2002-1

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

ALL NIPPON AIRWAYS

AIRBUS A320-200, JA8947

(DECOMPRESSION IN AN AIRCRAFT CABIN)

September 27, 2002

Aircraft and Railway Accidents Investigation Commission

Ministry of Land, Infrastructure and Transport

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

ALL NIPPON AIRWAYS FLIGHT 465

AIRBUS A320-200, JA8947

DECOMPRESSION IN AN AIRCRAFT CABIN

OVER THE SEA OF JAPAN 75 KM N.W. OF TOYAMA CITY, TOYAMA PREFECTURE, JAPAN

AT ABOUT 11:45 JST, DECEMBER 27, 2001

September 27, 2002

Decision by the Aircraft and Railway Accidents Investigation Commission(Air Sub-committee Meeting)

Chairman	Junzo Sato
Member	Ryouhei Katsuno
Member	Susumu Kato
Member	Sumio Matsuura
Member	Yukiko Kakimoto
Member	Kozaburo Yamane

1. PROCESS AND PROGRESS OF THE SERIOUS INCIDENT INVESTIGATION

1.1 Summary of the Serious Incident

On Thursday December 27, 2001, an Airbus A320-200 of All Nippon Airways (ANA), registration JA8947 (hereinafter referred to as the said aircraft), departed Niigata Airport at 11:20 (JST) as scheduled passenger flight 465 to Naha Airport. The aircraft was cruising at flight level (FL) 350 bound for Naha Airport over the Sea of Japan approximately 75km northwest of Toyama City when a drop in cabin air pressure occurred at around 11:45. As a result, the said aircraft made an emergency descent and diverted to Osaka International Airport, where it landed at 12:25.

There were 55 persons on board flight 465—49 passengers, the Captain and five other crew members. There were no injuries to persons on board.

This incident was treated as a serious incident under Civil Aviation Regulation Operating Standard Article 166 Section 4 Item 10 “Abnormal drop of cabin pressure in an aircraft”.

1.2 Outline of the Serious Incident Investigation

1.2.1 The Organization of the Investigation

On December 27, 2001, the Aircraft and Railway Accidents Investigation Commission (ARAIC) assigned an Investigator-in-Charge and two other investigators with responsibility for investigating this serious incident.

1.2.2 Cooperating Parties

Personnel from the Ministry of Land, Infrastructure and Transport’s Civil Aviation Bureau (CAB) cooperated in the investigation of the aircraft and other matters in relation to this serious incident.

1.2.3 Cooperation by Foreign Authorities

The German Federal Bureau of Aircraft Accident Investigation (BFU) cooperated as witnesses to the detailed investigation of safety valves of the cabin pressurization system.

1.2.4 The Implementation of the Investigation

The investigation proceeded as follows.

December 28–29, 2001	Investigation of the aircraft and collection of witness statements.

December 28, 2001–January 10, 2002	Analysis of DFDR data and CVR recordings
December 31, 2001	Collection of witness statements
January 8–24, 2002	Safety valve investigation
February 6–8, 2002	Additional safety valve investigation at the manufacturer's facility (witnessed by the BFU)

1.2.5 Hearings from Persons relevant to the Cause of the Serious Incident

Hearings were held to hear the opinions of persons concerned with the cause of this incident.

2. FACTUAL INFORMATION

2.1 Flight History

On December 27, 2001, the said aircraft was planned to operate as All Nippon Airways (hereinafter referred to as the said company) scheduled flight 465 from Niigata Airport to Naha Airport.

The flight plan of the said aircraft submitted to Niigata Airport Office of the Civil Aviation Bureau was as follows:

FLIGHT RULES: IFR, DEPARTURE AERODROME: Niigata Airport, CRUISE SPEED:456kt, CRUISE ALTITUDE: FL350, ROUTE: HAKUBA (Fixed point)–V30–JEC (Miho VORTAC)–V54–HKC (Kagoshima VORTAC)–A582–ONC (Erabu VORTAC)–NHC (Naha VORTAC), DESTINATION AERODROME: Naha Airport, TIME:02:10UTC, TOTAL EET: 2 hours 42minutes, ENDURANCE: 4 hours 24 minutes.

The said aircraft took off from Niigata Airport at 11:20 with 55 persons on board—49 passengers and six crew members. At around 11:45, while cruising at FL350 over the Sea of Japan approximately 75km northwest of Toyama City, the pressure altitude of the cabin (the cabin altitude), which had been maintained at 6,000ft, started to increase. Since this indicated that the air pressure in the cabin was dropping, the said aircraft made an emergency decent to a flight altitude of 12,000ft and diverted to Osaka International Airport, where it landed at 12:25.

(1) The outline of the circumstances of the occurrence of this serious incident based on the statements of the Captain and First Officer is as follows.

On the day of the incident, the said aircraft was planned to fly two legs: from Osaka International Airport to Niigata Airport, then from Niigata Airport to Naha Airport.

The said aircraft took off from Niigata Airport at 11:20, and the autopilot was engaged at around 10,000ft. Thereafter, the said aircraft leveled off at FL280 and FL310 during its climb in accordance with instructions from Tokyo Air Traffic Control Center before finally reaching FL350.

At around 11:43, while cruising at FL350 around 40nm northwest of TOE (Toyama VORDME) and cleared direct to JEC (Miho VORTAC), the First Officer, who was the Pilot Flying, recognized that an aural warning had sounded accompanied by illumination of the Master Caution. The First Officer confirmed from the ECAM (Electronic Centralized Aircraft Monitor) display that the gate of the safety valve of the cabin pressurization system was open and that the cabin altitude had exceeded the specified limit.

The Captain took over control of the aircraft, promptly decided to make an emergency decent, and donned his oxygen mask along with the First Officer. The First Officer confirmed by communication with the cabin crew that the passenger oxygen masks had dropped automatically, and so did not deploy them manually. The seat belt signs were also switched on in accordance with the emergency decent operating procedures.

The Captain deployed the speed brakes and, with the autopilot remaining engaged, effected a 3,000ft/min descent at airspeed of approximately 260kt. Then, as a result of the cabin altitude exceeding 13,000ft, he increased airspeed to 300kt to obtain a greater rate of aircraft descent. The cabin altitude ultimately reached 21,600ft. At an aircraft altitude of around 24,000ft, the Captain confirmed that all passengers and cabin crew members had donned oxygen masks, and continued descending at a rate of 2,000ft/min and a cabin altitude descent rate of 1,000ft/min.

The Captain confirmed that the aircraft altitude was less than 13,000ft, and cancelled the donning of passenger oxygen masks.

Because there was much cloud at around 10,000ft and turbulence had been forecast, the aircraft cruised at 12,000ft. We decided to divert to Osaka International Airport, with ATC clearance to this airport.

Although ATC asked about the preparation of firefighting appliances and ambulances, these were not requested since there was no structural damage to the aircraft which would have affected landing, and no passengers had experienced hypoxia or sustained injuries.

The said aircraft landed at Osaka International Airport at around 12:25.

(2) The outline of the circumstances of the occurrence of this serious incident based on the statements of the cabin crew is as follows.

Cabin crew members experienced unusual feelings in the ears and difficulty in breathing, but heard no abnormal sounds. The seat belt signs were switched on prior to the emergency decent. The passenger oxygen masks dropped automatically, so the passengers were instructed to fasten their seat belts and to put the oxygen masks on. At that time, it was difficult to hear the prerecorded cabin announcement concerning the oxygen masks and seat belt fastening. Among the passengers, one person complained of earache and another complained of feeling unwell, but there were no injured persons.

(3) The outline of the circumstances of the occurrence of this serious incident based on the statements of passengers is as follows.

Passengers stated that their ears started hurting and that the temperature in the cabin decreased, then the oxygen masks dropped. They were able to use the oxygen masks without difficulty since they had watched the pre-takeoff video explaining their use. Thereafter, there was a cabin announcement that the aircraft was making an emergency descent because of trouble with a safety valve that controlled air pressure. The cabin crew and passengers remained relatively calm and there was no state of confusion.

This serious incident occurred at around 11:45 at an altitude of 35,000ft over the Sea of Japan, approximately 75km northwest of Toyama City.

2.2 Injuries to Persons

There were no injuries to any of the 55 persons—49 passengers (including 4 infants) and six crew members—on board the aircraft.

2.3 Damage to Aircraft

There was no damage to the aircraft.

