AI2008-3

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

AIR NIPPON CO., LTD.
BOEING 737-500, JA8419
OVER THE SEA APPROXIMATELY 60 NM SOUTHEAST OF KUSHIMOTO VORTAC
JULY 5, 2006

June 27, 2008

Aircraft and Railway Accidents Investigation Commission
Ministry of Land, Infrastructure, Transport and Tourism

The investigation for this report was conducted by Aircraft and Railway Accidents Investigation Commission, ARAIC, about the aircraft serious incident of AIR NIPPON CO., LTD. BOEING 737-500, JA8419 in accordance with Aircraft and Railway Accidents Investigation Commission Establishment Law and Annex 13 to the Convention of International Civil Aviation for the purpose of determining cause of the aircraft accident and contributing to the prevention of accidents and not for the purpose of blaming responsibility of the accident.

This English version report has been published and translated by ARAIC to make its reading easier for English speaking people those who are not familiar with Japanese. Although efforts are made to translate as accurate as possible, only the Japanese version is authentic. If there is difference in meaning of the texts between the Japanese version and the English version, texts in the Japanese version are correct.

Norihiro Goto,
Chairman,
Aircraft and Railway Accidents Investigation Commission

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

AIR NIPPON CO., LTD.
BOEING 737-500, REGISTRATION JA8419
OVER THE SEA APPROXIMATELY 60 NM SOUTHEAST OF
KUSHIMOTO VORTAC
AROUND 08:10 JST, JULY 5, 2006

June 20, 2008
Adopted by the Aircraft and Railway Accidents Investigation Commission
(Air Sub-committee)

Chairman	Norihiro Goto
Member	Yukio Kusuki
Member	Shinsuke Endo
Member	Noboru Toyooka
Member	Yuki Shuto
Member	Akiko Matsuo

1. PROCESS AND PROGRESS OF THE SERIOUS INCIDENT INVESTIGATION

1.1 Summary of the Serious Incident

The event covered by this report is classified under the category of "Abnormal Cabin Depressurization" as stipulated in Clause 10 (at the time of the occurrence; later amended to Clause 11 effective as of October 1, 2006), Article 166-4 of the Civil Aeronautics Regulations of Japan.

On July 5 (Wednesday), 2006 at 07:24 JST, a Boeing 737-500 airplane, JA8419, operated by Air Nippon Co., Ltd. took off Fukuoka Airport as All Nippon Airways scheduled flight 2142.

At about 08:10, while flying at approximately 37,000 ft approximately 60 nm southeast of Kushimoto VORTAC, a cabin depressurization warning was displayed and the oxygen masks in the cabin were automatically deployed. The aircraft made an emergency descent and, at 09:09, landed on Chubu International Airport.

Of the 46 persons on board the aircraft, including the Pilot in Command, 4 other crewmembers and 41 passengers, no one was injured.

1.2 Outline of the Serious Incident Investigation

1.2.1 Investigation Organization

On July 5, 2006, the Aircraft and Railway Accidents Investigation Commission (ARAIC) assigned an investigator-in-charge and another investigator for the investigation of this serious incident.

1.2.2 Representatives from Foreign states

Accredited representative from the United States of America, the state of design and manufacture of the aircraft, participated in the investigation of this serious incident.

1.2.3 Implementation of the Investigation

July 5 - 9, 2006	Interviews, investigation of the aircraft, and removal of related equipment
July 12 - 14, 2006	Teardown examination of the removed equipment
July 21, 2006	Inspection of equipment functions and damage conditions
July 28, 2006	Inspection of equipment damage conditions
October 5 - November 2, 2006	Analysis of deposits and detergent solution inside the pneumatic system components
January 12, 2007	Investigation to check for water ingress into the bleed air system components during engine washing
March 30 - April 5, 2007	Investigation to confirm equipment functions

1.2.4 Comments from the Parties Relevant to the Cause of the Serious Incident

Comments were collected from the parties relevant to the cause of the serious incident through interviews.

1.2.5 Comments from the Participating State

Comments were invited from the participating state.

2. FACTUAL INFORMATION

2.1 History of the Flight

On July 5, 2006, a Boeing 737-500, registered JA8419 (hereinafter referred to as "the aircraft"), operated by Air Nippon Co., Ltd. (hereinafter referred to as "the company"), was flying as All Nippon Airways scheduled flight 2142 from Fukuoka Airport to Narita International Airport.

The aircraft took off Fukuoka Airport at 7:24 with 46 people on board, including the Pilot in Command (PIC), 4 other crewmembers and 41 passengers. In the cockpit, the PIC occupied the left seat as pilot flying (primarily responsible for aircraft maneuvering tasks) and the First Officer occupied the right seat as pilot not flying (primarily responsible for non-maneuvering tasks).

The flight plan submitted to the Air Traffic Management Center, Fukuoka Area Control Center of the Ministry of Land, Infrastructure, Transport and Tourism is as outlined below.

Flight rules:	Instrument flight rules (IFR)
Departure point:	Fukuoka Airport
Estimated off-block time:	07:10
Cruising speed:	439 kt
Cruising altitude:	FL370
Route:	TAE (Oita VOR) - V37 (Airway) - KEC (Kushimoto VORTAC) - A1 (Airway) - ORGAN (Reporting point) - Y231 (RNAV route) - MAMAS (Reporting point) - ANGEL (Reporting point) - VENUS (Reporting point)
Destination:	Narita International Airport
Estimated flight time:	1 h and 26 min
Alternate aerodrome:	Tokyo International Airport
Quantity of loaded fuel as expressed in endurance:	3 h and 37 min

2.1.1 History of the Flight based on Records of the Digital Flight Data Recorder, Cockpit Voice Recorder and ATC Radio Communications

The history of the flight is summarized below, based on the records of the digital flight data recorder (hereinafter referred to as "DFDR"), the cockpit voice recorder (hereinafter referred to as "CVR") and ATC radio communications.

07h42m17s	The aircraft reached Flight Level*[1] (hereinafter referred to as "FL") 370 that had been approved by the Tokyo Area Control Center (hereinafter referred to as "Tokyo Control").
08h09m06s	While flying at FL370, the throttle levers were retarded.
08h10m05s	While flying at FL370, the master caution light and the system annunciator's AIR COND light came on.

*1: Flight Level means a surface of constant atmospheric pressure, which is based on standard sea level pressure of 29.92 in Hg. In Japan, altitudes at or above 14,000 ft are normally indicated by Flight Levels in hundreds of feet.

08h10m21s	While flying at FL370, the crew requested clearance from Tokyo Control to descend to FL290 due to a problem with the cabin pressurization system.
08h10m31s	Tokyo Control cleared the descent to FL290.
08h10m40s	The aircraft began descending.
08h10m44s	The cabin altitude warning horn sounded.
08h10m50s	The crew requested clearance from Tokyo Control for an emergency descent due to cabin depressurization.
08h10m56s	Tokyo Control cleared the emergency descent.
08h13m27s	The oxygen masks in the cabin were automatically deployed.
08h17m30s	The aircraft reached 10,000 ft.

(See Figure 1.)

2.1.2 Flight Crew Statements on History of the Flight

(1) PIC

After finishing the briefing in the dispatch room, I conducted an exterior check of the aircraft and received a maintenance mechanic's report stating that no abnormalities were found with the aircraft. I determined that there was nothing that would pose any problems and accepted the aircraft.

During the phase from engine start to takeoff, everything operated normally including the air conditioning system.

After takeoff, during cruise at FL370, when we were about over Matsuyama, a cabin attendant (hereinafter referred to as "CA") told us that she felt the cabin air a bit cold and requested raising the temperature. The First Officer adjusted the temperature control.

I then felt that the temperature rise was less quick than usual. Warm air usually comes out as soon as the control knob (mix valve) is moved to a higher temperature, but at that time I felt only a little difference of air temperature.

When we passed Shikoku region and were about to reach the Kii Peninsula, considering on-board radar indication of developed cloud echo we requested change of heading to Tokyo Control and flew around south of the echo region. I thought that we would have no more echo region by the time we would reach abeam Kushimoto and that, after passing that point, we would make a request for direct flight to the next point. We then flew the direct course to SAKIT with clearance from Tokyo Control. During that portion of the flight, the aircraft was shaken by turbulence and we immediately decreased our airspeed using the speed selector on the MCP (Mode Control Panel).

At about 60 nm southeast of Kushimoto, the master caution light and the system annunciator's AIR COND light came on. I checked the overhead panel and found that both of the two BLEED TRIP OFF lights illuminated. This indicated that the bleed air systems from both engines had stopped supplying bleed air.

The duct pressure should normally be about 38 psi at FL370, but it was as low as about 5 psi when the master caution light came on.

Concerns about the cabin altitude arose in my mind, so I checked and found that the cabin altitude had risen to about 9,000 ft. It should be about 8,000 ft when flying at about FL370.

I knew from a previous occurrence that using the wing anti-ice system when flying at FL370 usually causes a substantial demand for bleed air, and this requires the use of 9th-stage bleed air, which may cause bleed air at too high a temperature to cool down adequately to flow through the duct and may ultimately cause a “bleed trip” condition.

We were not using the wing anti-ice system at that time.

Expecting a shortage of oxygen inside the aircraft since the cabin altitude continued rising, I ordered the First Officer to put on an oxygen mask.

It was at that time that I decided to make an emergency descent.

A short time after receiving ATC clearance and starting the emergency descent, the horn for the “cabin altitude warning system” began sounding, which warns of cabin altitude exceeding 10,000 ft, so we continued to descend to 10,000 ft. Being in an emergency, we also set the transponder to the emergency code.

Subsequently, because the cabin altitude should have exceeded 14,000 ft, the passenger address system automatically started broadcasting a pre-recorded emergency-descent cabin announcement (hereinafter referred to as “pre-recorded announcement”) and, at the same time, the oxygen masks were deployed automatically. During the emergency descent to 10,000 ft, I checked the cabin altitude rate of climb and found it considerably large.

While hearing the passenger address (hereinafter referred to as “PA”), I noticed the CA saying, “Please put on your masks” between the pre-recorded announcement cycles.

We completed the checklist upon reaching 10,000 ft and, as the cabin altitude was then also 10,000 ft, I instructed the First Officer to take off his oxygen mask and I took mine off also, and I cancelled the emergency code setting. I then gave the CAs permission to take off their oxygen masks. The CA’s answer to my question about the situation in the cabin was that there were no problems to report with none of the passengers suffering from hypoxia.

We requested to Tokyo Control a holding flight, before changing the destination, which was cleared by Tokyo Control.

After completing the preparations for approach, I made an announcement over the PA, saying “We have made an emergency descent to a safe altitude because of a problem with the pressurization system that had developed while cruising at 37,000 ft. We have changed our destination to Chubu International Airport, the nearest airport, and are heading there now.”

(2) First Officer

After takeoff as I was going to turn off the seat belt sign, I told the CAs, “The seat belt sign will be turned off, but shaking is always possible since we are flying in clouds. So, you should be duly careful during passenger service.” After a while, a CA told us, “Please raise the cabin temperature a bit as it is cold in the cabin.” I then moved the temperature control on the overhead panel by, I think, approximately one unit toward a warmer temperature. The temperature did not rise quickly, but a while later it rose to 22 - 23°C, a temperature that made me feel a little warmer than before.

When the master caution light and the system annunciator's AIR COND light came on during the flight, I looked at the overhead panel and found that both of the two "BLEED TRIP OFF" lights illuminated. I operated the pack switches on the overhead panel, but this did not change the situation at all. I checked the cabin altitude and found that it was rising gradually, reaching 9,400 - 9,500 ft in contrast with the normal cabin altitude of about 8,000 ft at approximately FL370.

