurate test methods also produce inaccurate test results such as failure and performance degradation.

(3) Continued success incubates potential failure, because it tends to lead to over confidence and less subsequent mindfulness. A development team must tighten its parameters and improve its management,

especially when it achieved a breakthrough in its project. The same applies corporate management.

8. Background

The H-II launch vehicle was manufactured 100% domestically in Japan. Based on the achievements of its predecessor aircrafts, it was designed to offer low-cost and high reliability for launching of geostationary satellites and payloads into orbits.

In 1984, NASDA started the full-scale development of the H-II launch vehicle and its launch site. After completing conceptual design, system design, basic design and detailed design, NASDA conducted ground system tests using the ground test vehicle (GTV) for about 6 months from September 1991 until March 1992.

Before the launch of the 5th vehicle in 1998, the H-II launch vehicle was utilized in a total of 5 launches since the first successful launch in 1994 (No. 1 for experimental missions on February 4, 1994; No. 2 for an experimental mission on August 28, 1994; No. 3 for an experimental and satellite missions on March 18, 1995; No. 4 for a satellite mission on August 17, 1996; and No. 6 for observation and test satellite missions on November 28, 1997).

While scheduled launch of the No. 5 (COMETS) was postponed due to malfunction of the Advanced Earth Observing Satellite (ADEOS) in 1997, the No. 6 was launched as scheduled. This caused the launch order to disagree with the vehicle numbering.

References

[1] National Space Development Agency of Japan (1998) “Launch Failure of the 5th H-II Launch Vehicle / the Communications and Broadcasting Engineering Test Satellite (COMETS) “Kakehashi””, http://www.nasda.go.jp/press/1998/06/comets_980611_01_j.html#1