AI2018-6

AIRCRAFT SERIOUS INCIDENT INVESTIGATION REPORT

ALL NIPPON AIRWAYS CO., LTD.
J A 8 5 A N

September 27, 2018

Japan Transport Safety Board

The objective of the investigation conducted by the Japan Transport Safety Board in accordance with the Act for Establishment of the Japan Transport Safety Board and with Annex 13 to the Convention on International Civil Aviation is to prevent future accidents and incidents. It is not the purpose of the investigation to apportion blame or liability.

Kazuhiro Nakahashi
Chairman
Japan Transport Safety Board

Note:

This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.

AIRCRAFT SERIOUS INCIDENT
INVESTIGATION REPORT

MULTIPLE MALFUNCTIONS IN ONE OR MORE SYSTEMS
EQUIPPED ON AIRCRAFT IMPEDING
THE SAFE FLIGHT OF AIRCRAFT
TOKYO INTERNATIONAL AIRPORT
AT AROUND 08:22 JST, MAY 27, 2016

ALL NIPPON AIRWAYS CO., LTD.
BOEING 737-800, JA85AN

August 23, 2018
Adopted by the Japan Transport Safety Board

SYNOPSIS

＜Summary of the Accident＞

On Friday, May 27, 2016, at 08:22 Japan Standard Time (JST: UTC + 9 hours; all times are indicated in JST on a 24-hour clock), a Boeing 737-800, registered JA85AN, operated by All Nippon Airways Co., Ltd, took off from Tokyo International Airport as scheduled flight 561 but, as it was climbing, turned back at 08:27 because there was a warning indicating a drop in cabin pressurization and landed at 09:11. Upon detailed inspection of the same aircraft, no damage to the aircraft was observed; however, it was found that both valves for the intake of bleed air from the left and right engines into the respective air conditioning packs had temporarily malfunctioned and were closed.

There were 170 people on board the aircraft, consisting of a Captain, five other crewmembers, and 164 passengers. One passenger suffered minor injuries.

＜Probable Causes＞

It is highly probable that this serious incident occurred when, as the aircraft was being continuously operated without a malfunction involving temporary shutdowns of the left air conditioning pack being perceived by the flight crewmembers or mechanics, the left air conditioning pack shut down at the time of the flight's take off and then the right air conditioning pack, which had the same service hours and service environment, also shut down, and as a result pressurization was not maintained.

It is probable that the left and right air conditioning packs shut down because, in both cases, the reference regulators inside the valves that control airflow to the air conditioning packs (eFCV) were stuck, and as a result the eFCVs closed from the rising bleed pressure and air was not supplied to the air conditioning packs.

Abbreviations and Acronyms used in this report include the following:

ACAU:	Air Conditioning Accessory Unit
ACMS:	Aircraft Condition Monitoring System
ACARS:	Aircraft Communication Addressing and Reporting System
ALT:	Altitude
ALTN:	Alternate
AUTO:	Automatic
CPC:	Cabin Pressure Controller
CVR:	Cockpit Voice Recorder
ECS:	Environmental Control System
eFCV:	electronic Flow Control Valve
FCSOV:	Flow Control and Shutoff Valve
FDR:	Flight Data Recorder
FL:	Flight Level
FLT:	Flight
fpm:	feet per minute
ft:	feet
MCDU:	Multi-Purpose Control Display Unit
NTSB:	National Transportation Safety Board
OFV:	Outflow Valve
PACK:	Package
PF:	Pilot Flying
PFTC:	Pack Flow Temperature Controller
PM:	Pilot Monitoring
P/N:	Parts Number
psi:	pounds per square inch
psid:	pounds per square inch differential
QAR:	Quick Access Recorder
slfpm:	sea level feet per minute
S/N:	Serial Number

Unit Conversion Table

1ft:	0.3048m
1in:	25.40mm
1nm:	1,852m
1lb:	0.4536kg
1kt:	1.852km/h (0.5144m/s)
1atm:	1,013hPa (29.92inHg)
1psi [lbf/in^2]:	0.07031kgf/cm^2 (6894.76Pa)