As I was told by the PIC, "Put on your oxygen mask. We are going to make an emergency descent," I put it on, and then, as required by the procedure, turned on the seat belt sign and set the engine start switch to the "continuous" position. We declared an emergency to Tokyo Control and started descending after receiving clearance. Shortly after, while we were descending, I heard the pre-recorded announcements in English, Chinese and Japanese, "Put on your oxygen masks," and I also heard the CAs loudly giving the same instructions to the passengers. The speed at that time was 310 kt.

Finding that the cabin altitude was equal to the actual altitude when we reached 10,000 ft, I told the CAs, "We are now at a safe altitude, so the masks may be taken off. Please let me know about the conditions in the cabin." Nothing abnormal was found.

(3) CAs (Mainly the purser's statement supplemented by other CAs' statements)

During the crew briefing held in the aircraft prior to departure, the PIC told us that the aircraft would shake due to a seasonal rain front and this would necessitate keeping the seat belt sign on for at least about 30 min.

We felt a little shaking during the climb but the seat belt sign went off in under 30 min.

Immediately before starting passenger service, it was cold in the cabin so that I asked the flight crew to raise the cabin temperature. The First Officer responded, "That's what I expected. I have been trying to bring up the temperature but it refuses to rise." All CAs felt cold.

After finishing the passenger service, we all sat in our seats when the seat belt sign came on at about 08:13 - 08:14, although we were told that we would start descending at 08:28.

A minute or two after we sat in our seats, the oxygen masks deployed with a thud in the cabin, but there wasn't any noticeable problem at that time. We did not experience ear popping or any further drop in cabin temperature. A while later, pre-recorded announcements started in Japanese, English and Chinese in sequence. I instructed the passengers, saying, "Please put on your oxygen masks immediately." However, since my voice was drowned out by the pre-recorded announcements, I also gestured to the passengers to put on the masks. The passengers were slow to respond and they seemed to be only faintly aware of the emergency situation. However, they gradually started putting on their masks, probably because they realized that they should when they saw the CAs wearing masks and heard the continuously repeated pre-recorded announcements.

I then made announcements over the PA a couple of times in Japanese and English with a mask on my face. At that time, I saw that all passengers were wearing masks.

A while later, I was told by the flight crew, "We are now at a safe altitude, so the masks may be taken off." I was also asked about the situation in the cabin. I responded, "The cabin is perfectly calm."

We started checking the passengers, and found that no one appeared upset and the entire cabin was calm. No one complained of feeling sick and there was nothing abnormal in the cabin. When I was told that we would be flying to Chubu International Airport a while later, I made an announcement to that effect, which was soon followed by an announcement by the PIC saying, "Because of a problem with the cabin pressurization system, we are going to fly to Chubu International Airport."

This serious incident occurred at about 08:10, over the sea (lat. 33º21'N, long. 136°42'E) about 60 nm southeast of Kushimoto VORTAC.
(See Figures 1 and 4.)

2.2 Injuries to Persons

None

2.3 Damage to the Aircraft

There was no damage to the aircraft.

2.4 Crew Information

(1) PIC	Male, aged 33	
Airline transport pilot certificate (airplane)		October 6, 2005
Type rating for Boeing 737		July 21, 1998
1st class aviation medical certificate		
Validity		Until September 11, 2006
Total flight time		5,300 h and 20 min
Flight time in the last 30 days		51 h and 53 min
Total flight time on the aircraft type		5,065 h and 20 min
Flight time in the last 30 days		51 h and 53 min
(2) First Officer	Male, aged 59	
Commercial pilot certificate (airplane)		October 9, 1973
Type rating for Boeing 737		December 27, 1994
1st class aviation medical certificate		
Validity		Until December 7, 2006
Total flight time		14,266 h and 49 min
Flight time in the last 30 days		52 h and 33 min
Total flight time on the aircraft type		6,943 h and 44 min
Flight time in the last 30 days		52 h and 33 min

2.5 Aircraft Information

2.5.1 Aircraft

Type	Boeing 737-500
Aircraft serial number	27430
Date of manufacture	May 10, 1995
Certificate of airworthiness	No. To-10-588
Validity	The period through which the maintenance manual (Air Nippon Co., Ltd) is applied, beginning on October 28, 1998
Airworthiness category	Airplane, Transport category
Total flight time	23,685 h and 58 min
Time in service since the last periodical check (C07 check on June 30, 2006)	20 h and 57 min

(See Figure 3.)

2.5.2 Engines

Type	CFM International Model CFM56-3C1	
Engine No.	No. 1	No. 2
Engine serial No.	858417	858198
Date of manufacture	June 28, 1996	March 27, 1995
Total time in service	21, 055 h and 49 min	19,279 h and 25 min
Time in service since the last periodical check (C07 check on June 30, 2006)		20 h and 57 min

2.5.3 Weight and Balance

When the serious incident occurred, the aircraft's weight and position of center of gravity are estimated to have been 96,400 lb and 17.1% MAC, respectively, both of which are estimated to be within the allowable ranges (maximum landing weight of 110,000 lb, and 5.0-29.5% MAC based on the estimated aircraft weight at the time of the serious incident).

2.5.4 Fuel and Lubricating Oil

The fuel was aviation fuel JET A-1 and the lubricating oil was BP Turbo Oil 2380.

2.5.5 Information on the Aircraft's Cabin Altitude Warning System

The cockpit of the aircraft was equipped with a cabin altitude warning system. The system provides an audible alarm when the cabin altitude exceeds approximately 10,000 ft, and the alarm stops when the cabin altitude drops back below approximately 10,000 ft, or when the cutout switch on the overhead panel is manually pushed.

2.5.6 Information on the Aircraft's Cabin Oxygen System

The cabin of the aircraft was equipped with an oxygen supply system. When the cabin altitude reaches approximately 14,000 ft, a pressure switch trips, and causes the oxygen masks in the cabin to deploy automatically. When the system is activated, the following lights come on in the cockpit: the "Pass Oxy ON" light on overhead panel, the system annunciator "OVERHEAD" light and the master caution light on the glare shield.

2.6 Information on the DFDR and CVR

The aircraft was equipped with a DFDR (Part Number 980-4100-DXUS) of Sundstrand, U.S.A., and a CVR (Part Number 2100-1020-00) of L-3 Communications, U.S.A.

The DFDR retained records of all data of the aircraft from the takeoff at Fukuoka Airport to its landing at Chubu International Airport. However, cabin altitude related data were not included in the recorded items.

Capable of recording data for a period of up to 2 h, the aircraft's CVR retained all voice and other sound data related to this serious incident.

The DFDR data was time referenced by checking the VHF transmission keying data against the time signals recorded together with the ATC communications records.

2.7 Tests and Research for Fact-Finding

Teardown and Functional Examination of Each Component Related to the Air Conditioning System

Cockpit and cabin air temperature and pressure are controlled using the two air conditioning packs on the aircraft. The air conditioning system is supplied with part of the high-temperature, high-pressure air created by the engine compressors and taken partway through its flow (hereinafter referred to as "bleed air").

In order to examine the functions of the equipment related to the air conditioning system of the aircraft, the following components that had been installed on the aircraft at the time of the occurrence of this serious incident, were removed from the aircraft and underwent teardown and functional examination as per the company's maintenance manual, the results of which are presented below.

2.7.1 Pressure Regulator and Shutoff Valves (PRSOVs)

(1) The No. 1 valve had piston rings with the edges discolored to brown.

Shallow scores were found on the valve body and the lower section of the butterfly plate. The damage was attributable to contamination that filled the groove in the butterfly plate seal ring and prevented the seal ring from being compressed.

The inner surface of the actuator housing had scores that were caused by a piston ring set stuck due to contamination.

(2) The No. 2 valve had traces of water ingress in its actuator cover.

The valve linkage hinge was corroded with granular contamination on it.

(See Figure 2 and Photographs 1 and 2.)

2.7.2 High-Stage Valves (HSVs)

(1) The No. 1 valve had slight traces of water ingress on the inside and outside surfaces of the hollow piston actuator rod.

Traces of water ingress were found on the actuator cover.

(2) The No. 2 valve had traces of water pools on both faces of the piston actuator.

Traces of water ingress were found on the inside and outside surfaces of the hollow piston actuator rod.

The valve linkage hinge was corroded.

The outer periphery of part of the spring was worn due to interference with other parts.

(See Figure 2 and Photographs 3 and 4.)

2.7.3 High-Stage Regulators (HSRs)

(1) The No. 1 regulator had a small score on the diaphragm mounting area.

(2) The No. 2 regulator had deposits of contamination in the area around the reverse flow check mechanism on the diaphragm end side, where traces of water ingress were also found.

(See Photographs 5 and 6.)

2.7.4 Pre-coolers

(1) The No. 1 pre-cooler had been used for 7,556 h and 01 minute over 6,901 landings since the last overhaul.

Air leakage was found from a welded corner.

(2) The No. 2 pre-cooler had been used for 10,271 h and 35 min over 9,729 landings since the last overhaul.

There were openings both near the center of the ram air outlet core and in a straight-line weld, from where heavy air leakage was detected.

(3) As a result of the functional tests conducted on the No. 1 and No. 2 pre-coolers at the manufacturer, the pressure drop of the No. 1 unit (0 psi pressure drop within 10 seconds) and that of the No. 2 unit (27 psi pressure drop within 10 seconds) were both found to conform to the design standard (33 psi or smaller pressure drop within 10 seconds after applying 50 psi initial pressure).

(See Figure 2 and Photographs 7 and 8.)

2.7.5 Pre-cooler Control Valves (PCVs)

(1) Functional examination of No. 1 PCV

① The results of the functional examination conducted on the servo reference pressure regulator and actuator reference pressure regulator showed that both the servo reference pressure and actuator reference pressure did not reach the permissible range when the specified air pressure was applied.

② Examination of orifice feedback function

Servo reference pressure did not reach the permissible range when the specified air pressure was applied.

③ Examination of overall functions

The remote temperature sensor port pressure as measured with the butterfly plate moved to the “full open” position exceeded the permissible range.

In addition, the butterfly plate was found to have shifted toward the “open” side from the normal position.

(2) Teardown examination of No. 1 PCV

① Traces of water ingress and contamination deposits were found inside the actuator housing.

② The vent hole in the servo body assembly was found to be narrowed due to contamination.

③ The retainer of the actuator reference pressure regulator diaphragm was found broken into three pieces.

④ The servo reference pressure regulator had traces of water ingress on the guide set side of the guide-set-to-poppet-valve connection.

The poppet valve was found to be partially darkened due to wear.

⑤ The actuator reference pressure regulator had traces of water ingress and deposits of contamination on the guide set side of the guide-set to poppet-valve connection.

(3) Functional examination of No. 2 PCV

① The results of the functional examination conducted on the servo reference pressure regulator and actuator reference pressure regulator showed that both the servo reference pressure and actuator reference pressure exceeded the permissible range when the specified air pressure was applied.

② Examination of orifice feedback function

Servo reference pressure and remote temperature sensor port pressure exceeded the permissible range when the specified air pressure was applied.

③ Examination of overall functions

The butterfly plate was found to have shifted toward the "closed" side from the normal position.

(4) Teardown examination of No. 2 PCV

Traces of water ingress and contamination deposits were found inside the actuator housing.

(See Figure 2 and Photographs 9 and 10.)

2.7.6 Pre-cooler Sensors

(1) The results of the functional test on the No. 1 sensor showed that the signal pressure level exceeded the limit when the bleed duct air temperature was lowered to 387°F. Due to the insufficient drop in signal pressure level, the PCV was in a condition difficult to close.

The ball in the valve assembly was not free to move. In addition, the sensor was entirely fouled with contamination deposits.