2.4 Crew Information

2.4.1 Flight Crew

(1) Captain: Male, aged 37

Airline Transport Pilot License	No.A105133
Type Ratings	
Airplane multiengine (land)	Issued April 30, 1986
Airbus A320-200	Issued April 17, 1991
Class 1 Airman Medical Certificate	No.12651496
Term of Validity	Until April 5, 2002

Total flight time	6,470 hours 54 minutes
Flight time during the previous 30 days	21 hours 25minutes
Total flight time on Airbus A320-200	3,050 hours 29 minutes
Flight time during the previous 30 days	21 hours 25minutes

(2) First Officer: Male, aged 31

Commercial Pilot License	No.A315574
Type Rating	
Airplane multiengine (land)	Issued August 22, 1996
Airbus A320-200	Issued May 12, 2000
Instrument Rating	No.7372
	Issued August 22, 1996
Class 1 Airman Medical Certificate	No.12651303
Term of Validity	Until July 7, 2002
Total flight time	1,157 hours 00 minutes
Flight time during the previous 30 days	31 hours 24 minutes
Total flight time on Airbus A320-200	905 hours 00 minutes
Flight time during the previous 30 days	31 hours 24 minutes

2.5 Aircraft Information

2.5.1 The Aircraft

Type	Airbus A320-200
Serial number.	685
Date of manufacture	April 16, 1997
Certificate of Airworthiness	Tou-10-586
Term of validity	Until valid data of ANA Maintenance Program Manual from October 28, 1998
Total flight time	10,067 hours 10 minutes
Flight time since scheduled maintenance “4C” Check on December 25, 2001	2 hours 24 minutes

2.5.2 The Engines

Type: CFM International model CFM56-5A1

	Serial number	Date of manufacture	Total time in service
No.1	731920	February 25, 1997	10,067 hours 10 minutes
No.2	731711	May 20, 1992	17,693 hours 21 minutes

2.6 Meteorological Information

2.6.1 The aviation weather observations (METAR) provided by Toyama Airport located approximately 75km southeast of the point at which the incident occurred were as follows.

Time of Observation	11:00 JST	12:00 JST
Wind Direction	180 degrees	VRB
Wind Speed	04 kt	03 kt
Visibility	30 km	30 km
Cloud amount	1/8	1/8
Cloud type	cumulus	cumulus
Height of cloud base	2,500 ft	2,500 ft
Cloud amount	3/8	6/8
Cloud type	stratocumulus	altocumulus
Height of cloud base	6,000 ft	10,000 ft
Cloud amount	6/8	---
Cloud type	altocumulus	---
Height of cloud base	9,000 ft	---
Temperature	5°C	7°C
Dew point	–1°C	–3°C
QNH	30.20 inHg	30.16 inHg

2.6.2 According to the statements of the flight crew, Visual Meteorological Conditions were prevailing at the altitude and in the vicinity of the point of occurrence of the serious incident. Also, there was approximately 3/8 cloud cover at around 20,000ft in the vicinity of the Noto Peninsula, but the ground was visible.

2.7 Information on the Aircraft Recorders

The said aircraft was equipped with an Allied Signal model 980-4700-003 Digital Flight Data Recorder (DFDR), and a Fairchild model A200S Cockpit Voice Recorder (CVR) on which voices and sounds in the cockpit are recorded and stored for two hours.

The DFDR and CVR recorded all data from the time the said aircraft departed Niigata Airport until it landed at Osaka International Airport.

The recording on the said aircraft's QAR (Quick Access Recorder) was also used to obtain data not recorded by the DFDR.

2.8 Tests and Research to Find Facts

2.8.1 Safety Valve Overview

The cabin pressurization system of the Airbus A320 is designed to maintain a maximum cabin altitude of 8,000ft (approximately 11.03psi) when the aircraft is cruising at high altitude by controlling the opening and closing of an outflow valve. Further, it is designed to limit the differential pressure between the cabin pressure and the ambient pressure to a maximum of 8.06psi.

In addition, the set of two safety valves is installed on the aft pressure bulkhead to protect the aircraft structure in case of that such the malfunction of pressurization system as unable to be controlled by the outflow valve may occur. These safety valves are pneumatic valves consisting of two chambers and control part.

As shown in Figure 4, if the cabin pressure rises such that the differential between the cabin pressure and the ambient pressure exceeds a specified limit (positive pressure), the diaphragm (⑧ in Figure 4) in the control valve moves to the right, the gate ③ of the safety valve opens and the cabin pressure is relieved. On the other hand, if the cabin pressure becomes less than the ambient pressure (negative pressure), the gate ③ of the safety valve opens by the opening of a poppet valve ⑪ in the cabin chamber, and the differential pressure between the inside and outside of the cabin is regulated within the specified limits.

(See Figures 4 and 6 and Pictures 1 and 2.)

Reference: The relationship between Altitude and Standard Atmospheric Pressure

At Sea Level:	1 atmosphere	(approx. 14.70psi, 1013hPa)
At an altitude of 8,000ft:	approx. 3/4 atmosphere	(approx. 11.03psi, 760hPa)
At an altitude of 18,000ft:	approx. 1/2 atmosphere	(approx. 7.35psi, 507hPa)
At an altitude of 34,000ft:	approx. 1/4 atmosphere	(approx. 3.68psi, 253hPa)

2.8.2 Investigation of the communications of the said aircraft's air to ground data link system

The said company's ground facility automatically received and recorded downlink data from the said aircraft's ACARS (Aircraft Communications Addressing and Reporting System) air to ground data link system. The following information on warnings had been recorded:

(1) 11:45: SAFETY VALVE OPEN
(Safety valve not fully closed)

(2) 11:46: EXCESS CAB ALTX
(Cabin altitude exceeded 9,550 ft±350 ft)

(3) 11:48: LO DIFF PRXX
(Loss of cabin pressure)

2.8.3 Investigation of the cabin pressure system of the said aircraft

On December 28, 2001, the cabin pressurization system and structure of the said aircraft were investigated at the hanger of the said company at Osaka International Airport. The set of two safety valves was installed in the aircraft, serial numbers 9632127 (S/N127) and 9632129 (S/N129). It was found by a positive differential pressure test (Positive Relief Test) that the gate of the safety valve (S/N129) opened at 5.16psi. The Aircraft Maintenance Manual (AMM) specifies that the gate opens in the range 8.52–8.67psi. No other anomalies were found except for this safety valve.

The history of this safety valve is as follows.

The set of two safety valves in question, S/N127 and S/N129, had been installed in another aircraft of the same model belonging to the said company since manufacture in 1997.

The maintenance program manual of the said company specifies a functional test of the safety valves as a required inspection item to be accomplished during the “4C” aircraft maintenance check (carried out at 60-month intervals). On November 8, 2001, during the aircraft’s first 4C Check, these valves were found to be outside operating tolerances (the gate valve should not open at the specified maximum positive differential pressure), and they were removed from the said aircraft.

Thereafter, the differential pressure at which the safety valves should operate (the actuation differential pressure) was adjusted at an Approved Repair Station (ARS) certified by the Civil Aviation Bureau of Japan. The Component Maintenace Manual (CMM) prescribes the limit at which the gate should open as 8.55–8.60psi. At that time, S/N127 and S/N129 were adjusted to approximately 8.59psi and approximately 8.57psi respectively. Subsequently, they were tagged with “Authorized Release Certificate” in accordance with Civil Aviation Regulation Operating Standard Article 41, and were stored as serviceable spare parts of the said company.

During the first 4C Check of the said aircraft, it was found that the safety valves fitted at that time were out of tolerance (they should not have opened when the differential pressure reached the positive maximum pressure specified). They were removed and replaced with S/N127 and S/N129, which had been stored as spare parts, on December 25, 2001. After that, the said aircraft made three flights before the occurrence of this serious incident, and the maximum cruising altitude reached during that period was 25,000ft (maximum differential pressure: 7.37psi).

There were no maintenance records on S/N127 and S/N129, apart from the above-mentioned adjustment of the differential pressure.

2.8.4 Detailed Investigation of the Safety Valves

The set of two of safety valves installed in the said aircraft at the time of the incident was removed and subjected to functional and other tests at the ARS. The results of these tests were as follows:

(1) Functional test of S/N129

① A visual check revealed no abnormalities.

② In functional test for positive differential pressure, the valve could not support a pressure differential of more than 0.39psi, a worse condition than when it had been installed in the aircraft.

③ The stem assembly (an internal part of the control valve) was assembled into a good safety valve (S/N127) and the positive differential pressure functional test was repeated. As a result, the gate opened at 0.44psi. The focus of the search for the abnormal operation therefore shifted elsewhere.

④ The parts of the control valve apart from the stem assembly were substituted with parts from a good safety valve (S/N127) and the positive differential pressure functional test repeated. As a result, the gate has opened at approximately 9.01psi, nearly the specified limit, and the anomalous behavior was not exhibited.

(2) Disassembly Investigation

① Servo Chamber of S/N129

a. Visual inspection of the inside of the servo chamber revealed no abnormalities. Also, no foreign particles were found in the orifice of the servo chamber through which cabin air flows.

b. No foreign particles were found in the filter of the servo chamber.

② Comparison of Control Valves of S/N127 and S/N129

a. The internal state of the stem assemblies was confirmed by X-ray inspection photographs. As far as visual inspection of the X-ray photographs could show, the shapes of the internal parts of both valves were the same, and no foreign objects etc. were found to have entered. However, the amount of deformation of the stem spring of S/N129 was slightly larger than the other.

b. Comparing the two stem valves, the total length etc. of the stem poppet, the external dimensions of each part, and the spring loads were found to be virtually the same. Further, visual inspection revealed no bending of the stem poppet of either valve.

(3) Visual Inspection of the Stem Assembly using a Microscope

Microscopic inspection of the stem poppet and of the seat assembly, which forms part of the stem assembly, revealed the following.

① On S/N129, several foreign particles, scratches and contamination were confirmed around the contacting surface of the stem poppet of the seat assembly, and the bush hole in which the stem poppet slides was found to be partially worn. Also, several burrs were found on the edge of a drill hole in the seat assembly.

② On S/N127, a few burrs were found on the edge of a drill hole in the seat assembly, but no other abnormality was found.
(See Photographs 3–7.)