1. PROCESS AND PROGRESS OF THE AIRCRAFT INCCIDENT INVESTIGATION

1.1 Summary of the Serious Incident

On Friday, May 27, 2016, at around 08:22 Japan Standard Time (JST: UTC + 9 hours; all times are indicated in JST on a 24-hour clock), a Boeing 737-800, registered JA85AN, operated by All Nippon Airways Co., Ltd, took off from Tokyo International Airport as scheduled flight 561 but, as it was climbing, turned back at 08:27 because there was a warning indicating a drop in cabin pressure and landed at 09:11. Upon detailed inspection of the aircraft, no damage was observed; however, it was found that both valves for the intake of bleed air from the left and right engines into the respective air conditioning packs had temporarily malfunctioned and were closed.

There were 170 people on board the aircraft, consisting of a Captain, five other crewmembers and 164 passengers. One passenger suffered minor injuries.

1.2 Outline of the Serious Incident Investigation

On Tuesday, May 31, 2016, this incident was certified as an aircraft serious incident falling under "multiple malfunctions in one or more systems equipped on aircraft impeding the safe flight of aircraft" specified in clause 9, Article 166-4 of the Civil Aeronautics Act Enforcement Regulations (Ordinance of the Ministry of Transport No. 56 of July 31, 1952).

1.2.1 Investigation Organization

The Japan Transport Safety Board received a serious incident notification, and then designated an investigator-in-charge and two other investigators to investigate the serious incident.

The Japan Aerospace Exploration Agency cooperated in the internal examination of pertinent equipment relating to the serious incident.

1.2.2 Representatives from the Relevant State

An accredited representative of United States of America, as the State of Design and Manufacture of the aircraft involved in this serious incident, participated in the investigation.

1.2.3 Implementation of the Investigation

May 31, 2016	Examination of relevant documents
June 1, 2016	Aircraft examination and examination of relevant documents
June 6, 2016	Interviews
June 7, 2016	Aircraft examination (ground test)
June 16, 2016	Aircraft examination (flight test)
July 6, 2016	Internal examination of left and right eFCV[*1]

*1 "eFCV" stands for "electronic Flow Control Valve." It refers to a flow control valve that regulates with computerized control the flow of air that is bleed from an engine and sent to an air conditioning pack. In the maintenance manual, eFCV is generally expressed as "flow control and shutoff valve" (FCSOV), a term that includes conventional valves that pneumatically controlled valves (FCV).

July 20 and 21, 2016	Functional test (unit test) of the left and right eFCV and disassembly and inspection of the right eFCV.
August 16 and 17, 2016	System-level test*2 using the left eFCV
September 28, 2016	Functional test (unit test) of the left and right ACAU*3
October 21, 2016	Functional test (unit test) of the left and right PFTC*4, flow sensors*5, and pressure sensors*6
October 27, 2016	Teardown inspection of the left eFCV

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

Comments were invited from the parties relevant to the cause of this serious incident.

1.2.5 Comments from the Relevant State

Comments were invited from the Relevant State.

2. FACTUAL INFORMATION

2.1 History of the Flight

On May 27, 2016, Boeing 737-800, registered JA85AN (hereinafter referred to as "the Aircraft"), operated by All Nippon Airways Co., Ltd (hereinafter referred to as "the Company"), took off from Tokyo International Airport (hereinafter referred to as "the Airport") and was climbing as the Company's scheduled Flight 561 (hereinafter referred to as "the Flight"), which was its first operation of the day.

The flight plan for the Aircraft is outlined below:

Flight rules:	Instrument flight rules (IFR)
Departure aerodrome:	Tokyo International Airport
Estimated off-block time:	08:00
Cruising speed:	462 kt
Cruising altitude:	Flight Level (FL*7) 280
Route:	JYOGA (waypoint) – Y56 (air route) (rest omitted)
Destination aerodrome:	Kochi Airport
Total estimated elapsed time:	1 h 09 min

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*2 "System-level test" refers to a test that takes place after mounting a set of equipment onto a test rig used for development of the relevant system. In the system-level test conducted here, the removed eFCV, PFTC, ACAU, flow sensors, and pressure sensors were mounted on a test rig to test the flow control system from the engines to the air conditioning packs based on a failure cause analysis by the manufacturer.