(2) There were no abnormalities found with the No. 2 sensor.

(See Figure 2 and Photograph 13.)

2.7.7 Bleed Air Regulators (BARs)

(1) With the No. 1 BAR, the results of the functional examination of the reference pressure regulator showed a control pressure exceeding the permissible range.

Contamination deposits on and around the reference pressure regulator valve were wet with moisture, which impaired movement of the valve.

The relief valve poppet was worn.

(2) With the No. 2 BAR, the results of the functional examination of the reference pressure regulator showed a control pressure exceeding the permissible range.

The results of the functional examination of the relief valve showed a control pressure downstream did not reach the permissible range.

The valve, spring and retainer of the reference pressure regulator were rusted red due to water ingress.

The relief valve poppet was worn.

(See Photographs 11 and 12.)

2.7.8 Analysis of Deposits on the Components

In order to identify the constituents forming the deposits on the PCV, PRSOV and other components, qualitative analysis was conducted using an energy dispersive X-ray fluorescence analyzer (EDX), in addition to a Fourier transform infrared spectroscope analyzer (FT-IR) and an X-ray diffractometer. The analyses identified the deposits as detergent residues and their constituents agreed with those of the solids formed through condensation of the alkali detergent (meeting the "RMCG21" standard) that had been used at the company to water-wash the engines.

2.7.9 Water Washing Test for Engine Gas Path Cleaning on a Same Type Engine as the Aircraft's Engines (CFM56-3)

(1) With both the bleed air switch and anti-ice switch set to OFF, and in accordance with the Aircraft Maintenance Manual (hereinafter referred to as the "AMM"), water was sprayed onto the 12 o'clock position of the fan blade root. It was then found that 2 - 3 ml of water entered the PCV. Small amounts of water were also found on the supply side of the HSR.

(2) With both the bleed air switch and anti-ice switch set to OFF, water was sprayed onto the fan blade root, starting from the 6 o'clock position and moving clockwise. It was then found that approximately 12 ml of water entered the PCV.

(3) With the bleed air switch set to ON and the anti-ice switch set to OFF, and in accordance with the AMM, water was sprayed onto the 12 o'clock position of the fan blade root. It was then found that approximately 14 ml of wash water entered the PCV. Pools of wash water were also found on the supply and control sides of the HSR.

(4) After conducting the tests described in (1) - (3) above on January 12, 2007, the test engine was removed from the aircraft. On January 25, the related components were removed from the engine and a teardown examination was conducted; the examination results showed ingress of large amounts of water into these components. In addition, the PCV, PRSOV and BAR developed red rust.

2.8 Other Relevant Information

2.8.1 Information on the Engine Bleed System

Bleed air is supplied from the 5th or 9th stage of the engine compressor.

As N1[*2] drops and the 5th-stage pressure is no longer sufficient, bleed air is supplied from the 9th stage where higher-pressure air is available. The 5th-stage pressure is at a sufficient level during takeoff, climbing and cruising, so the 9th-stage valve is closed in these phases.

With the engine bleed air switch set to ON, the PRSOV valve maintains the pressure of

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*2: "N1" is the speed of the shaft that connects the low-pressure compressor to the low-pressure turbine of the engine and is expressed in %, which represents the ratio of the actual shaft speed to a reference shaft speed.

bleed air from the 5th or 9th stage at levels appropriate for system operation. Also, when the temperature of bleed air becomes too high, the PRSOV reduces the bleed air output flow.

The pre-cooler is a heat exchanger that uses fan air to cool and maintain bleed air at a temperature of approximately 390°F/199°C.

The PCV regulates the flow of fan air to the pre-cooler. The butterfly plate of the PCV closes when the temperature of bleed air from the engine is low and opens when the temperature becomes high, thus maintaining the temperature of duct air between 390°F/199°C and 440°F/227°C.

If the temperature or pressure of engine bleed air exceeds the preset limit, the corresponding sensor causes the bleed trip off light (warning light) to illuminate.
(See Figure 2.)

2.8.2 Information on the Engine Bleed Air Control of the Aircraft

Under typical conditions while flying at FL370, if N1 is 37 – 53%, 9th-stage bleed air is supplied to the duct without regulation by the high-stage regulator. If N1 is 53 - 84%, 9th-stage bleed air is regulated at 32 ± 6 psi by the high-stage regulator before being supplied to the duct. If N1 rises to approximately 84%, source of bleed air is changed to the 5th stage from the 9th stage.

If N1 is 84 - 96%, 5th-stage bleed air is supplied to the duct. If N1 is 96 - 100%, 5th-stage bleed air is supplied to the duct after being regulated at 42 ± 8 psi by the pressure regulator shutoff valve.

At about 08:08, the aircraft was flying at a cruising altitude of FL370 and N1 was then 85% for both the No. 1 and No. 2 engines.

Approximately 30 seconds after N1 dropped to 54%, the engine output was raised again for both the No. 1 and No. 2 engines, and N1 was then stabilized at approximately 82%.
(See Figure 5.)

2.8.3 Illumination of the Bleed Trip Off Light

Illumination of the bleed trip off light indicates the closure of the engine bleed valve (PRSOV) due to overheating (490°F/254°C) or overpressure (180 psi).

2.8.4 490°F Bleed Overheat Switches

The switch closes if the air temperature in the bleed duct exceeds 490 ± 10°F / 254 ± 3°C. When the switch closes, the engine bleed air overheat relay inside the corresponding air conditioning module is energized.

When the relay is energized, the PRSOV closes, causing the bleed trip off light on the overhead panel to illuminate.
(See Figure 2.)

2.8.5 Water Washing of the Aircraft's Engines for Engine Gas Path Cleaning at an Overseas Maintenance Facility

On June 10, 2006, the aircraft was ferried to a maintenance facility in China for a C-check. The aircraft received airframe maintenance and other servicing and then, on the morning of June 26, the No. 1 and No. 2 engines underwent water washing.

Because the detergent was sprayed towards 6 o'clock position of the spinners, not in compliance with the company's procedures, by the instruction of the inspector, this time to fresh water was sprayed towards the 12 o'clock position of each spinner. After rinsing, the engines were test-run in accordance with the AMM to completely remove any water that would have entered the ducts and other components.

Subsequently, the aircraft underwent the remaining part of the airframe maintenance service. After that, flight test was performed on June 29 and then it was ferried to Japan on the afternoon of July 1.

It was the first time that the company performed engine water washing at an overseas maintenance facility.

2.8.6 The company's on site investigation for the Engine Washing

According to the company's report, the engine washing was performed as follows;

When carrying out the water washing, I set the bleed air switches for both the No. 1 and No. 2 engines to OFF and the anti-ice switch to OFF, and then at the first time I sprayed the detergent towards the 6 o'clock position of each spinner. Because the detergent failed to enter the engine cores, at the second time I sprayed towards the 12 o'clock position of each spinner, with good results.

Most of the detergent sprayed at the first time came out of the fan exits, but at the second time it came out of the engine core exits.

I then rinsed the engines with water three times as specified in the AMM. The flow rate of water during the rinsing was about 22 liters per minute. I then ran the engines free of load for 5 min as specified in the AMM, performed checks including the engine anti-ice, then ran the engines at idle power with the air conditioning system set to ON.

2.8.7 Statements of Personnel in charge of teardown examination and functional examination

I have done many teardown and functional examinations of valve related components thus far, but this was the first time that I saw such traces of water ingress and contamination deposits resulting from water ingress in valves and other components.

2.8.8 Engine Water Wash Information Issued by the Company

The TSI (Technical Service Information) and Aircraft Quality Information issued by the company on October 1, 2005 for its Aircraft Maintenance Department include the following descriptions.

(Excerpts)

We have experienced a problem with a Boeing 737-500 after engine water washing, the cause of which was ingress of an unexpectedly large quantity of water into the engine core section and by entry of water into the engine oil system. This TSI outlines the problem and summarizes what must be especially noted during engine water washing.

Points that must be strictly observed during engine water washing are the following:

(1) During water washing, observe the recommended flow rate of water supply to the engine. The recommended flow rate is 19 - 23 liters/minute.

** Spraying water at flow rates exceeding the above limit can cause water to enter the engine oil system.*

(2) *When spraying water for engine water washing, the spray must be directed at the area around the flange bolts behind the cone aft of the spinner and centered upon the 12 o'clock position of the engine.*
This is the most efficient way of letting water flow into the engine core.

2.8.9 Procedures of the Company related to Engine Water Washing

The AMM of the aircraft describes the steps to follow after engine water washing as shown below.

(Excerpts)

Within 2 h after water washing, drain water in accordance with the procedure described in this AMM.

(1) *Operate the engine at low idle for 5 minutes.*
(2) *Make sure these switches are in the OFF position:*
Engine 1 Bleed
Engine 2 Bleed
Put the applicable ENG-ICE switch in the ON position.
(3) *Make sure there is an increase in the EGT of approximately 15°C.*
(4) *Put the ENG ANTI-ICE switch in the OFF position.*
(5) *Move the forward thrust lever until the engine speed is in high idle.*
(6) *Put the applicable ENG ANTI-ICE switch in the ON position.*
(7) *Make sure there is an increase in the EGT of approximately 15°C.*
(8) *Put the ENG ANTI-ICE switch in the OFF position.*
(9) *Make the engine idle stable at the low idle position and operate the engine for 5 minutes.*
(10) *Shut down the engine.*

2.8.10 BLEED TRIP OFF Light Illumination Previously Experienced by the Aircraft

As a result of an investigation of problems experienced by the aircraft in flight, the following case was identified as relevant.

Problem outline:

On April 23, 1999, the left BLEED TRIP OFF light illuminated when the aircraft was about to begin a descent after flying at 33,000 - 37,000 ft.

Maintenance action taken:

Bleed air related components were replaced, but the problem persisted. Later, the problem was resolved by replacing the pre-cooler with a replacement part.

2.8.11 Actions to Take When the Pressurization System Develops a Problem in the Air

In Subsection 10-4-7 Pressurization System Failure, Section 10-4 Actions to Take in Different Emergency Cases in Chapter 10 Emergency Procedures, the company's Operations Manual (hereinafter referred to as "OM") describes as follows the actions to take in the event of rapid cabin depressurization during flight.

(Excerpts)

If the aircraft's pressurization function is lost while flying, the flight crew shall immediately take action following the relevant prescription in the Airplane Operations Manual.

If the aircraft must fly below the minimum safe altitude defined in Section 3-7-1 (Restrictions Related to Performance Limitations) of this manual, the Pilot in Command shall pay utmost attention to avoid collision and shall notify ATC of the fact as soon as possible.

2.8.12 Procedure in case of Cabin Altitude Warning or Rapid Cabin Depressurization

The company's Airplane Operations Manual (hereinafter referred to as "AOM") provides the following descriptions in the "CABIN ALTITUDE WARNING HORN / RAPID DEPRESSURIZATION" section of Chapter 2 Procedures in Emergencies / System Failures (Supplement).

(Excerpts)

(1) CABIN ALTITUDE WARNING HORN / RAPID DEPRESSURIZATION

Condition: One or more of the following circumstances has arisen.

- *Intermittent cabin altitude / configuration warning horn sounds.*
- *Cabin pressure is lost rapidly at an altitude above 10,000 ft.*

Oxygen Masks ··················ON PLT[*3]

Pack Switches ··················HIGH PNF

Pressurization Mode Selector ··················MAN PNF

[If the cabin rate of climb drops after setting the pack switches to HIGH, select MAN after the cabin rate of climb stabilizes.]

Outflow Valve Switch ··················CLOSE PNF

[It is not necessary to set to CLOSE if the cabin rate of climb has dropped.]