(4) Adjusting Ranges of Adjusting Screw

The adjusting screw, which sets the valve's positive differential pressure cracking point (indicated as "set screw" in Figures 4 and 5), was driven in to an abnormal depth on S/N129. The length from the control cover to the tip of adjusting screw head was measured as 1.63mm, but is nominally around 5.6mm.

It was found to be normal on S/N127.

(5) Dimensional Measurement of the Stem Bush Hole of S/N129

From outside the seat assembly, a pin gage with 0.9mm diameter could be inserted into the stem bush hole in which the stem poppet slides, but a pin gage with 1.14mm diameter could not be inserted.

The minimum internal diameter specified for the said bush hole is 1.155mm. It was thus confirmed that the said bush hole had been drilled to a smaller diameter than the specified minimum.

(See Figures 4–6.)

2.8.5 Additional Investigations of the Safety Valve

Following drop test, and functional tests followed by reassembly of the stem assembly were performed to further investigate safety valve S/N129 that had been installed in the said aircraft. The results of these tests, which were conducted at the safety valve manufacturer's facilities, are summarized as follows.

(1) Drop test

In the drop test, the stem poppet was dropped vertically into the stem bush hole with the seat assembly in an upright position. Normally, the stem poppet dropped into the seat assembly smoothly without resistance. However, in the test, the stem poppet did not pass smoothly through the stem bush hole.

(2) Reassembly of the stem assembly

During the reassembly of the stem assembly, burrs were pushed out from the stem bush.

(3) Confirmation of stem poppet movement after reassembly

The compression force against the spring load of a spring in the stem assembly was found to be within specified limits.

(4) Air leak test after reassembly

No air leak was found beyond specified limits.

(5) As the result of the investigation in subsection 2.8.4 (4), it was confirmed that the adjustment range of adjusting screw was abnormal. This was because the thickness of a shim used when the stem assembly was assembled into the control valve was 2.16mm instead of the nominal 0.9mm. The shim was therefore adjusted to normal thickness.

(6) Functional test for positive differential pressure after reassembly

The anomalous operation of the valve described in sections 2.8.3 and 2.8.4 was not reproduced.

2.8.6 Analysis of DFDR Data and CVR Recordings

(1) Analysis of the DFDR data

The result of analyzing the recordings of the DFDR etc. was as follows:

The said aircraft took off from Niigata Airport on 11:20 and reached its cruising altitude of FL350 at around 11:37. At this time the differential pressure between the inside of the cabin and the outside indicated 8.03psi, and the cabin altitude indicated around 6,600ft.

From 11:45:38, the cabin altitude started to increase suddenly.

At around the same time, the cabin pressure controller (CPC), which controls cabin pressurization, commanded the outflow valve (OFV) to close in order to keep cabin pressure from falling.

At 11:45:50 the said aircraft started to descent. The recorded cabin altitude peaked at 21,600ft at 11:48:20, and then decreased with the descent of the said aircraft.

At around 11:52, the CPC commanded the OFV to open in order to maintain the rate of change of cabin altitude at –750ft/min (the minus sign indicates cabin pressure increasing). As a result of this control, as the aircraft descent rate exceeded the cabin altitude descent rate for a time, the cabin altitude exceeded the flight altitude for a time.

At around 11:53, the said aircraft leveled off. Consequently, the CPC ceased control of a rate of change of the cabin altitude and commanded the OFV to close.

After 11:56 the cabin altitude of said aircraft maintained a constant value rather lower than the flight altitude, and the rates of change of flight altitude and cabin altitude were virtually unchanging.

(See Figure 2.)

(2) Analysis of the CVR Recordings

The result of analyzing the CVR recordings was as follows:

No abnormal alert sounds etc. related to cabin pressure were recorded before 11:45:38. At 11:45:38, the Captain and First Officer recognized from the ECAM display that the cabin pressure was dropping because the gate of a safety valve had opened. Five seconds later, the Captain decided to make an emergency descent and he and the First Officer donned oxygen masks. Thereafter, the CVR recorded the voices of the Captain and First Officer mixed with sounds of oxygen supply from the oxygen masks. The sound of the cabin altitude warning was recorded on the CVR recordings twenty-five seconds after the Captain and First Officer had recognized the abnormal cabin pressure.

After around ten seconds, the Captain had recognized the abnormal cabin pressure; he made a request to make an emergency descent to ATC. Forty seconds after that, the prerecorded cabin address regarding putting on oxygen masks, fastening seat belts etc. played automatically.

At around 11:50, the Captain judged that the abnormal cabin pressure would not recover, and decided to land at Osaka International Airport. At around 11:54, the Captain confirmed that the cabin altitude had become lower than 13,000ft and cancelled the passenger indication to use oxygen masks. At around 11:56 the Captain confirmed the cabin altitude had become lower than 10,000ft, and he and the First Officer released their oxygen masks. At around 12:25 the said aircraft landed at Osaka International Airport.

2.9 Other Relevant Information

2.9.1 Airplane Operating Manual of the Said Aircraft

The manual specifies that in the event of sudden decrease in cabin pressure, oxygen masks should be put on immediately, and if decompression occurs, speed brakes should be fully extended and an emergency descent made to 10,000ft, with the aircraft flown either at maximum airspeed or at an appropriate airspeed (if there are concerns about structural failure, airspeed should be decreased to a suitable value while paying attention to controlling the aircraft). ATC should be notified beforehand, with the intentions of the pilot etc. reported clearly.

Further, it is specified that at the time the cabin altitude reaches 13,000ft or below, the cabin crew should be notified that oxygen masks may be released.

2.9.2 Effect of Decompression in a Cabin on the Human Body

According to “Aerospace Medicine: Flight and the Human Body” (by Haruo Ikeda, published by Houbun-Shorin, November 1971), the effects of cabin decompression on the human body are as follows.

(1) Hypoxia

The symptoms of lack of sufficient oxygen to human body cells or tissues are called “hypoxia”, and there are following relations:

Altitude (ft)	Stage	Symptoms
0–10,000	Indifferent	None, but visual sensitivity reduced at night.
10,000–15,000	Compensatory	Major symptoms may not appear due to compensatory mechanisms.
15,000–20,000	Disturbance	Hazards of visual disturbance and intellectual impairment, etc.
above 20,000	Critical	Danger of rapid loss of consciousness with little or no warning and loss of life.

The Time of Useful Consciousness (TUC) is defined as the amount of the time between the start of oxygen deficiency and the appearance of slight indications of loss of consciousness. The following table shows the TUC at various altitudes; however, TUC varies according to the individual.

Altitude (ft)	Time of Useful Consciousness
22,000	5 minutes
25,000	2–3 minutes
28,000	1 minute 30 seconds
30,000	1 minute 15 seconds
35,000	45 seconds

(2) Decompression Sickness

Decompression sickness results from the expansion and contraction of gases trapped in the ears, nasal passages etc. and from nitrogen and other gases dissolved in the blood, tissues etc. coming out of solution.

Trapped gases cause symptoms of earache, nose ache, stomach ache etc. Bubbles formed by gases coming out of solution cause symptoms of arthralgia of the shoulders, elbow, hands etc. and also difficulty in breathing, aching lungs etc. due to the restriction of blood vessels. Although rare, restriction of blood vessels in the brain by evolved gas bubbles can cause loss of consciousness and visual impairment.

2.9.3 Classification of "Abnormal drop of cabin pressure in an aircraft" specified by the United States Federal Aviation Administration

Advisory Circular (AC) 61-107 issued by Federal Aviation Authority (FAA) of the United States contains the following classification of degrees of decompression rate.

(1) Explosive Decompression

This is a phenomenon in which cabin pressure equalizes with ambient pressure in less than 0.5 seconds. There is a high probability of damage to the human body by decompression sickness etc.

Because it is considered that unsecured objects will fly around, all loose items such as baggage should be properly secured before flight. Also, aircraft with smaller pressurized cabin volumes are more prone to this type of decompression.

(2) Rapid Decompression

This drop of cabin pressure is not as abrupt as in the case of explosive decompression, and the likelihood of damage to the human body by decompression sickness etc. is significantly lower.

(3) Gradual Decompression or Slow Decompression

This decompression is difficult to perceive by bodily sensations as opposed to cases (1) and (2) above. The consequent possibility that recognition will be late makes this type of decompression dangerous.

Generally, automatic visual and aural warning systems provide indication of decompression so that it may be detected even if the pilot does not recognize it by bodily sensations.

A Safety Recommendation dated December 20, 2000 issued by the United States National Transportation Safety Board (NTSB) describes in a Reference Note that Rapid Decompression is a phenomenon in which pressure reduces to ambient within a period of between 0.5 second and 10 seconds, whereas Gradual Decompression is a phenomenon in which pressure decreases to ambient over a long period of the time.

2.9.4 Concerning the replacement of the Safety Valves at the "4C" Check of the Said Aircraft

In the event of replacement of a safety valve, there is no specification in the AMM of the said aircraft that calls for a subsequent test to confirm that the gate opens and closes at the appropriate differential pressures. However, it is specified that when the opening and closing of the said valves is verified, it must be confirmed that this is displayed on the cockpit instruments.

According to the maintenance records, the replacement of the safety valves was accomplished in accordance with the specification of the AMM.