*3 "ACAU" stands for "Air Conditioning Accessory Unit." It is a device that serves as an interface with other devices to provide data on the aircraft's operational status to the PFTC.

*4 "PFTC" stands for "Pack Flow and Temperature Controller." It is a device that controls the air conditioning packs by adjusting the opening position of the eFCV and controls temperature in each section of the cabin based on the flow rate, pressure, and temperature of bleed air from the engines that flows into the air conditioning packs and various data concerning the aircraft's operational status.

*5 A "Flow sensor" detects the flow rate of bleed air flowing into an air conditioning pack for supply to the PFTC.

*6 A "Pressure sensor" detects the pressure of bleed air flowing into an air conditioning pack for supply to the PFTC.

*7 "FL" stands for flight level and is pressure altitude of the standard atmosphere. It is the altitude indicated by value divided by 100 of the index of the altitude indicator (unit: ft) when QNH is set to 29.92 inHg. FL is usually applied when flight altitude is 14,000 ft or above in Japan. For example, FL 200 indicates an altitude of 20,000 ft.

Fuel load expressed in endurance: 2 h 44 min
Alternate airport: Takamatsu Airport, Osaka International Airport

In the Aircraft at that the serious incident occurred, the Captain sat in the left seat as the PF*8 and the First Officer sat in the right seat as the PM.*8

The flight history up to the time of the serious incident is outlined below, based on the fault code record and the air traffic control communication record left in the flight data recorder (hereinafter referred to as "FDR"), the quick access recorder (hereinafter referred to as "QAR"), and the Cabin Pressure Controller*9 (hereinafter referred to as "CPC") and statements from the Captain, the First Officer, and chief flight attendant.

2.1.1 History of the Flight Based on Records of the FDR, QAR, CPC, and Air Traffic Control Communication

08:09:51	The left and right air conditioning packs*10 of the Aircraft started after both engines were started.
08:21:32	The Aircraft began its takeoff roll (both engines' output increased).
08:21:47	The left air conditioning pack shut down. Air speed began to increase and the outflow valve*11 (hereinafter referred to as "OFV") began to close.
08:21:59	The OFV closed fully.
08:22:12	The Aircraft took off from the Airport.
08:22:25	The right air conditioning pack shut down.
08:27:42	A warning device that indicates when the cabin altitude*12 has been exceeded operated. (See Appendix Figure 2①; cabin altitude: approx., 10,100 ft; flight altitude: FL141)
08:29:35	The Aircraft asked Tokyo Area Control Center (hereinafter referred to as "Tokyo Control") for FL160 and received permission for FL160.
08:30:04	The left air conditioning pack started. (See the left side of Appendix Figure 2 ②)
08:30:08	The right air conditioning pack started. (See the right side of Appendix Figure 2 ②) (Cabin altitude: approx., 14,000 ft; flight altitude: FL155)
08:30:15 - 08:30:59	The fully closed OFV began to open. After opening to 26%, the OFV again closed fully. (See Appendix Figure 2 ③)
08:31:41	The left air conditioning pack shut down. (See Appendix Figure 2 ④)
08:32:15	The pressurization mode was switched from AUTO to MAN (manual).

*8 "PF" (Pilot-Flying) and "PM" (Pilot-Monitoring) are the terms to identify pilots on the basis of role sharing when operating aircraft by two pilots. The PF is mainly in charge of aircraft control and the PM is mainly in charge of monitoring the flight status, cross-checking of PF's operations, and performing tasks other than flying.

*9 "Cabin Pressure Controller" (CPC) refers to a device that automatically controls cabin pressure with an outflow valve (OFV). See 2.9.3.

*10 "Air conditioning pack" is a unit of equipment that keeps air in the cabin at the desired temperature. It is generally referred to as "air conditioning pack" or "environmental control system (ECS) pack".

*11 "Outflow valve" (OFV) refers to a pressure regulation valve that controls cabin pressurization by regulating the amount of air released from the cabin to the aircraft's exterior.