- *After recovery of cabin pressure, continue manual operation.*

<u>If the cabin altitude cannot be controlled:</u>

[Accomplish individual pilot's checklists simultaneously under the control of the Pilot in Command.]

Emergency Descent ··················INITIATE PF

[Call out "Emergency Descent" over flight interphone.]

Altitude Selector ··················10,000 FT OR LOWEST SAFE ALTITUDE, WHICHEVER IS HIGHER PF

[Set level-off altitude.]

[Lowest Safe Altitude is the lowest of the altitudes available from safe altitude information sources ("MEA,"[*4] *"MOCA,"*[*5] *"MORA"*[*6] *and "Grid MORA"*[*7]*) and "an altitude of 2,000 ft above the highest obstacle along the route."]*

LVL CHG Switch ··················PUSH PF

<u>If there is no structural damage:</u>

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*3: In normal procedures, "PLT" means all flight crew members.

*4: "MEA" is the minimum en-route altitude in instrument flight rule operations.

*5: "MOCA" is the minimum obstacle clearance altitude, which is determined by adding a specific vertical distance to the height of obstacles within a certain distance from the centerline of the airway or other type of route.

*6: MORA is the minimum off-route altitude, which is determined by adding a certain clearance to obstacles within 10 nm on either side of the centerline of the route.

*7: Grid MORA is determined by adding a certain clearance to obstacles within an area enclosed by latitude and longitude lines.

Speed Selector ………………………………………………SET VMO/MMO[*8] *PF*

- *Accomplish high-speed descent.*

Thrust Levers ………………………………………………CLOSE PF

Speed Brake …………………………………………………FLIGHT DETENT PF

HDG Selector and

HDG SEL Switch (if desired) ………………………… SET AND PUSH PF

Cabin Signs ………………………………………………ON PNF

Passenger Oxygen Switch (if required) ……………… ON PNF

[Set switch to ON if passenger oxygen system fails to operate at a cabin altitude higher than 13,000 ft.]

Engine Start Switches ………………………………… CONT PNF

Transponder ……………………………………………… 7700

Speed Brake ……………………………………………… DOWN DETENT PF

[Level off by smoothly moving the speed brake lever to the down position. Stabilize at the desired air speed.]

Altimeters …………………………………………………SET&X-CHECK PLT

Crew Oxygen Regulators ……………………………… NORMAL PLT

[Flight crew must use oxygen masks if the cabin altitude exceeds 10,000 ft. To save oxygen, set the NORMAL/100% selector to NORMAL.]

Engine Start Switches ………………………………… CONT/OFF PNF

- *After the cabin altitude drops to 13,000 ft or below, tell the cabin crew that they may take off their oxygen masks.*

  [After the cabin altitude drops to 10,000 ft or below, the flight crew may take off their oxygen masks.]

(2) *BLEED TRIP OFF*

Condition: Illumination of BLEED TRIP OFF light indicates that the temperature or pressure of engine bleed air is excessively high.

Wing Anti-Ice Switch …………………………………… OFF PNF

Trip Reset Switch ………………………………………… PUSH PNF

[BLEED TRIP OFF light goes out when bleed air temperature drops below the limit.]

If BLEED TRIP OFF Light stays ON:

Pack Switch (Affected Side) …………………………… OFF PNF

[If the flaps are up, operative pack is regulated for high flow mode operation.]

- *Avoid icing conditions.*

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*8: VMO/MMO is the maximum operating limit speed, which must not be deliberately exceeded in any phase of flight, i.e. climb, cruise or descent.

3. ANALYSIS

3.1 The PIC and First Officer possessed adequate airman certificates and valid airman medical certificates.

3.2 The aircraft had a valid certificate of airworthiness and was properly maintained and inspected.

3.3 As to the history of events resulting in the abnormal drop in cabin pressure during cruising,

(1) The DFDR records described in 2.1.1 indicate that, while the aircraft was cruising at FL370, the master caution light and the system annunciator's "AIR COND" light illuminated in the cockpit at 08h10m05s,

(2) According to the DFDR records described in 2.1.1 and the statements of the PIC, the cabin altitude warning activated at 08h10m44s after the aircraft began its descent,

(3) According to the DFDR records and the statements of the PIC, after the cabin altitude warning activated, the oxygen masks in the cabin automatically deployed at 08h13m27s,

Based on the above and the descriptions in 2.5.5 and 2.5.6, it is estimated that the cabin altitude reached about 10,000 ft immediately after the aircraft began descent from FL370, which triggered the cabin altitude warning system, and within 3 min after that, the cabin altitude reached about 14,000 ft, causing the oxygen masks to automatically deploy in the cabin. It is also estimated based on the DFDR records that, at that time, the aircraft was descending towards 10,000 ft at a rate of 4,000 fpm.

3.4 Based on the descriptions in 2.1.2 (1) and 2.1.2 (2), it is estimated that, because of abnormal cabin depressurization that occurred while the aircraft was cruising, the PIC and First Officer put on their oxygen masks, set the pressurization mode selector to "MANUAL" and made a descent to 10,000 ft in accordance with the OM procedure mentioned in 2.8.11 and the AOM procedure mentioned in 2.8.12.

3.5 Bleed Air Sources of the Aircraft

As described in 2.8.2, N1 was 85% for both the No. 1 and No. 2 engines while the aircraft was flying at FL370, from which it is estimated that bleed air at that time was being supplied from the 5th stage of each engine's high-pressure compressor.

When the aircraft encountered turbulence while cruising at FL370 and the engine power was quickly reduced to prevent the increase in airspeed, N1 for both engines dropped from 85% to about 54%. It is estimated, as described in 2.8.2, that the bleed air source at that time changed from the 5th stage to the 9th stage of each engine's high-pressure compressor, which has higher temperature.

Then, approximately 30 seconds after N1 dropped to 54%, the engine power was increased again and N1 for both the No. 1 and No. 2 engines stabilized at about 82%.

3.6 Activation of No. 1 and No. 2 Overheat Switches

It is estimated that, when higher-temperature 9th-stage bleed air flowed into the pre-coolers, both the No. 1 and No. 2 PCVs, the role of which is to control the fan air, operated sluggishly due to contamination deposits and thus failed to allow sufficient fan air to flow to the pre-coolers, causing insufficient cooling and the No. 1 and No. 2 overheat switches to trip, which then caused both bleed valves to close (as indicated by illumination of both BLEED TRIP OFF lights), resulting in an abnormal drop in cabin pressure.

3.7 Causes of Contamination Deposits in Pre-cooler Control Valves (PCVs)

As to contamination deposits inside the PCVs, it is estimated that the cause was a significant amount of detergent having entered the bleed related valves and other components during water washing of the engines for gas path cleaning, which was conducted at the time of C-check of the aircraft as described in 2.8.5.

It is estimated that, even after the engine test run carried out to remove water in accordance with the AMM, water still remained in the bleed related valves and other components.

In addition, since the aircraft was parked for about three days after the engine test run, it is estimated that detergent in the remaining water dried out to form a solid residue, which subsequently constituted contamination that would have caused sluggish movement of the PCVs.

3.8 Actions Taken after Engine Water Washing

The results of the test conducted on an engine of the same type as that of the engines on the aircraft as described in 2.7.9 showed that water entered the valves and other components after water washing and also that leaving the engine untouched for several days caused the PCVs, PRSOVs and BARs to develop red rust.

Based on the test results, it is estimated that, in the case of this serious incident, the contamination deposits were formed because the engines had been left unused for three days after engine water washing.

When performing water washing, it is essential that the bleed air switch is set to OFF, the anti-ice switch is set to OFF, and then water is sprayed towards the 12 o'clock position of each spinner in accordance with the AMM. It is estimated that the serious incident could have been avoided if the aircraft had been put into service the day after the water was removed from the bleed related valves and other components as per the AMM or if water washing had been accomplished between flights.

3.9 Factors Contributing to Water Ingress into Valves and Other Bleed Related Components

It is considered that water and detergent that had remained in the bleed air manifolds of the 5th- and 9th-stage high-pressure compressors during the water washing for gas path cleaning, then entered the bleed-air related valves and other components via the supply lines (bleed ducts, etc.) and control lines when the engines were subsequently run at idle with the bleed switch set to ON as part of the post-water-washing procedure specified in the AMM.

4. PROBABLE CAUSE

It is estimated that this serious incident would have occurred through the following process: the aircraft encountered turbulence when flying at FL370, quickly reduced the engine power in order to avoid excessive airspeed, and this in turn caused a change of the source of bleed air, which resulted in bleed air with higher temperature flowing into the pre-coolers, but the bleed air was not cooled sufficiently, and the overheat switches activated, closing the bleed valves for both systems and thus preventing the air supply necessary for pressurization of aircraft, ultimately resulting in an abnormal cabin depressurization.

It is estimated that the overheat switches activated because the operation of the control valves (PCVs) was sluggish due to contamination.

It is estimated that contamination deposits on the bleed related valves and other components resulted from incomplete draining of water and detergent which entered these components in large quantities during water washing conducted for engine gas path cleaning.

5. REFERENTIAL MATTERS

5.1 Actions Taken by the Company to Prevent the Recurrence

After this serious incident, the company issued an AMM Bulletin, which has higher priority than the TSI, to implement improvements including those enumerated below as measures to ensure complete removal of water after water washing of the engines on aircraft of the same type as the aircraft involved in this serious incident. In addition, the company decided to carry out engine water washing at its own facilities.

(1) A reminder to all personnel concerned that the bleed switch must be set to OFF when performing water washing.

(2) The aircraft must be put in service for one or more flights within 48 hours after water washing of its engines. If it is not possible to fulfill this requirement, the engines must be run at 80% N1 or higher for five min.

(3) The pressure sensing lines for the 5th- and 9th-stage high-pressure compressors must be disconnected before water washing using detergent.

5.2 Actions Taken by the Aircraft Manufacturing Company to Prevent the Recurrence

The aircraft manufacturing company's AMM issued before this serious incident had stipulated in one item of the procedure that the anti-ice switches and bleed switches should be in the OFF position as a preparation work performed prior to the water spraying of the water washing. However, after this serious incident, taking into account the importance of this work, the aircraft manufacturing company amended the AMM as of July 12, 2007 and stipulated each switch operation as two independent items.