2.9.5 Concerning the Maintenance for S/N127 and S/N129

The only one maintenance service carried out on S/N127 and S/N129 as described in section 2.8.3, that was the adjustment of the setting at which the gate opened, was accomplished on November 16, 2001 at an ARS.

According to the maintenance records of the ARS, the adjustment was performed appropriately according to the updated CMM issued by the safety valve manufacturer. The adjustment screw of the control valve was driven inwards, and the setting brought to within specified limits by increasing the preload on spring-"A" shown in Figure 6.

Further, according to the CMM used at the time, one adjustment suffices to set the positive differential pressure.

3. ANALYSIS

3.1 Analysis

3.1.1 The Captain and First Officer had valid airman proficiency certificates and valid airman medical certificates in accordance with applicable regulations.

3.1.2 The aircraft had a valid certificate of airworthiness and had been maintained in accordance with applicable regulations.

3.1.3 It is estimated that the weather conditions at the time of the serious incident were not contributed with the serious incident.

3.1.4 Based on the statements of the Captain, cabin crew and passengers, the recordings of ACARS down link data and DFDR data, and the investigation of the safety valves, it was recognized that an abnormal loss of cabin pressure on the said aircraft had actually occurred.

According to the recordings of the DFDR etc., it took approximately three minutes for cabin pressure to be virtually equalized with ambient pressure. According to the classification of decompression in AC61-107, this event is recognized as a Gradual (slow) Decompression.

3.1.5 At the first 4C Check visit of the said aircraft, the gates of safety valves installed up to that time had not opened even at the maximum correct positive differential pressure. The safety valves were therefore replaced with S/N127 and S/N129 that had been stored as spare parts. At this point, as the AMM did not specify confirmation of the differential pressure function, a functional test of the gate opening of said valves was not carried out.

3.1.6 After the first 4C Check visit, the said aircraft made three flights before this serious incident occurred. It is estimated that the maximum cruising altitude reached during this period was 25,000ft, and that the maximum differential pressure between the inside and the outside of the cabin was 7.37psi. Further, it is estimated that during the flight in which this serious incident occurred, the said aircraft was cruising at an altitude of around 35,000ft, and the differential pressure between the inside and the outside of the cabin was around 8.03psi.

3.1.7 Based on the recordings of the DFDR etc., while the said aircraft was in cruise the cabin altitude increased abruptly from around 6,600ft to around 21,600ft. Following the descent of the said aircraft, after 11:56 the cabin altitude and the aircraft altitude maintained a constant differential, with the cabin altitude slightly lower than the flight altitude, and the rates of change of flight altitude and cabin altitude were virtually constant. It is considered that this is because the gate of a safety valve did not close after having opened. As described below, as a result of anomalies found in safety valve S/N129, it is estimated that the cause was the incorrect operation of safety valve S/N129.

(1) As the result of the investigation of the cabin pressurization system of the said aircraft as described in section 2.8.3 and the functional test of the safety valve as described subsection 2.8.4(1)②, it was found that the one of the set of two safety valves that had been installed, S/N129, opened at below the specified differential pressure limit. Therefore, it is estimated the pressurized air from the aircraft cabin had leaked through the gate of the safety valve S/N129.

(2) Based on the functional test of the safety valve as described subsection 2.8.4(1)③, because the abnormal behavior was transferred from safety valve S/N129 to safety valve S/N127, it is estimated that there were abnormalities in the stem assembly of safety valve S/N129.

(3) From the fact that there was no maintenance history indicating disassembly of the said valve prior to the occurrence of this serious incident, it is estimated that the anomalies—*viz.* the abnormalities existing inside the stem assembly (the existence of contamination and burrs at the edges of a hole, and the bush hole being of a smaller diameter than the specified limit), and that a thicker shim than specified had been used—had already been present at the manufacturing stage. Further, it is estimated that the increase in the preload of spring-“A” of the control valve during the adjustment work carried out at the ARS resulted in the gate opening at a value below

the specified limit.

(4) A higher cruise altitude had been selected for the flight concerned than had been flown in the other three flights since the 4C Check in which the safety valves had been replaced. It is considered possible that during cruise, changes in the environment due to vibrations during flight etc. resulted in the control valve operating (due to motion of the stem poppet, which was stuck to the seat housing) at a lower pressure differential than the limit that had been set, which caused the gate to open. It is further estimated that as a result of the abnormalities of the stem assembly described in (3) above, the motion of the stem poppet was restricted and as a result the open condition remained until the time of landing.

(5) The gate of the safety valve first opened at FL350 (differential pressure 8.03psi), it opened at 5.16psi at the time of investigation of the cabin pressurization system of the aircraft, and at the time of the detailed investigation of the safety valves a differential pressure above 0.39psi could not be supported. The function was thus getting clearly worse. Furthermore, when the differential pressure functional test was carried out after swapping the safety valve of S/N129 with that of S/N127, a differential pressure above 0.44psi could not be supported.

It is estimated that the reason for this deterioration in performance was the final jamming of the stem poppet, the movement of which had already had a tendency to be restricted.

(6) When the adjusting screw was driven inwards during the differential pressure adjustment maintenance work as described in the section 2.9.5, it is estimated that the result of the adjustment was within specified limits for the following reasons: anomalies that existed inside the stem assembly at the manufacturing stage (the diameter of bush hole being smaller than the specified value and the existence of foreign particles inside the stem assembly) caused increased friction between the bush and the stem poppet which resulted in the stem poppet not sliding smoothly; and a shim had been set inappropriately at the time of manufacture.

3.1.8 Based on the statements of the Captain and First Officer and the analysis of the CVR recordings, the Captain and First Officer donned oxygen masks five seconds after they had confirmed the abnormal cabin altitude on the ECAM display. It is recognized that their subsequent actions were carried out speedily and appropriately; five seconds after donning oxygen masks, they requested an emergency descent to ATC while almost simultaneously deploying full speed-brake, and commenced a descent to an altitude of approximately 12,000ft at the 260kt airspeed that had been maintained until that time, etc. In addition, it is considered that as oxygen masks were used appropriately, there was practically no affect on the bodies of the passengers and crew.

Although the Airplane Operating Manual of the said aircraft specifies that an emergency descent be made to an altitude of 10,000ft as described in the section 2.9.1, since according to the statements of the Captain and First Officer there was much cloud at around 10,000ft and some turbulence had been forecasted, it is recognized that the judgment to descend to and maintain an altitude of up to 12,000ft was appropriate.

The said Operating Manual further prescribes that an emergency descent should be made at maximum airspeed. While the maximum operating airspeed at FL350 was 280kt, the descent was initiated at the airspeed of 260kt that had been maintained until that time. Thereafter the airspeed increased and did not exceed 300kt during the descent. Comparing to the table below, the emergency descent was not conducted at maximum airspeed operating limits. It is estimated that this was because the Captain could not have dispel suspicions that there might have been structural failure besides the malfunction of the safety valves, and so in accordance with the said Operating Manual he made the emergency descent selecting an airspeed within normal operating airspeed ranges specified in OM.

Altitude (FL)	Maximum Operating Airspeed Limit (kt)
350	280
320	300
246 and below	350

4. PROBABLE CAUSE

In this serious incident, it is estimated that while the aircraft was operating at an altitude of 35,000ft for the first time since the replacement of the safety valves, the gate of a safety valve opened at a differential pressure lower than the specified limit and this open condition persisted. As a result there was a decrease in cabin pressure.

It is estimated that the opening of the gate of the safety valve below the specified pressure limit and the persistence of its open condition was caused mutually by the existence of anomalies in the stem assembly and an inappropriate shim adjustment, both at the time of manufacture of the said valve.

5. MATTERS FOR REFERENCE

5.1 Response of the Safety Valve's Manufacturer

(1) Corrective Measures taken related to the production of safety valves after 1998

Of the safety valves repaired since 1998, inspection when the valves were accepted for repair found that 40% operated at a greater positive differential pressure than the limit specified in the CMM. This necessitated remedial action from the point of view of protection of aircraft structures, and as a result the following corrective measures had been planned by March 2001:

① Improvements to the production process

a. Adjustment of the operating point

(a) Reduction of the rate of pressure change

(b) Carrying out of the adjustment process at least three times

b. Improvements at the time of control valve assembly

(a) Implementation of the stem poppet drop test (inspection to confirm that the stem poppet enters the bush hole of the seat assembly smoothly by dropping the stem poppet into the bush hole from the opposite direction).

(b) 100% inspection of the stem assembly spring load.

(c) To ensure that no burrs remain after drilling, implementation of supplier auditing, an additional cleaning process at the safety valve manufacturer, and 100% inspection of key dimensions.

(d) Total inspection for stem poppet straightness (no bending).

(e) Implementation of control valve leakage test.

(f) Training of personnel in correct shim adjustment.

② Improvement of CMM

a. Designation of the stem assembly as a non-repairable part.

b. Revision of the CMM, reflecting to make the production process consistent with the method of adjusting the operating point of the valve.

(2) Corrective Measures following this incident investigation

As a result of the additional safety valve investigations carried out in this serious incident investigation, a revised CMM reflecting the following contents was issued on March 13, 2002.

① Establishment of a minimum limit for adjustment screw protrusion.

② Execution of the Positive Relief Test at least three times to verify the set value. Also establishment of its tolerances of the lower and upper limits.