*12 "Cabin altitude" refers to pressurization (pressure) in the aircraft's interior (cabin) that is applied to protect crewmembers and passengers from changes in air pressure and to maintain the safety and comfort of an aircraft flying at a high altitude; it is expressed in terms of altitude of the standard atmosphere. It should be noted that normal cabin altitude is not to exceed 8,000 ft at the aircraft's maximum operation altitude. An excessive cabin altitude warning device activates when cabin altitude reaches and exceeds 10,000 ft, signifying a decrease in cabin pressurization.

	(From the fault code recorded in the CPC. See Appendix Figure 2 ⑤; cabin altitude: approx. 14,000 ft; flight altitude: FL160)
08:34:25	The Aircraft asked Tokyo Control for FL140 in order to descend to a roughly altitude equivalent to the cabin altitude and received permission to descend to 13,000 ft.
08:34:52	The left air conditioning pack started. (See Appendix Figure 2 ⑥)
08:36:05	The warning indicating that the cabin altitude was exceeded stopped. (See Appendix Figure 2 ⑦) (Cabin altitude: approx., 9,000 ft; flight altitude: approx., 13,700ft)
08:36:41	The Aircraft transitioned to level flight at a flight altitude of 13,000 ft. (Cabin altitude: approx., 6,800 ft. The cabin altitude then gradually rose as the Aircraft maintained level flight at 13,000 ft. [See Appendix Figure 2 ⑨])
08:37:20	The left air conditioning pack shut down. (See Appendix Figure 2 ⑧)
08:41:25	The Aircraft asked Tokyo Control for permission to return to the Airport.
08:46:17	The left air conditioning pack started. (See Appendix Figure 2 ⑩) (Cabin altitude: approx., 8,700 ft; flight altitude: approx., 12,900ft)
08:46:25	The Aircraft asked Tokyo Control for permission to descend to 10,000 ft and was granted permission to descend to 9,000 ft.
08:48:43	The Aircraft transitioned to level flight at a flight altitude of 9,000 ft.
08:50:28	The cabin altitude fell below -8,000 ft. (See Appendix Figure 2 ⑪) (Differential pressure [⊿P] between cabin and aircraft exterior = 8.79 psi)
08:50:29	The OFV started opening when the pressurization mode was switched from MAN to AUTO. (See Appendix Figure 2 ⑫)
08:51:06	The OFV opened to 75%. (See Appendix Figure 2 ⑬)
08:51:16	The AUTO FAIL light[*13] and ALTN light[*13] came on. (From the fault code recorded in the CPC. See Appendix Figure 2 ⑭)
08:51:32	The OFV closed fully.
08:51:36	The CPC was switched. (From the fault code recorded in the CPC.)
09:11:00	The Aircraft landed at the Airport.

2.1.2 Statements of Parties Relevant to the Serious Incident

(1) Captain

Prior to departure, the Captain conducted an external inspection of the aircraft and checked the instrumentation of the cockpit and there was no abnormality. After starting the engines, he taxied, took off from Runway 05, and climbed to 10,000 ft without a problem, and he did not physically notice any abnormality in pressurization. While climbing, he confirmed that there was no problem in bleed air from the engines by looking at the gauge for engine bleed air duct pressure (hereinafter referred to as “the Bleed Pressure”) of the bleed air system, but he did not check the cabin pressure on the Cabin Altitude Panel. Around the time that the Aircraft passed through FL140, the Cabin Altitude Warning suddenly activated with a warning light and alarm sound. While the Aircraft was climbing

*13 The AUTO FAIL light is a warning light that indicates that a failure has occurred in the control of cabin pressurization operating in the AUTO pressurization mode. The ALTN light is a green light that indicates that automatic pressurization control is operating in the ALTN (alternate) pressurization mode.