Figure 1　Estimated Flight Route

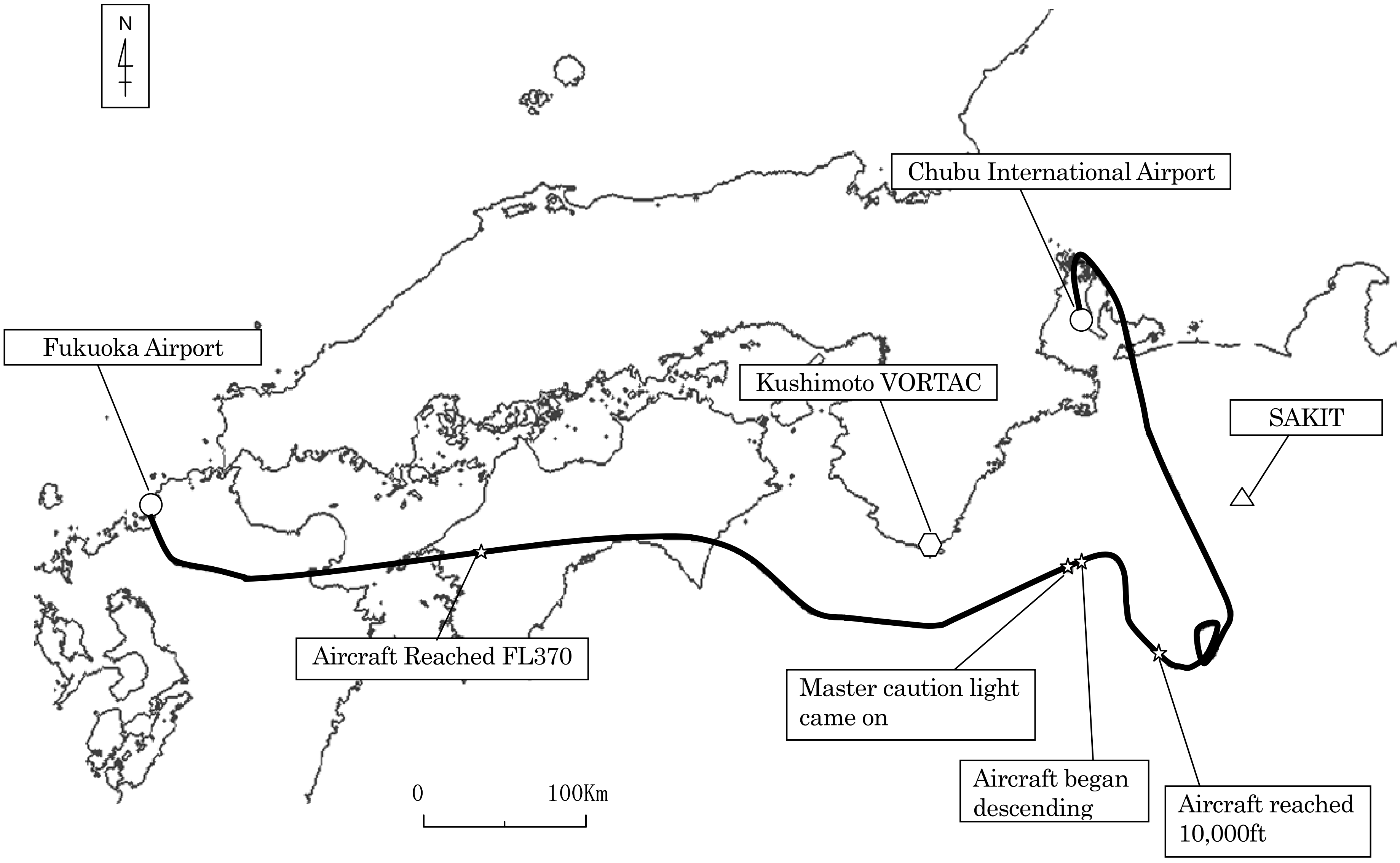

Figure 2 Schematic diagram for bleeding-air related components

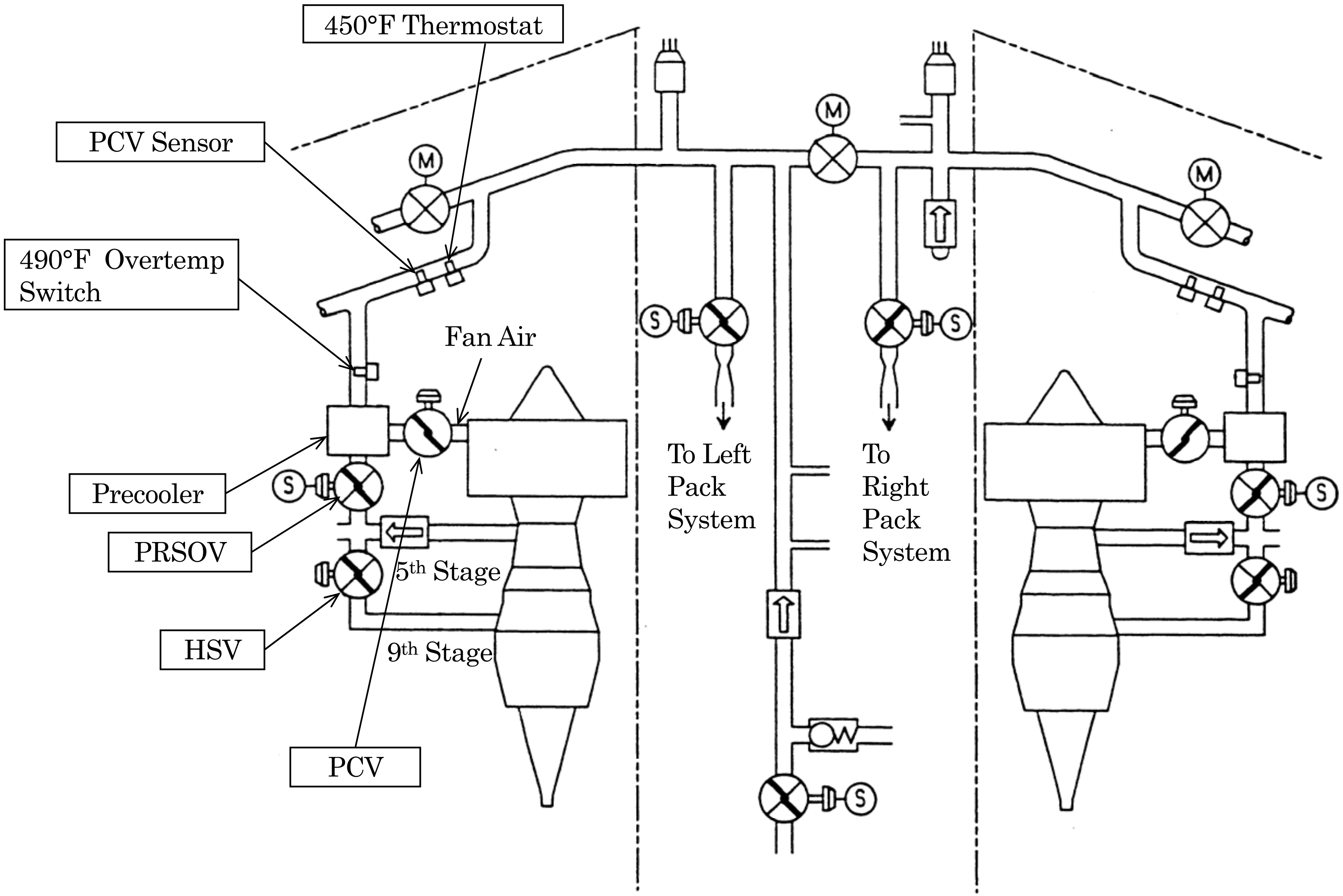

Figure 3　Three views of Boeing 737-500

Unit：m

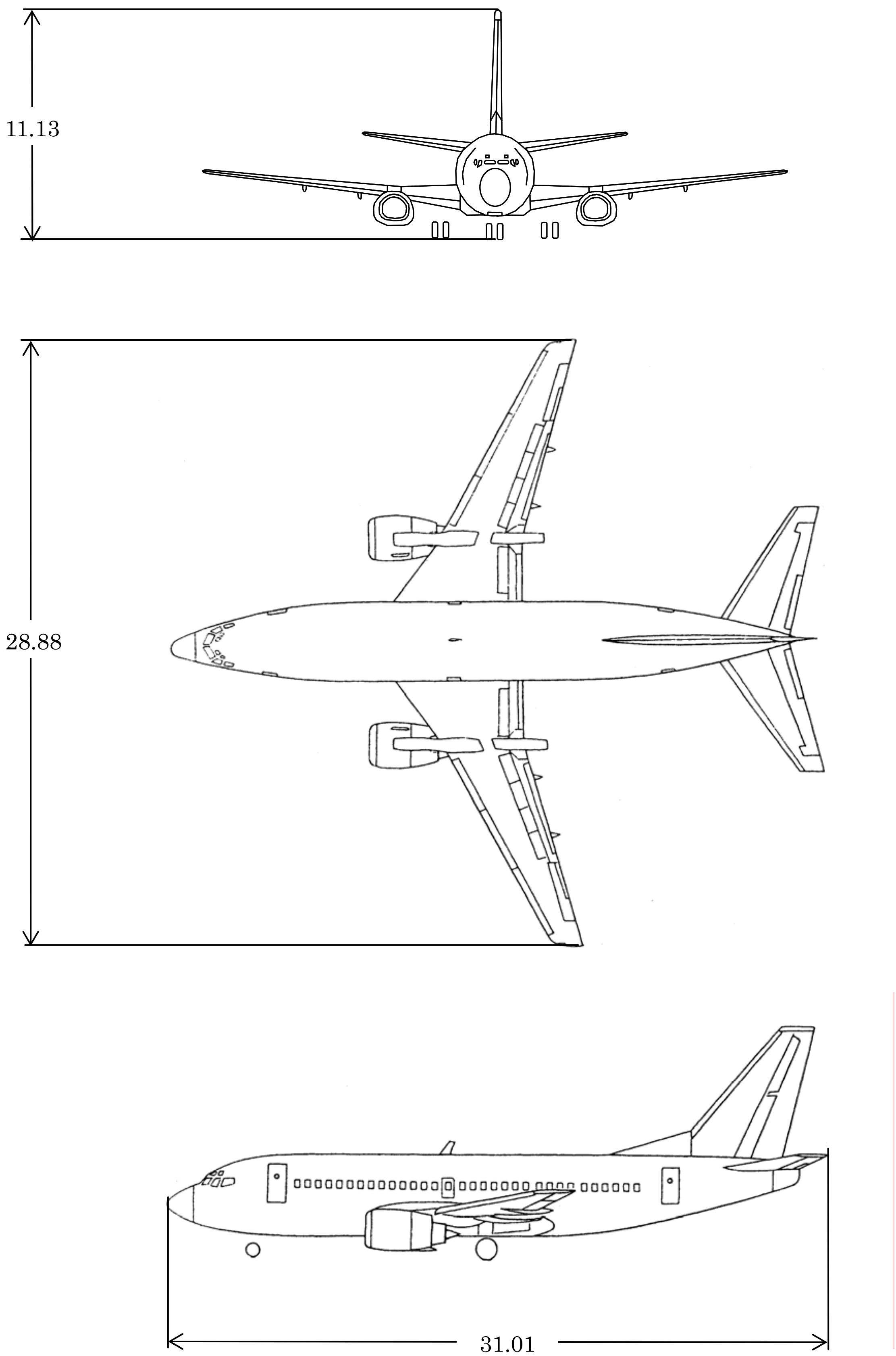

Figure 4 Records of DFDR

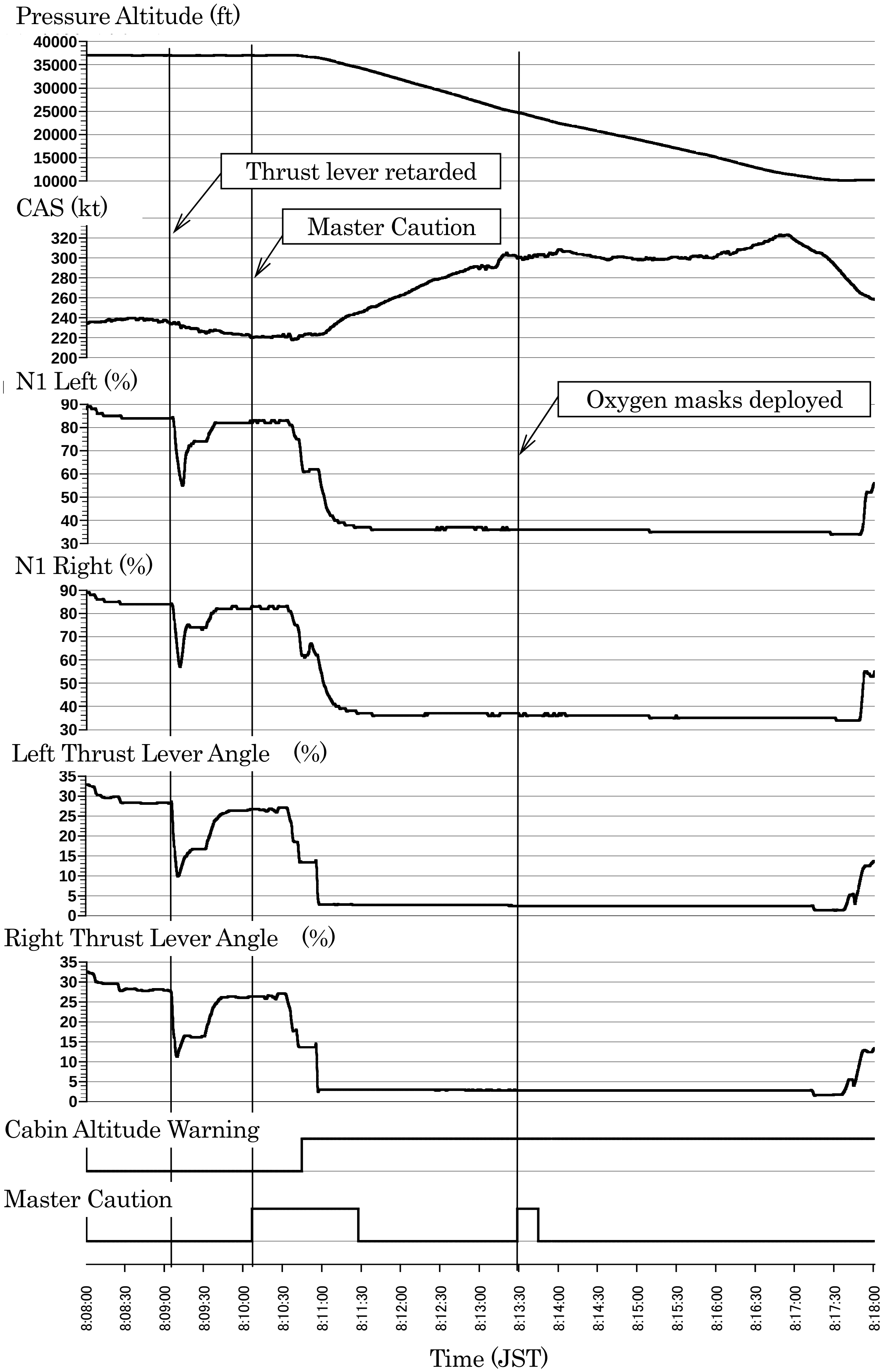