③ Supplement paragraphs relating to troubleshooting tests with confirmation of motion of the stem poppet and with leakage tests of the stem assembly and the control valve.

5.2 Response of the Aircraft Manufacturer

The AMM was revised on May 1, 2002, such that a Relief Test of the safety valves is also carried out three or more times with the valves installed in the aircraft.

5.3 Response of the ARS

(1) Based on an "Engineering Order" issued by the said company, the work sheet for repair was revised to specify that the Relief Test be repeated at least three times to verify no scatter of the calibrated value.

(2) The revised contents of the CMM as described in section 5.1 (2) were reflected to the work sheet on June 12, 2002.

5.4 Response of the said Aircraft Operator

(1) Provisional Measures

Relief Tests were conducted on the safety valves installed on Airbus A320-200 and A321-131 aircraft belonged to said aircraft operator.

(2) Permanent Measures

The stem assemblies of the safety valves installed in all Airbus A320-200 and A321-131 aircraft belonging to the said aircraft operator were replaced with ones manufactured on and after May 2001 and that incorporated the manufacturing improvements, and at the same time, the shim thickness of a stem assembly was verified and corrected as necessary.

Figure1　Three views

Unit：m

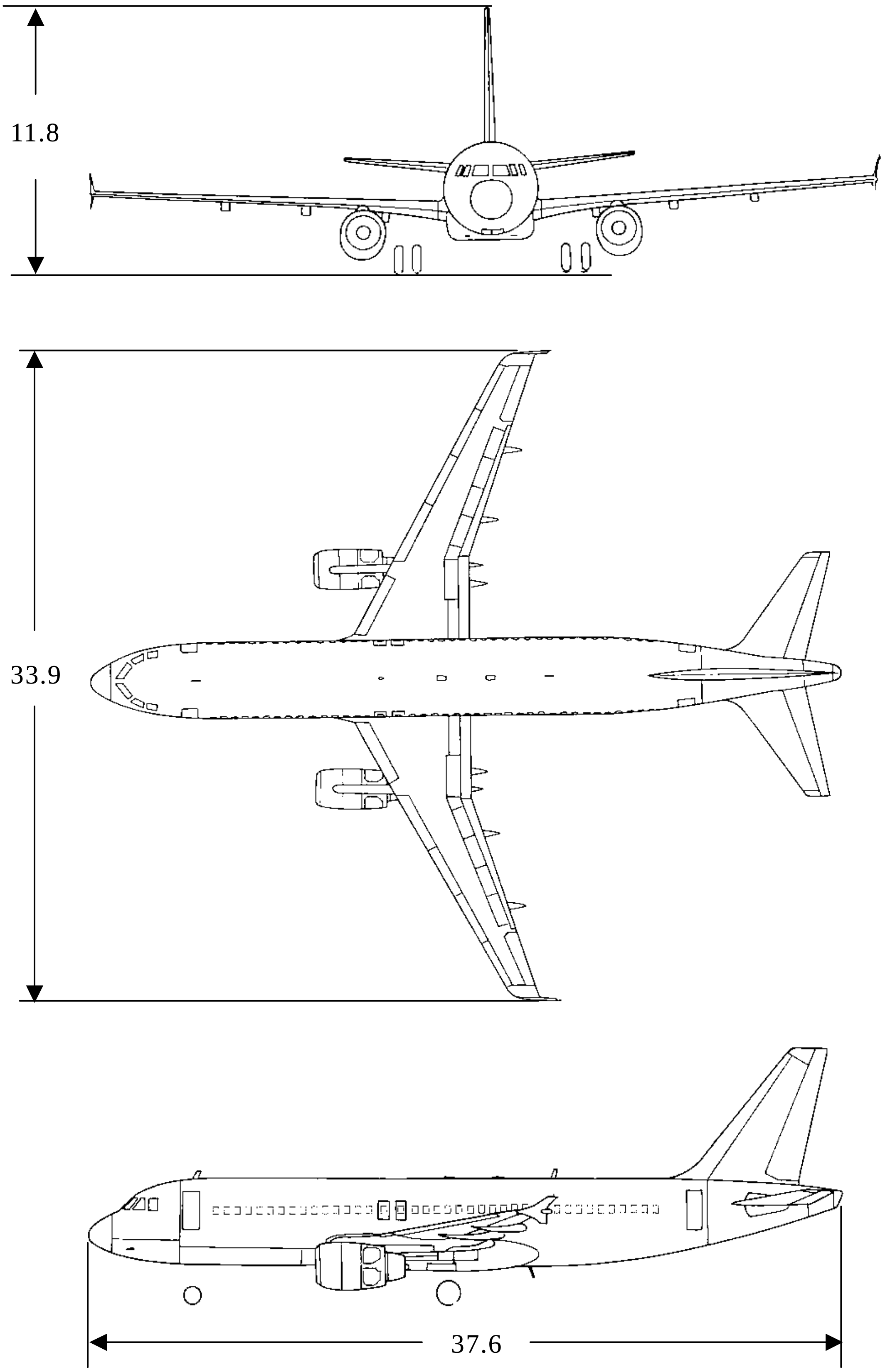


Figure 2　DFDR etc. data

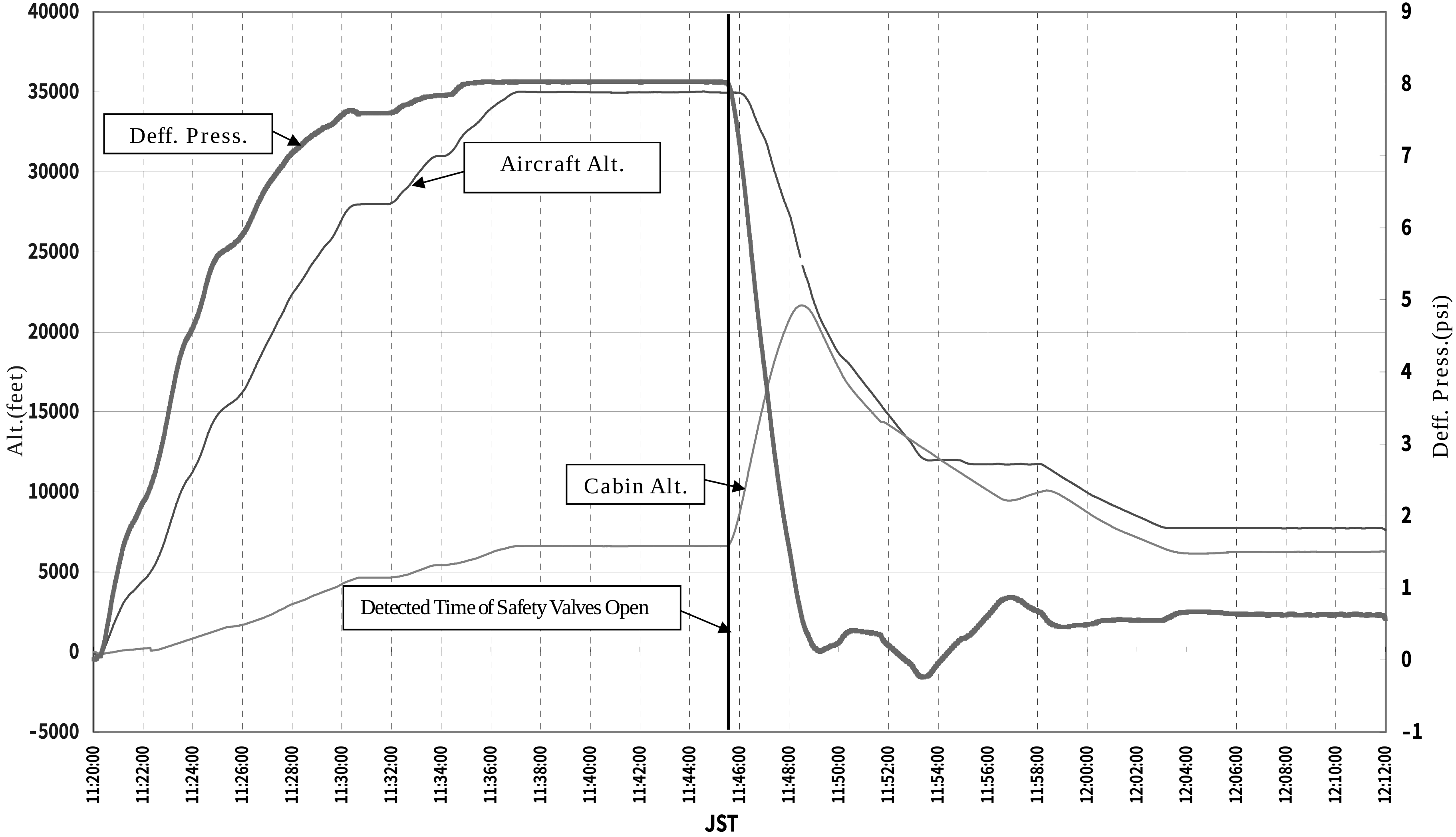


Figure 3 Installed Position of Safety Valves

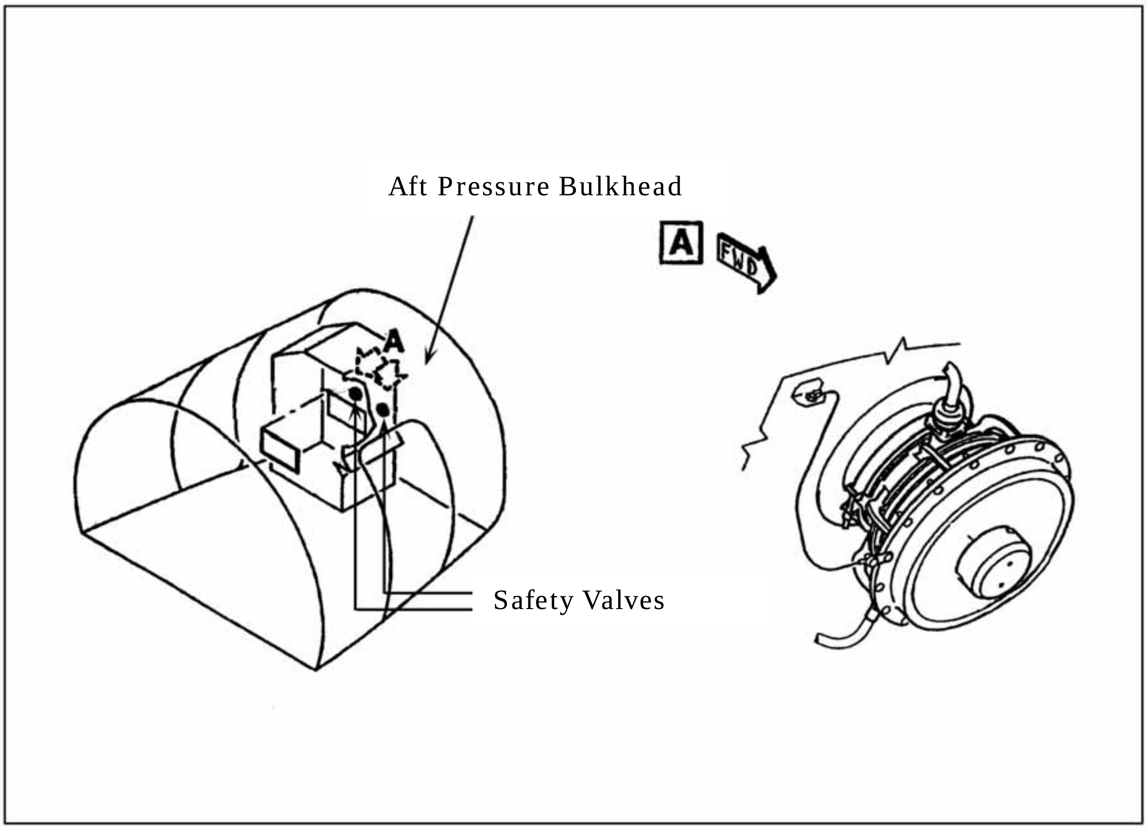
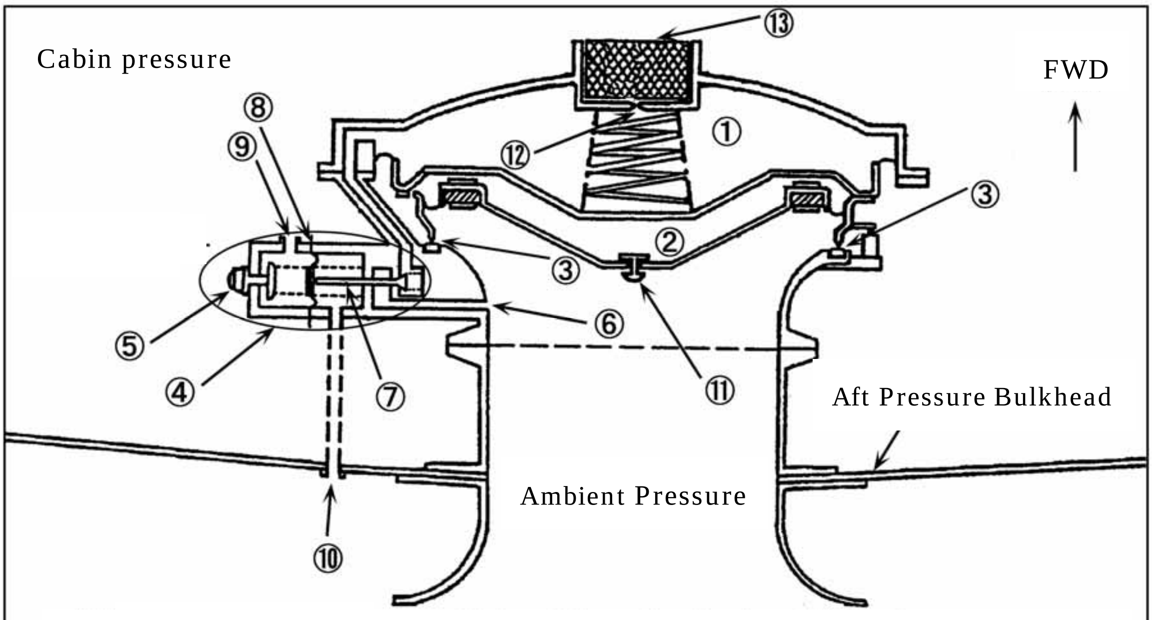


Figure 4 Cross-Sectional View of Safety Valve



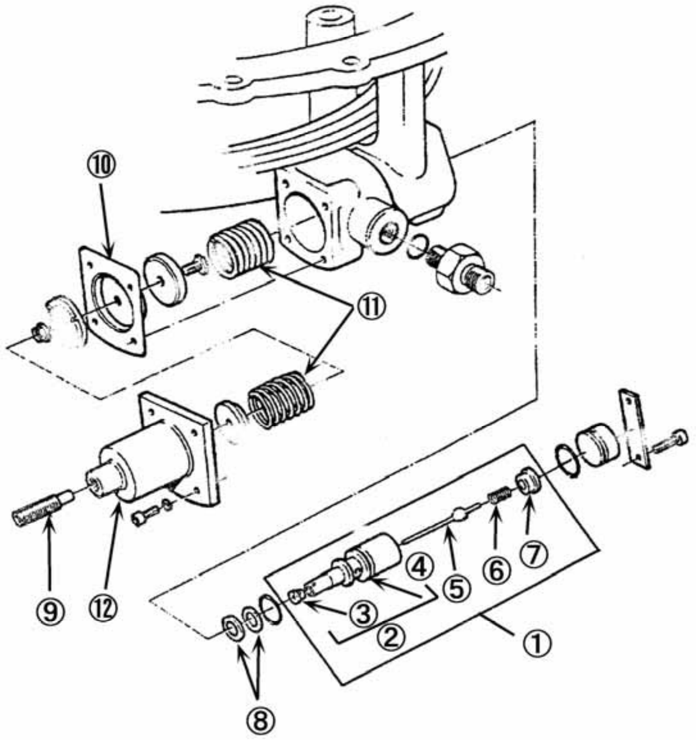
①Servo Chamber ②Cabin Chamber ③Gate ④Control Valve

⑤Setscrew ⑥Internal Bore ⑦Stem, Poppet ⑧Diaphragm

⑨Sensing Hole for Cabin Pressure ⑩Sensing Bore for Ambient Pressure

⑪Poppet Valve ⑫Airhole in Central Screw ⑬Air Filter

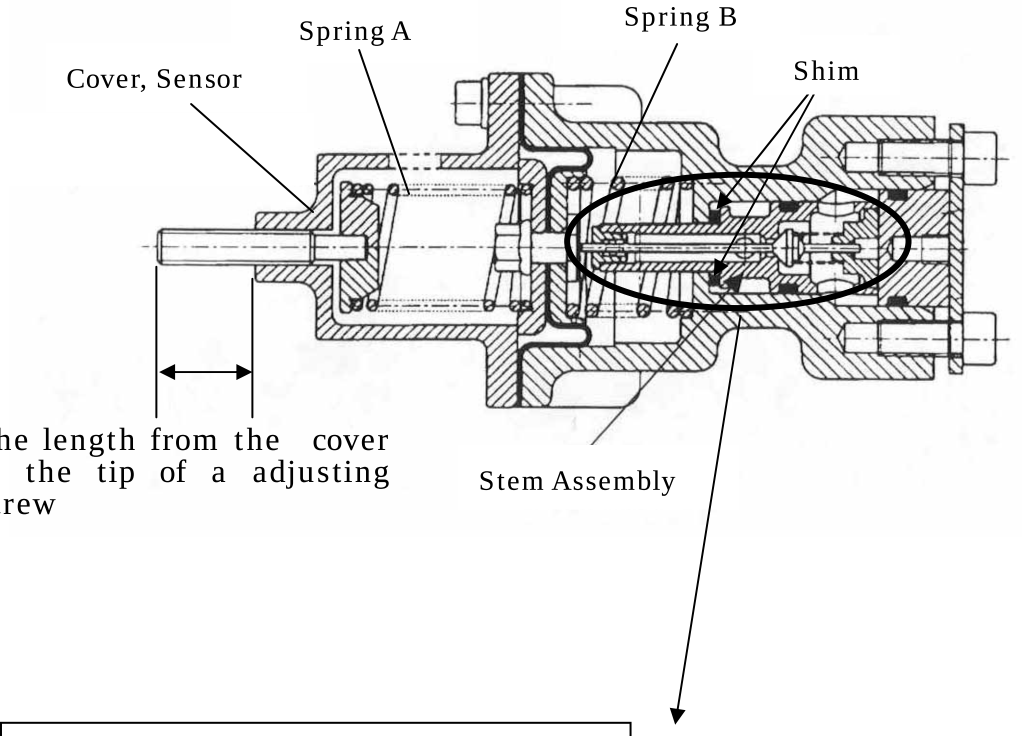
Figure 5　Internal Structure of Safety Valve