to FL280, the Captain first checked the Bleed Pressure and the cabin altitude and then asked Tokyo Control for a change in altitude in order to stop the Aircraft's climb and received permission to fly at FL160. While stabilizing the Aircraft by transitioning to level flight at FL160 and reducing speed from the climbing speed of approximately 300 kt to 250 kt, the Captain put on an oxygen mask, secured communications, and had the First Officer execute the Cabin Altitude Warning checklist. While visually observing the First Officer's operations, the Captain, being mindful of past accidents, repeatedly checked the air conditioning pack switches (hereinafter referred to as "the Pack Switches"), the Engine Bleed Air switch, and the Pressurization Mode Selector switch to confirm that they were in the proper positions, but he did not find any problems and therefore could not identify the cause. Because the cabin altitude did not fall even after executing the checklist, the Captain determined that pressurization was not working and, concerned that the oxygen masks might drop, he decided to descend from FL160 to below the cabin altitude. He descended to a flight altitude of 13,000 ft and confirmed from a flight attendant that there were no abnormalities in the cabin. He subsequently asked Tokyo Control to descend to 10,000 ft, the altitude at which he could remove his oxygen mask, and received permission to descend to 9,000 ft. While descending to 9,000 ft and after transitioning to level flight, the differential pressure (⊿P) of the cabin and outside rose enormously in the direction of pressurization, and the Captain became concerned that it would exceed the limit value of 9.1 psi. He felt pressure in his ears and had been told by the First Officer during execution of the Cabin Altitude Warning checklist that the OFV was already closed. Because this was not the OFV's normal position, he became aware that the OFV was not working correctly. He therefore thought to attempt automatic control using the CPC, which functioned when he switched Pressurization Mode Selector switch from MAN (manual) to AUTO, he felt the pressure in his ears lessen. He could not understand what was occurring while in flight.

(2) First Officer (FO)

The Aircraft took off and climbed normally but at around the time that it climbed above FL140, the cabin altitude warning device activated. The FO checked the Bleed Pressure while climbing but was not paying particular attention to the cabin altitude. When the warning device activated, the cabin altitude was rising from 12,000 ft to 13,000 ft. Both pilots put on oxygen masks. The FO executed the Cabin Altitude Warning checklist as instructed by the Captain. He set both Pack Switches to "HIGH" and attempted to close the OFV manually by switching the Pressurization Mode Switch from AUTO to MAN, but the OFV's position indicator already showed it was fully closed. Thinking it was possible that there was a malfunction in the indicator, he kept the switch to the side for closing the OFV for about 15 seconds. There was no movement in the indicator. While recognizing that there was a problem with pressurization, both pilots perceived that, because the cabin altitude was not rising rapidly, the situation was not so urgent as to require a sudden descent. When the Aircraft descended from level flight at FL160 to 13,000 ft, the cabin altitude was steady at 7,000 ft. Because there was a failure whose precise nature was unknown, it was decided to return to the Airport.

As the Aircraft was returning to the Airport at 13,000 ft, the cabin altitude again began to rise from 7,000 ft, and the FO thought that if it continued it would exceed 10,000 ft. Although the flight altitude had decreased to 9,000 ft, during that time the cabin altitude next fell rapidly (in the direction of pressurization) and sank to below 0 ft, and the indication for differential pressure (⊿P) between the cabin and outside was very close to the limit value. In addition, the FO observed that the rate of change indicator for cabin altitude had swung completely toward the descending side (in the direction of pressurization). Although he felt discomfort in his ears while descending from FL160 to 13,000 ft, he felt the most pressure in his ears while descending from 13,000 ft to 9,000 ft and his ears cleared. When the Captain returned the pressurization mode from MAN to AUTO, the FO heard the sound of air flowing in and felt cold air coming into the cockpit. He also heard from a flight attendant that "something like white smoke could be seen." While preparing to land at the Airport, the FO noticed that the amber AUTO FAIL light and green ALTN Light (see Figure 3) on the Cabin Pressurization Panel were simultaneously lit and saw that the panel was in the alternate mode.

(3) Chief Purser (CP)

When the CP was waiting for the seatbelt sign to turn off after around 15 minutes to 20 minutes had passed following takeoff, she received a communication from the Captain asking if she felt anything abnormal in the cabin and informing her that there was a problem with pressurization and therefore the Aircraft might return to the Airport. The CP had not noticed anything abnormal at that time. Around five minutes later, the Captain announced directly to the passengers that the Aircraft would return to Haneda due to a pressurization problem. Shortly afterward, the CP felt pressure in her ears and a drop in the cabin's temperature. She felt it was the most severe ear blockage she had ever experienced, and her ears became blocked again even after clearing them several times. At the same time, a white mist flowed downward from the top of the cabin and also blew out from the sides. Something resembling a white mist was lingering about 20 cm overhead near the aft galley and rearmost row of seats. There was no odor. Because reports to the Captain were made simultaneously by flight attendants in the cabin's fore and aft sections, the CP knew that the same conditions existed in the cabin. The Captain explained to the CP that what resembled white mist was water vapor. However, during this communication, the mist disappeared, and the CP reported this fact to the Captain. At around this time, there was a call from a passenger who complained of intense ear pain. Because, when viewed from the front, many passengers were anxious about ear pain, all four of the flight attendants left their seats with the Captain's permission to distribute candy and otherwise care for the passengers.