Figure 5　Bleed Air Control Table

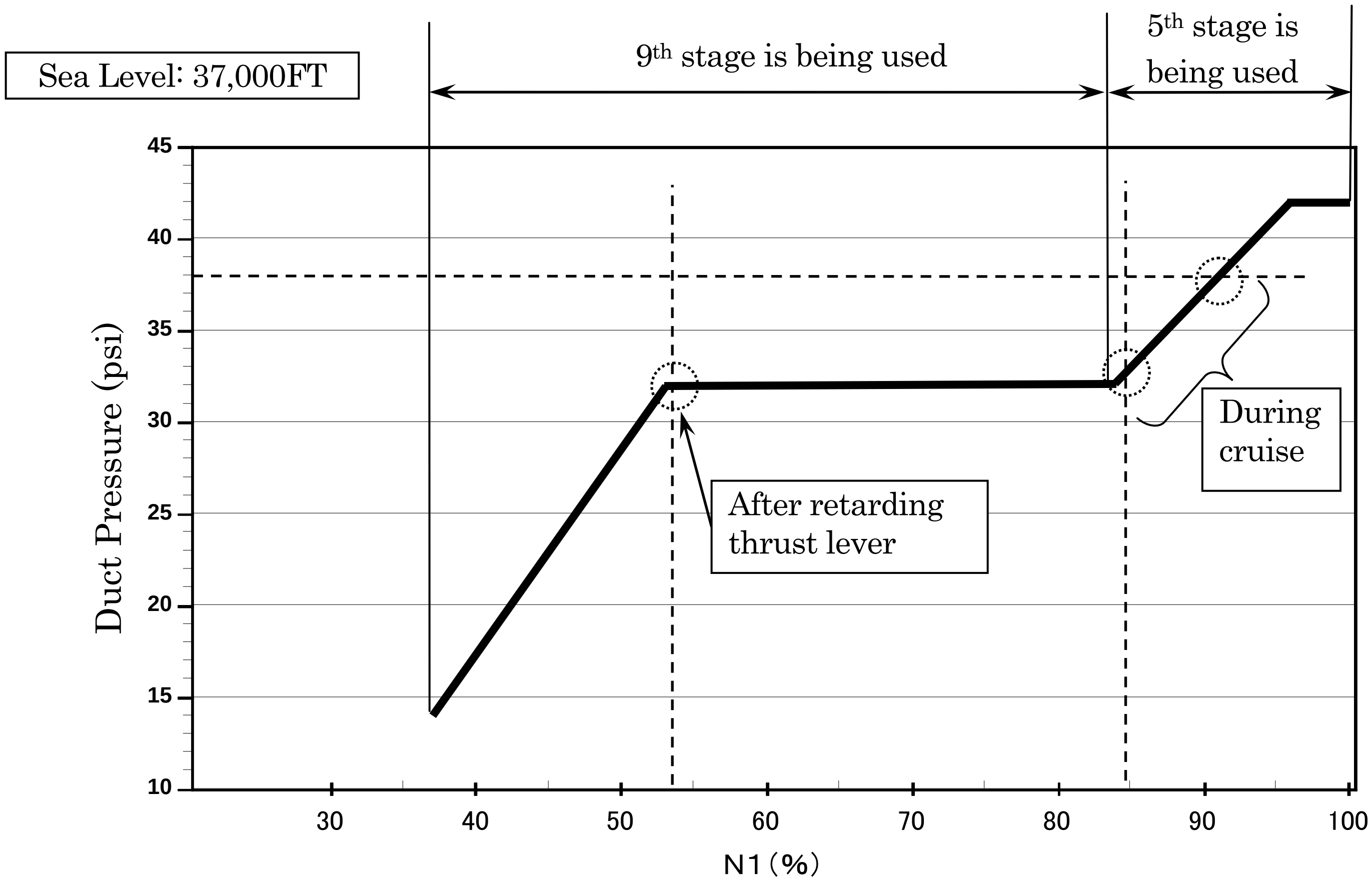

Photo 1　Dismantled No.1 PRSOV

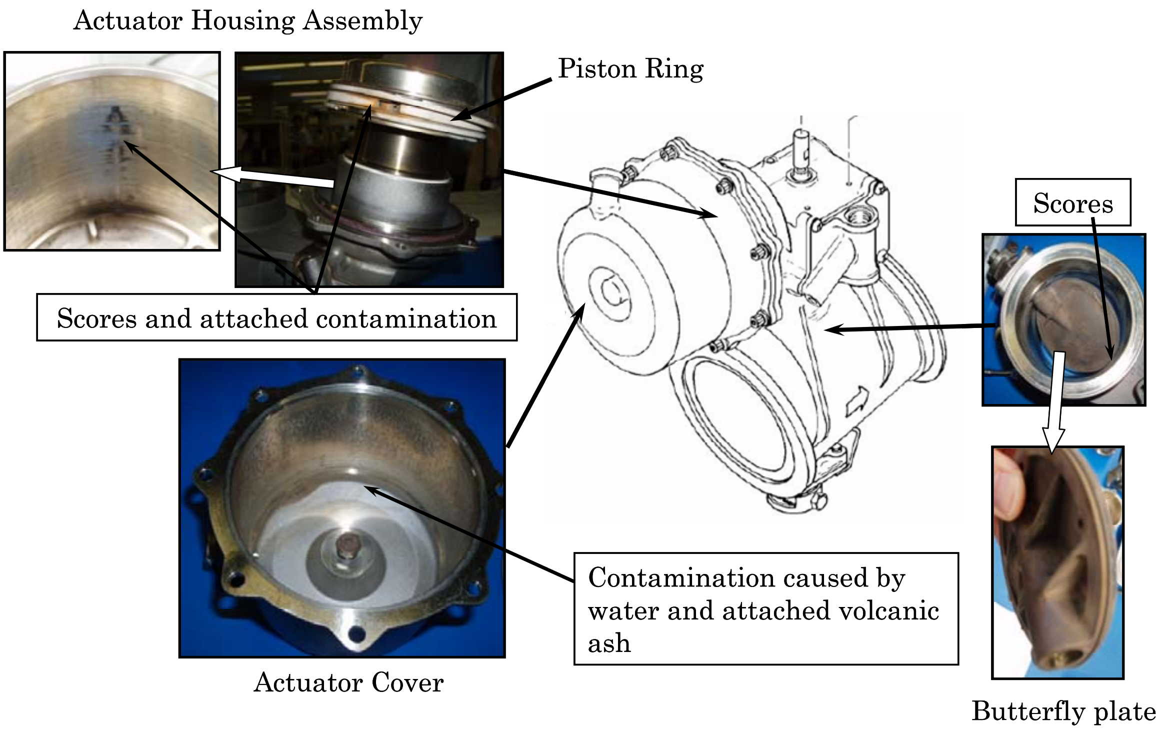

Photo 2　Dismantled No.2 PRSOV

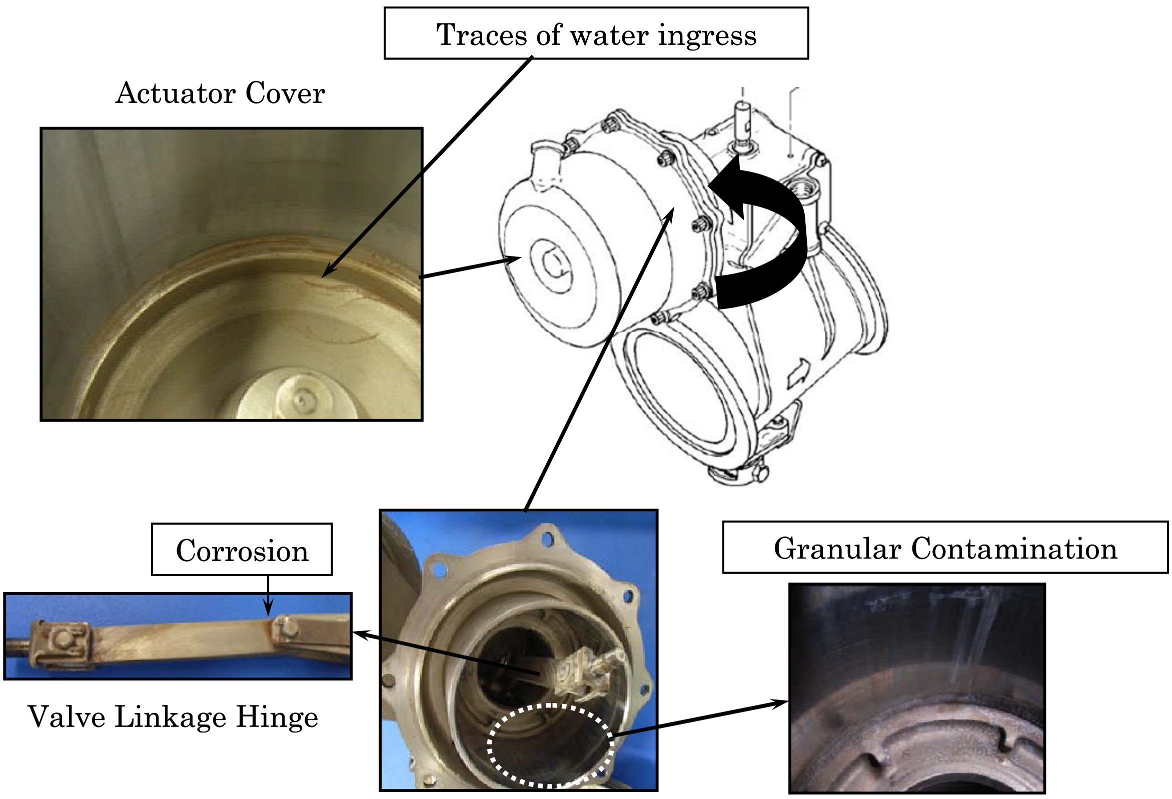

Photo 3　Dismantled No.1 HSV

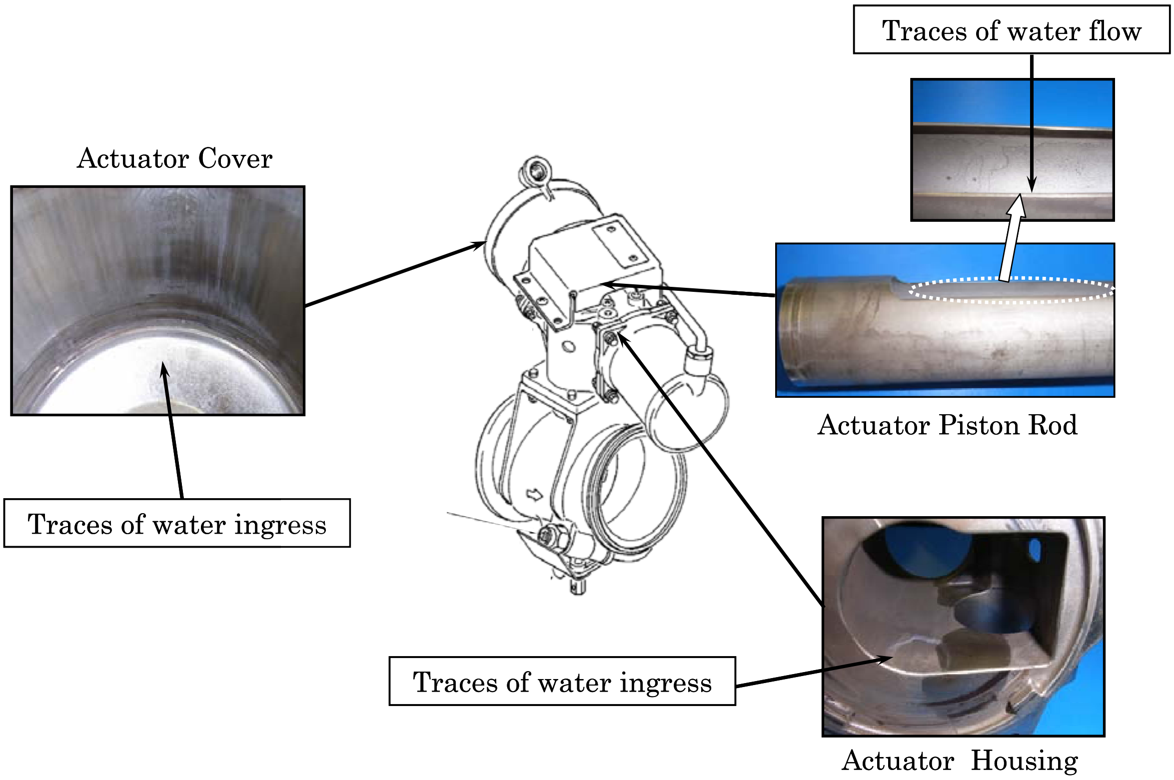

Photo 4　Dismantled No.2 HSV