①Stem Asembly
②Seat Asembly
③Bushing
④ Seat
⑤Stem Poppet
⑥Stem Spring
⑦Stem Guide
⑧Shim
⑨Set Screw
⑩Diaphragm
⑪Spring
⑫Cover of Control Valve

Figure 6 Cross-Sectional View of Control Valve

The Whole of Control Valve



Cross-Sectional View of Stem Assembly

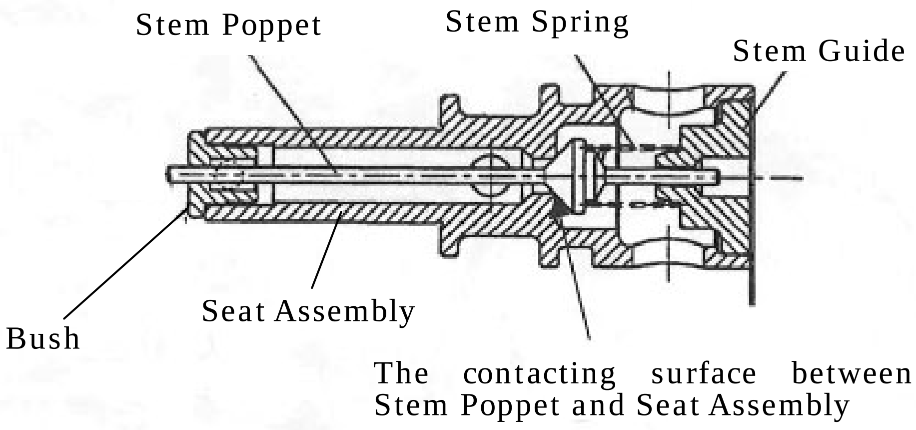
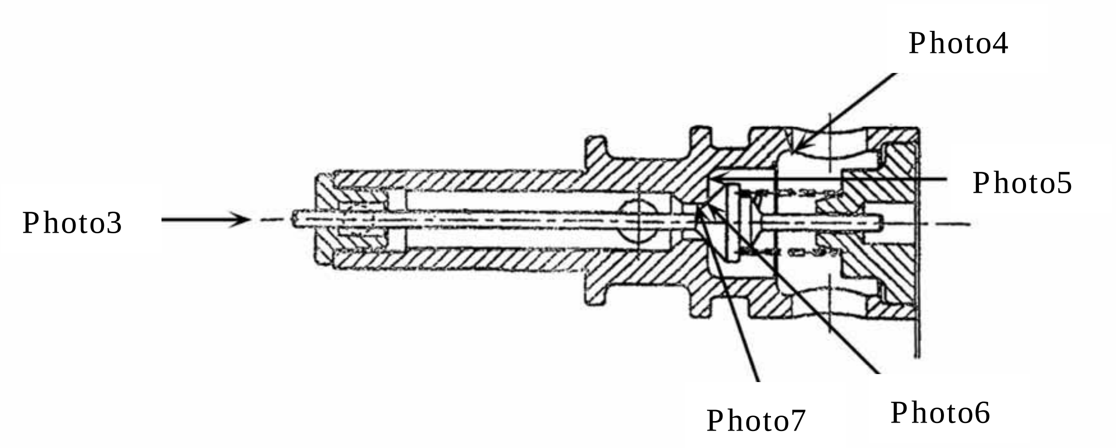


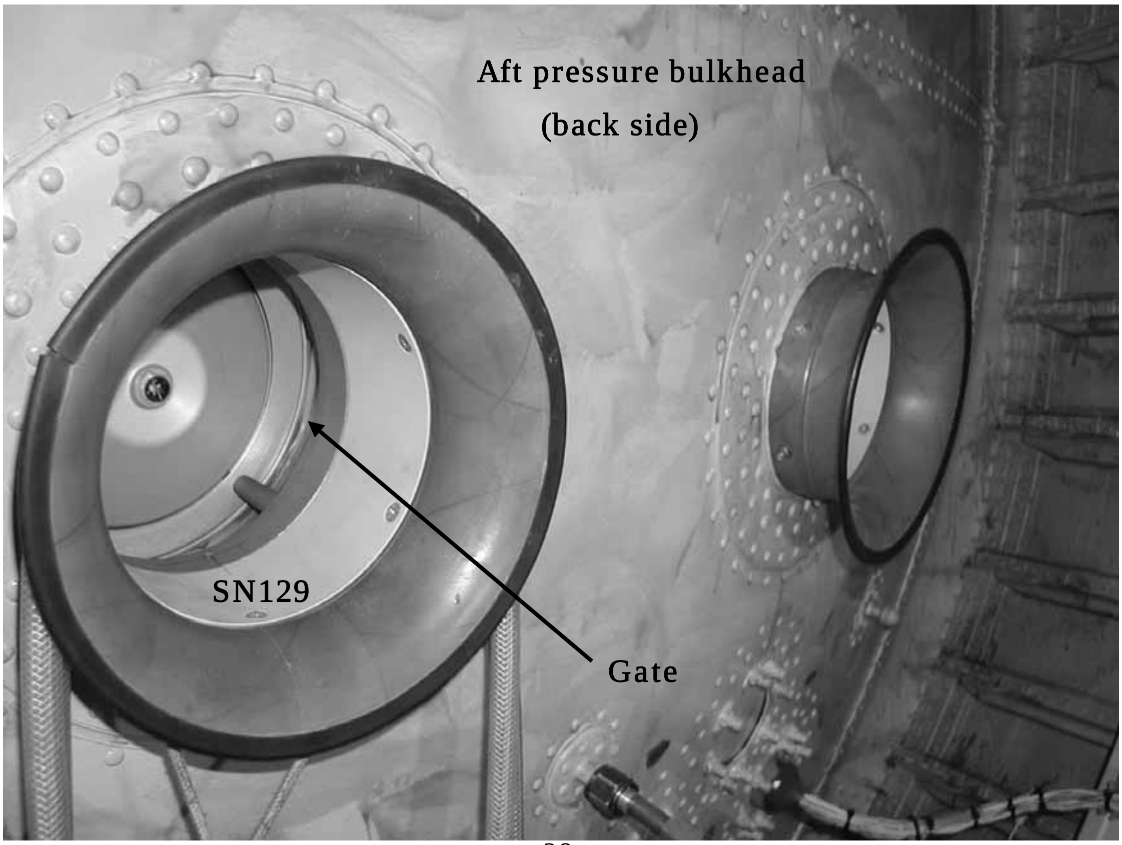
Figure 7　Description of photographed points

An arrow shows below the direction with fault observed under the microscope inspection about each part.