This serious incident occurred immediately after takeoff on Runway 05 of the Airport at around 08:22 on May 27, 2016.

(See Attached Figure 1 Estimated Flight Path)

2.2 Injuries to Persons

One passenger suffered a minor injury to the ears.

2.3 Damage to the Aircraft

No damage was sustained to the Aircraft.

2.4 Personnel Information

(1) Captain Male, Age 50

Airline transport pilot certificate (Airplane) September 16, 2003
Type rating for Boeing 737 June 20, 1996
Class 1 aviation medical certificate
Validity September 2, 2016
Total flight time 10,352 h 34 min
Flight time in the last 30 days 50 h 07 min
Total flight time on the type of aircraft 2,292 h 52 min
Flight time in the last 30 days on the type of aircraft 50 h 07 min

(2) First Officer (FO) Male, Age 29
Commercial pilot certificate (Airplane) October 19, 2012
Type rating for Boeing 737 February 19, 2015
Instrument flight certificate July 3, 2013
Class 1 aviation medical certificate
Validity October 8, 2016
Total flight time 1,045 h 05 min
Flight time in the last 30 days 51 h 37 min
Total flight time on the type of aircraft 789 h 30 min
Flight time in the last 30 days on the type of aircraft 51 h 37 min

2.5 Aircraft Information

2.5.1 Aircraft

Type Boeing 737-800
Serial number 62640
Date of manufacture January 25, 2016
Certificate of airworthiness No. 2016-004
Validity The period during which the Maintenance Manual (All Nippon Airways Co., Ltd,) applies from February 10, 2016
Category of airworthiness Airplane Transport T
Total flight time 675 h 11 min
Flight time since last periodical check
(A01C inspection: Carried out on April 24, 2016) 172 h 29 min
(See Appendix Figure 3 Three Angle View of the Boeing 737-800)

2.5.2 Regarding the Electronic Flow Control System of the Air Conditioning Packs Installed on the Aircraft

A fundamental design change concerning control of the airflow supplied to air conditioning packs was executed for all aircraft of the same aircraft type, including the Aircraft, that were delivered from the aircraft manufacturer (The Boeing Company) since February 2016. This change involved the introduction of an electronic flow control system having commonality with the Boeing 737 MAX that was under development at that time. In this connection, the eFCV and PFTC are installed to handle electronic flow control. The PFTC controls the eFCV so that flow to the air conditioning packs is optimized.

2.6 Meteorological Information

Aviation weather observations immediately prior to the serious incident, i.e., immediately prior to the Aircraft's takeoff from the Airport, were as follows.

08:20

Wind direction 360°; Wind velocity 4 kt; Prevailing visibility 1,500 m; RVR on Runway 05, from which the Aircraft took off, at least 1,800 m.

Current weather: Showers, mist

Cloud: Amount 1/8, Type Stratus, Cloud base 100 ft
Amount 5/8, Type Cumulus, Cloud base 300 ft
Amount 6/8, Type Cumulus, Cloud base 1,500 ft

Temperature 21°C; Dew point 21°C; Altimeter setting (QNH) 1,006hPa/29.73 inHg

Main aviation weather observations (weather, temperature, and dew point) during the times the Aircraft was parked from its arrival at Tokushima Airport two days prior to the serious incident (May 25, 2016) until the time of the serious incident's occurrence were as follows.