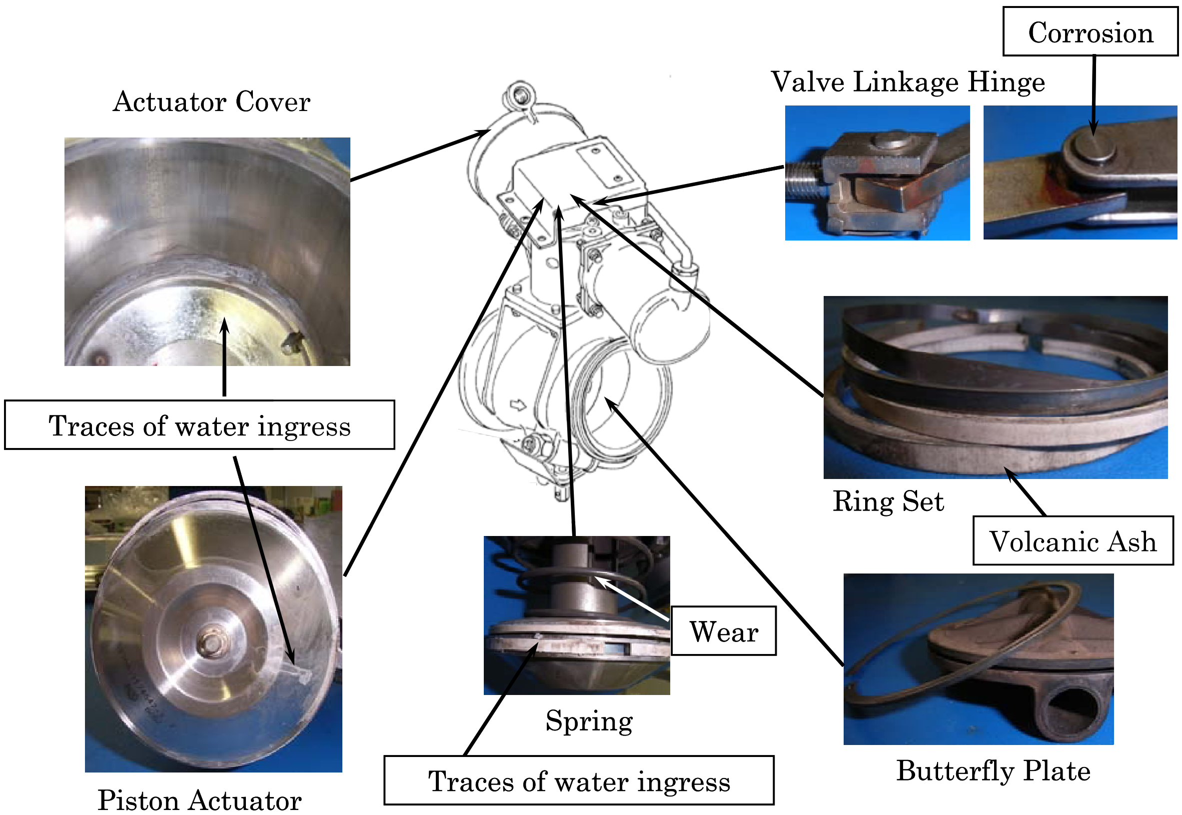

Photo 5　Dismantled No.1 HSR

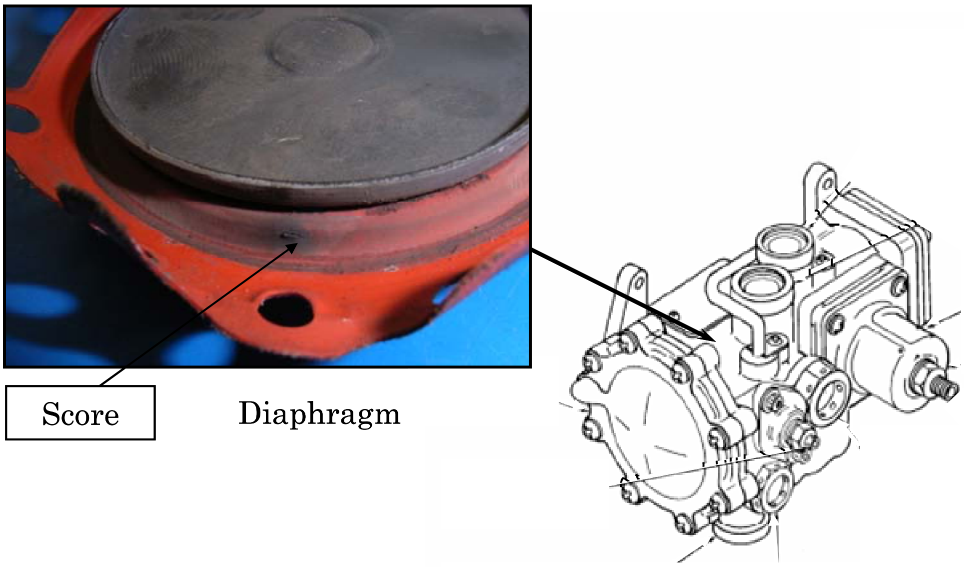

Photo 6　Dismantled No.2 HSR

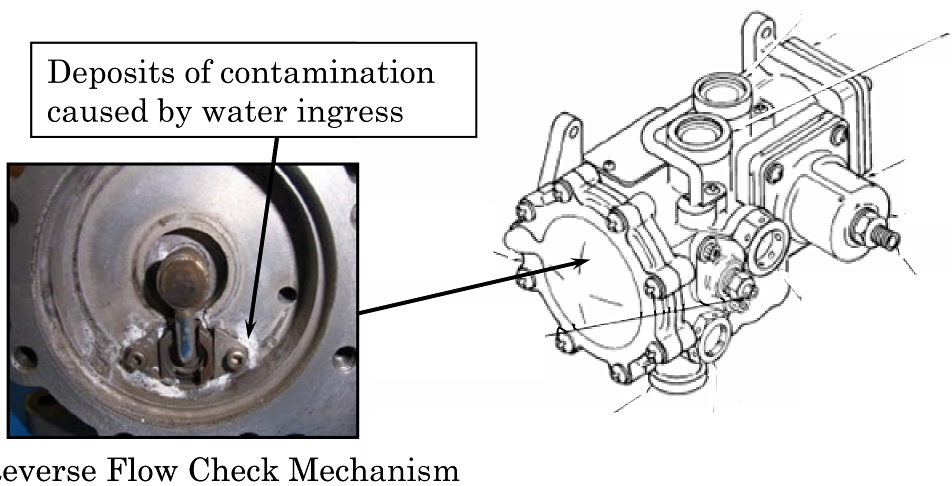

Photo 7　Test of No.1 Pre-cooler

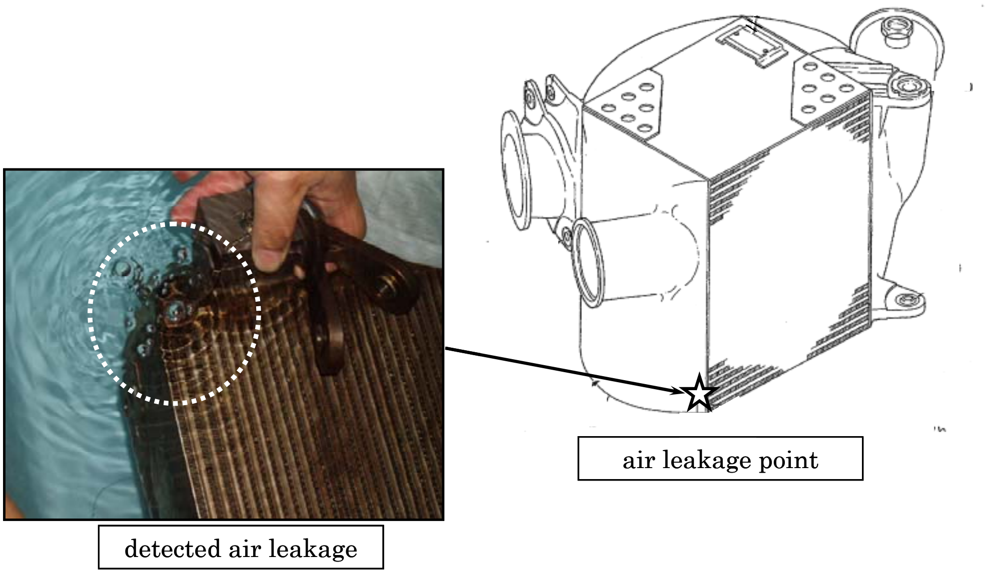

Photo 8　Test of No.2 Pre-cooler

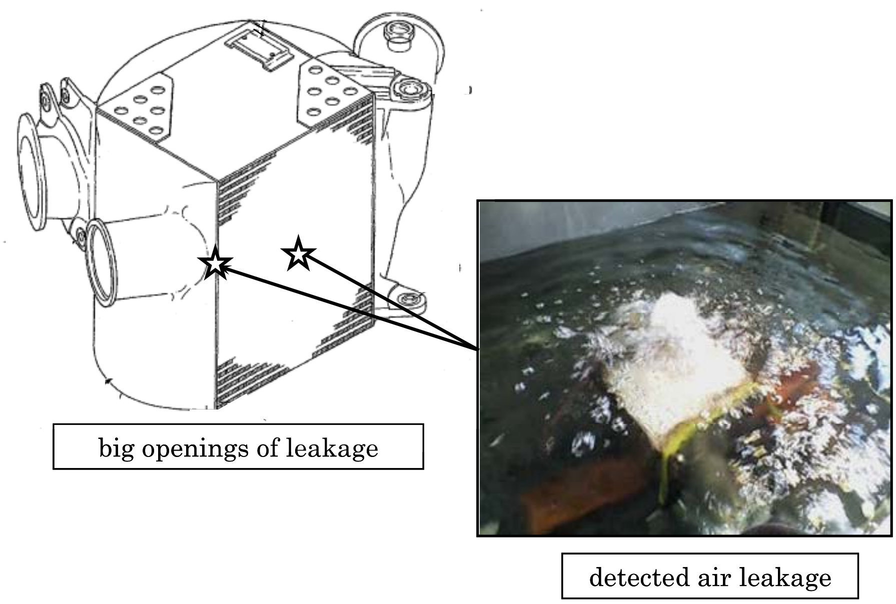