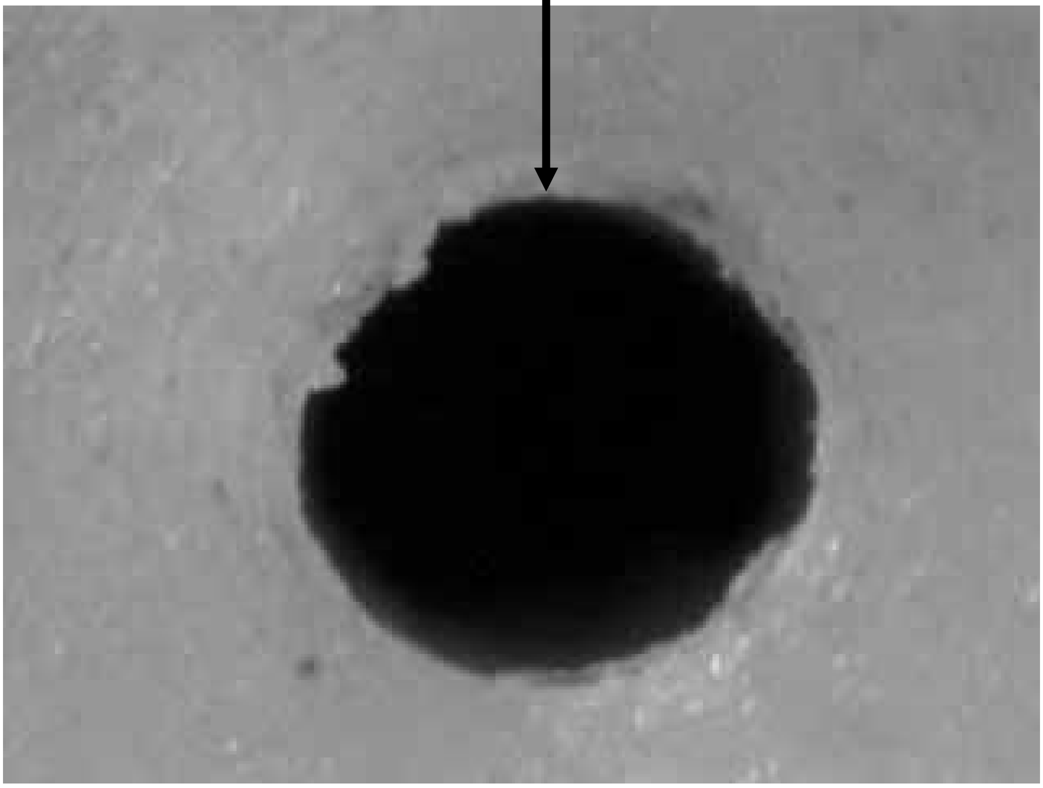
Photograph 1　Safety Valves front side

Photograph 2　Safety Valves outside cabin



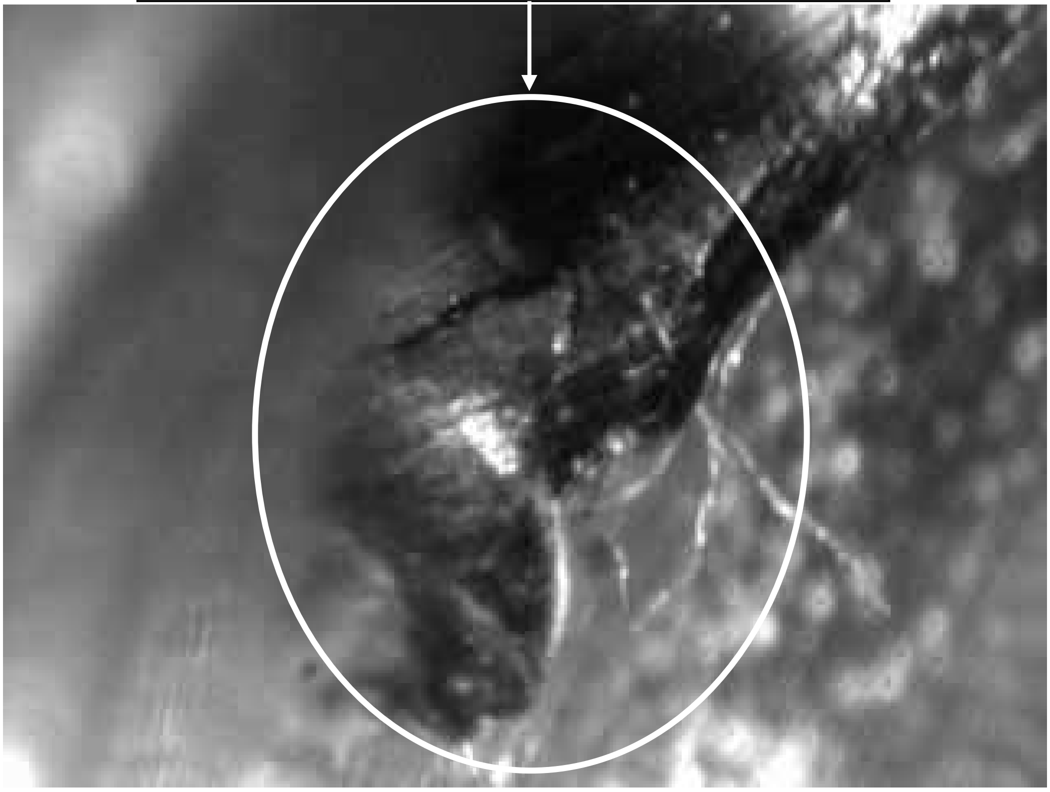
Photograph 3　Inside Stem, Poppet

The bush hole in which the stem poppet slides was found to be worn

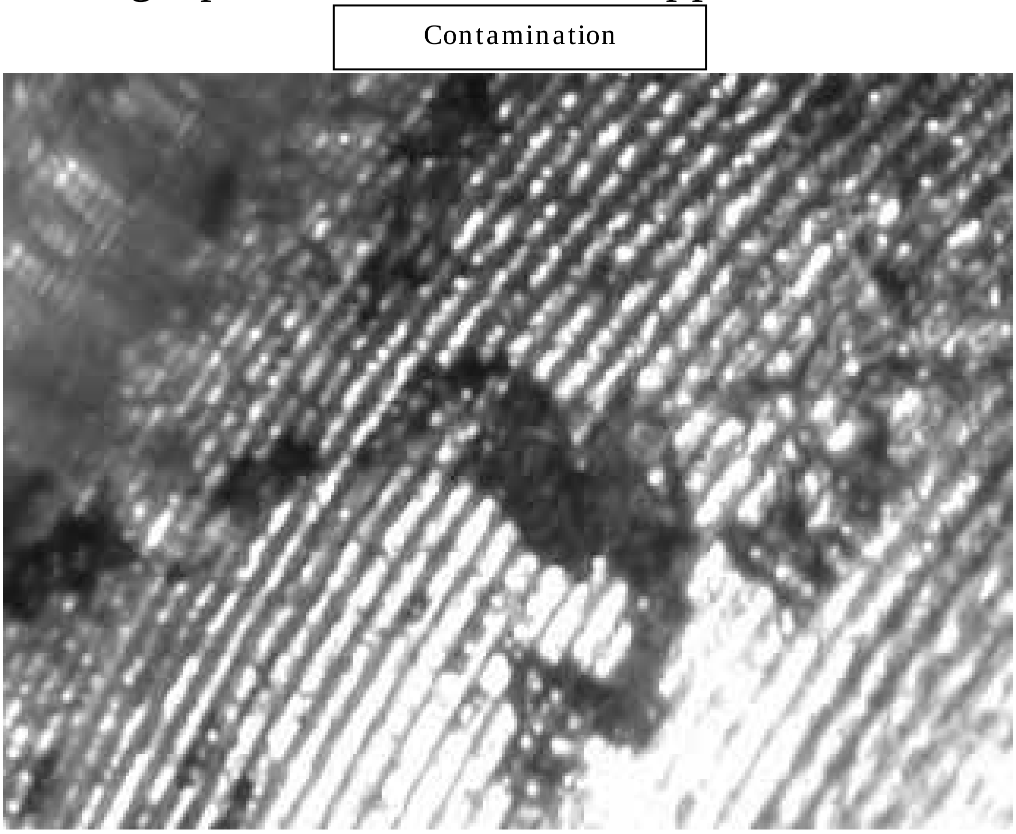


Photograph 4　Inside Stem, Poppet

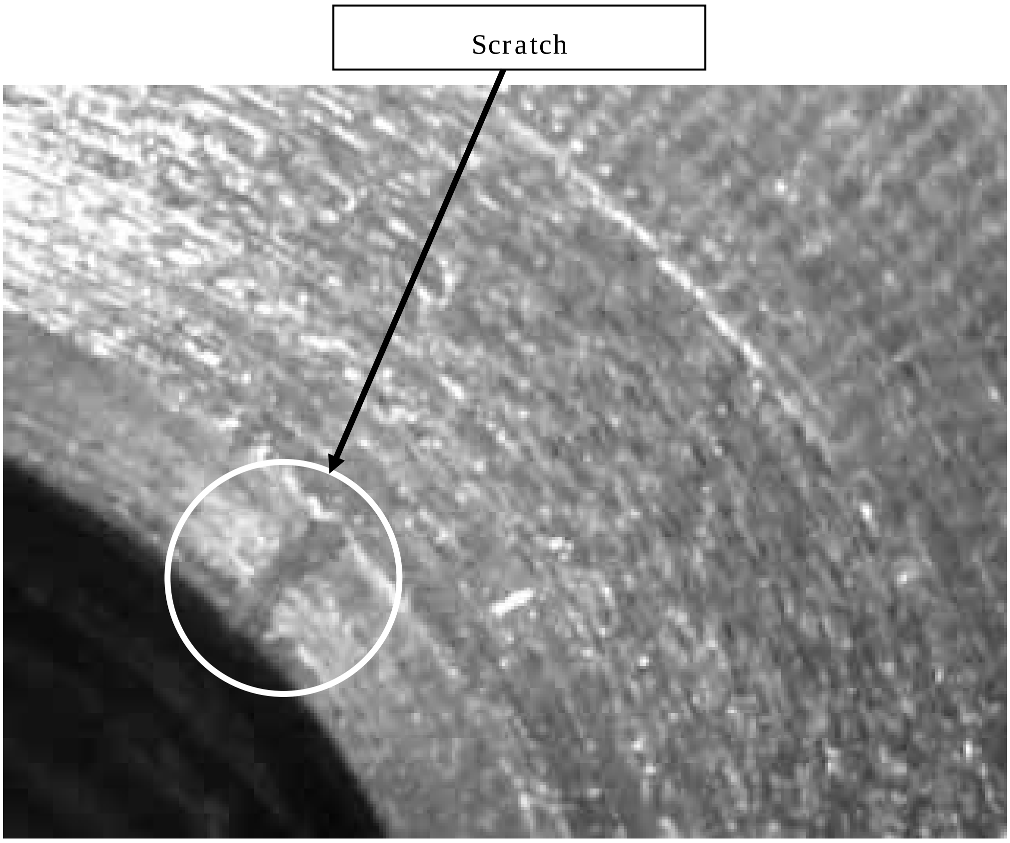
Several burrs were found on the edge of a drill hole



Photograph 5 Inside Stem, Poppet



Photograph 6 Inside Stem, Poppet



Photograph 7 Inside Stem, Poppet