(1) Tokushima Airport (arrival at 21:02, May 25; departure for Tokyo International Airport at 07:12, May 26)
May 25 21:00: Weather: Light showers, mist Temperature: 20℃ Dew point: 19℃
May 26 00:00: Weather: Mist Temperature: 20℃ Dew point: 19℃
03:00: Weather: Mist Temperature: 20℃ Dew point: 20℃
06:00: Weather: Light showers, mist Temperature: 20℃ Dew point: 20℃

(2) Tokyo International Airport (arrival at 08:36, May 26; departure for Odate-Noshiro Airport at 09:13)
08:30: Temperature: 23℃ Dew point: 20℃
09:00: Temperature: 23℃ Dew point: 20℃

(3) Odate-Noshiro Airport (arrival at 10:19, departure for Tokyo International Airport at 10:54)
11:00: Temperature: 24℃ Dew point: 19℃

(4) Tokyo International Airport (arrival at 12:14; departure for Miyazaki Airport at 13:16)
12:30: Temperature: 24℃ Dew point: 20℃
13:00: Temperature: 24℃ Dew point: 20℃

(5) Miyazaki Airport (arrival at 14:52; departure for Tokyo International Airport at 15:39)
15:00: Temperature: 26℃ Dew point: 23℃

(6) Tokyo International Airport (arrival at 17:22; departure for Okayama Airport at 18:08)
17:30: Temperature: 23℃ Dew point: 19℃
18:00: Temperature: 22℃ Dew point: 19℃

(7) Okayama Airport (arrival at 19:22; departure for Tokyo International Airport at 19:59)
20:00: Temperature: 21℃ Dew point: 20℃

(8) Tokyo International Airport (arrival at 21:28)
21:30: Temperature: 22℃ Dew point: 20℃
May 27 00:00: Temperature: 22℃ Dew point: 20℃
03:00: Weather: Light shower of rain Temperature: 22℃ Dew point: 20℃
06:00: Weather: Shower of rain , mist Temperature: 22℃ Dew point: 21℃

2.7 Information on Flight recorder

The Aircraft was equipped with an FDR capable of recording for approximately 25 hours and a cockpit voice recorder (hereinafter referred to as "CVR") capable of recording for approximately two hours, both of which were manufactured by L-3 Aviation Recorders of the United States (the company's name was changed to L-3 Aviation Products on January 1, 2017). The FDR retained a record of the time of that the serious incident occurred. However, the CVR's record had been overwritten and therefore no useful data were retained.

The time calibration for the FDR was conducted by comparing the time signals recorded in the ATC communication records with the VHF keying signals recorded in the FDR.

2.8 Failures of the Air Conditioning Packs Prior to the Serious Incident that were Recorded by the FDR

Checking of the operational records beginning on May 17, 2016, that were retained in the FDR found that incidences in which the eFCV closed and the left air conditioning pack temporarily shut down occurred even before the serious incident. The record is as shown in Table 1. It should be noted that there were no records indicating that the right eFCV had closed.

Table 1 Record of Closing by the Left eFCV

Day the left eFCV closed	No. of flights counting back from flight of the serious incident	Duration of time the left FCV was closed during the flight
May 18	51 flights prior	1 sec
May 20	41 flights prior	1 sec
May 25	13 flights prior	3 sec
May 26	7 flights prior	44 min 50 sec
May 26	6 flights prior	34 min 16 sec
May 26	5 flights prior	36 min 38 sec
May 26	4 flights prior	19 min 12 sec
May 26	3 flights prior	20 min 13 sec
May 26	2 flights prior	39 min 59 sec
May 26	1 flight prior	43 min 16 sec
May 27 (day of serious incident)	Flight of serious incident	20 min 36 sec

2.9 Information on the System and Equipment Investigation

2.9.1 Outline of the Air Conditioning and Pressurization System

On the Aircraft, high-pressure bleed air from the engines is supplied from valves (eFCV) that control the air conditioning packs' flow to the cabin through the air conditioning packs and used for air-conditioning and pressurization of the cabin. Air that flows into the cabin is released to the aircraft's exterior through the OFV (see Figure 1). It should be noted that "eFCV" is called "pack valve" in the Airplane Operations Manual.

The amount of air flowing into the cabin is adjusted through the PFTC's control of the eFCVs located upstream of the air conditioning packs, and the amount of air released outside the aircraft is adjusted through the CPC's control of the OFV located at the final point downstream of the pressurization system.