Photo 9　Dismantled No.1 PCV

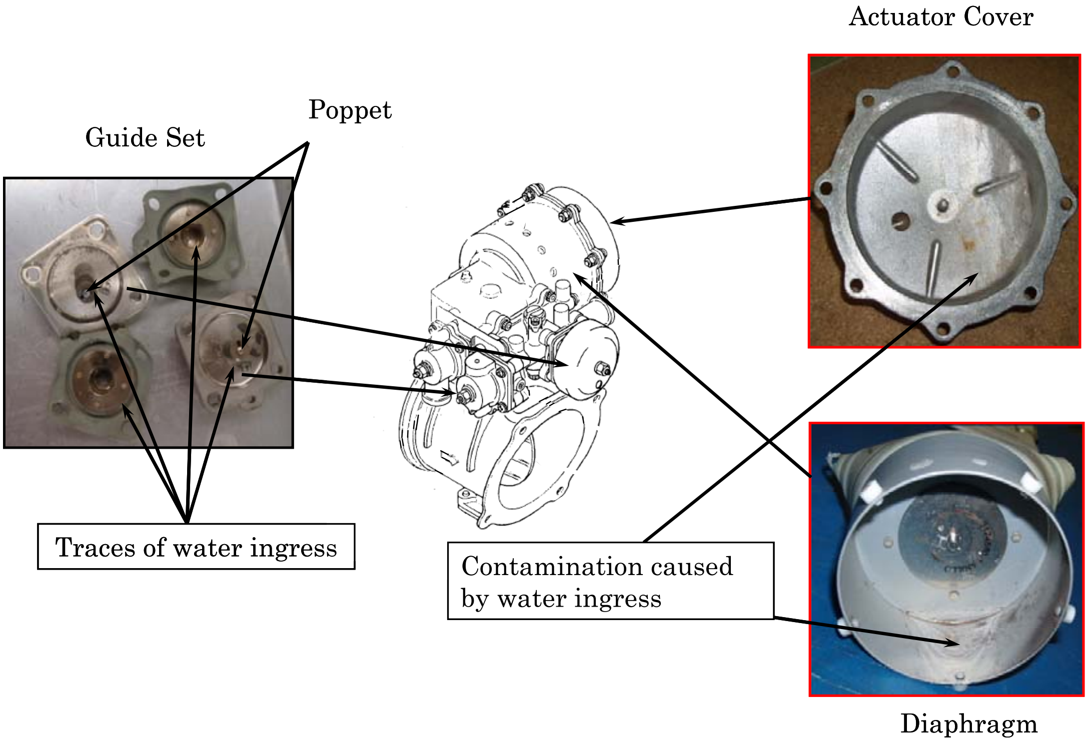

Photo 10　Dismantled No.2 PCV

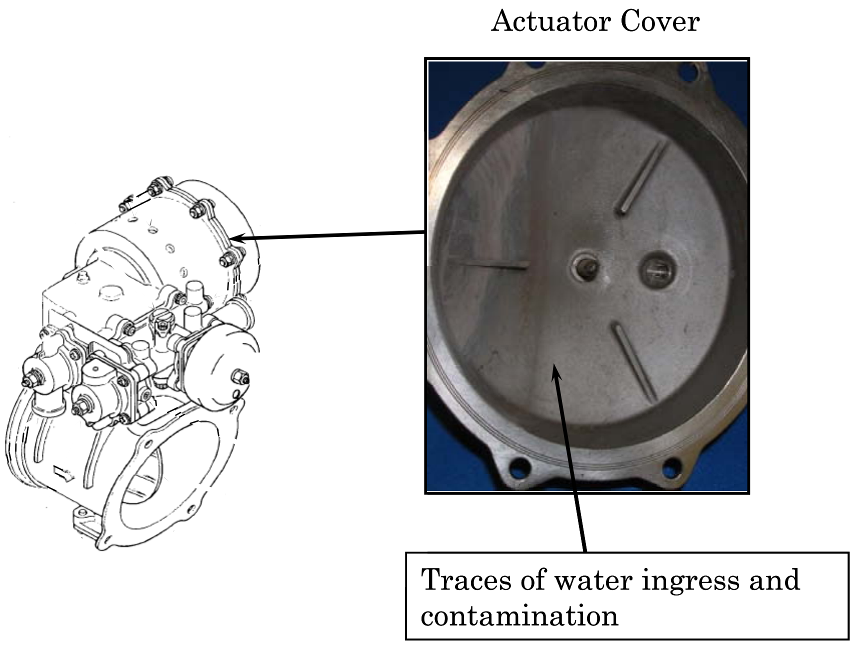

Photo 11 Dismantled No.1 BAR

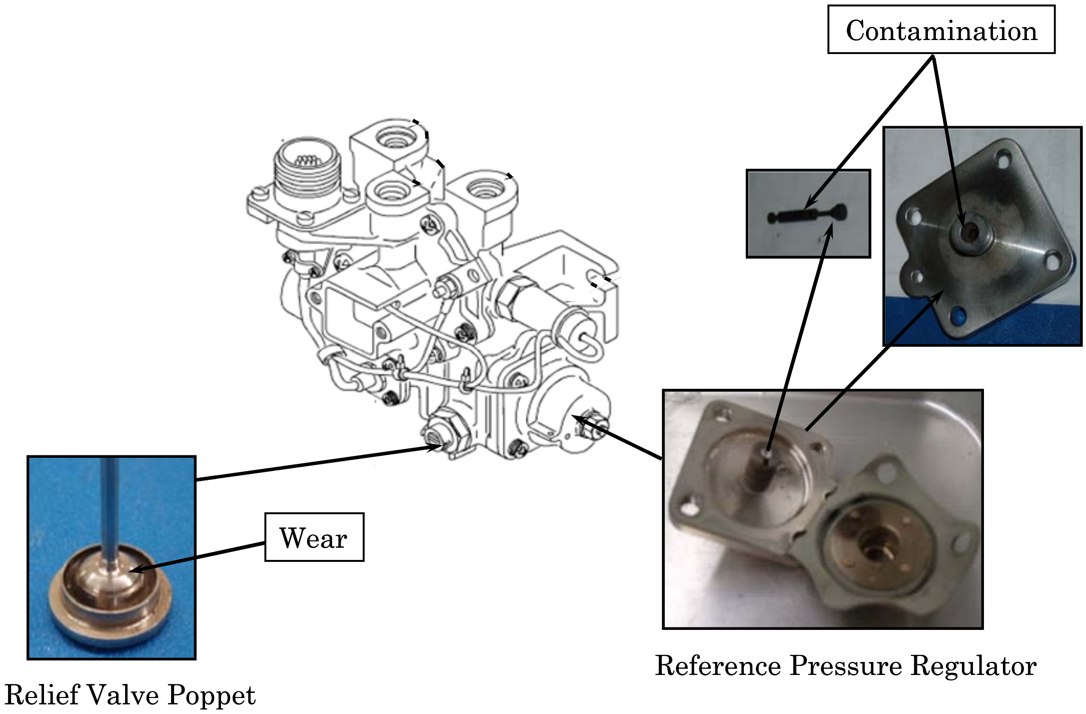

Photo 12 Dismantled No.2 BAR

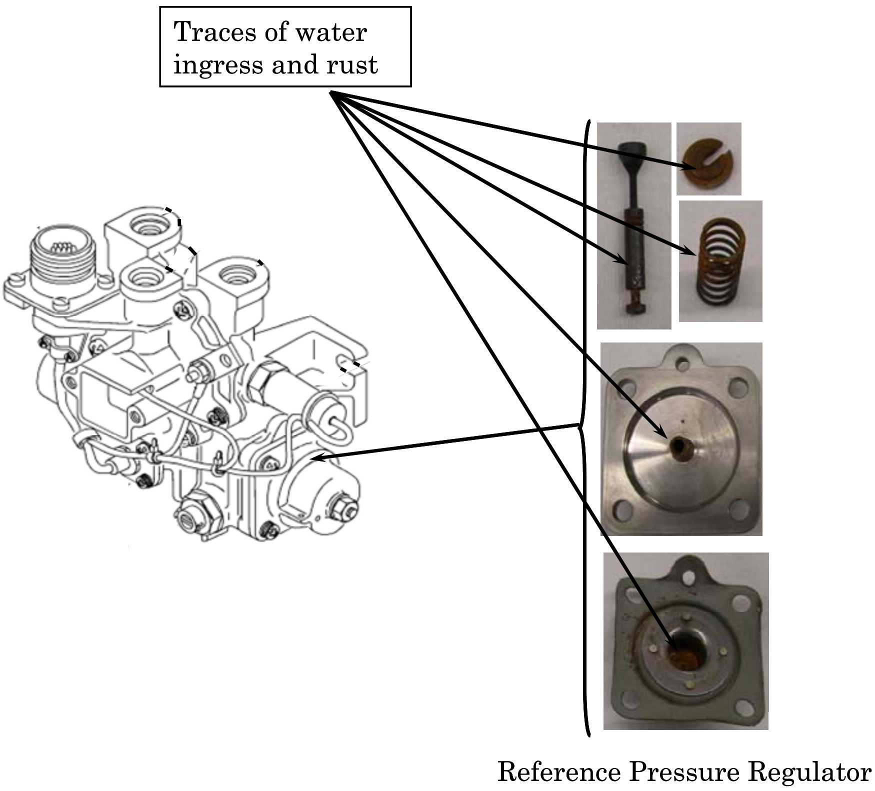

Photo 13　Dismantled No.1 Pre-cooler Sensor