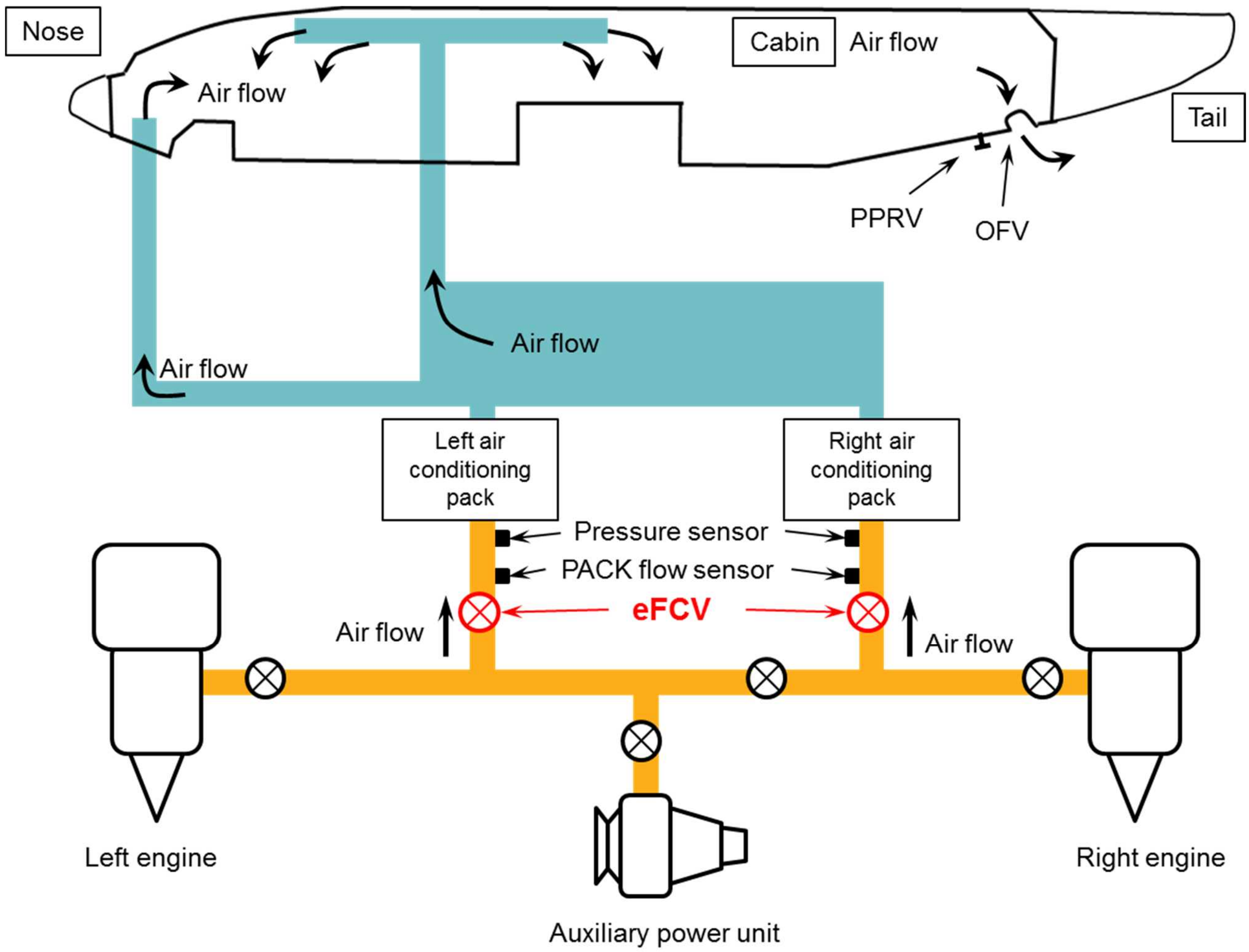

Figure 1 Sketch of the Air Conditioning and Pressurization System of the Aircraft

2.9.2 Regarding Operation of the Air Conditioning Packs

As is shown in Figure 2, there are left and right Pack Switches for controlling each of the air conditioning packs on an cockpit overhead panel. Ordinarily, when they are used in the AUTO position and both air conditioning packs are operating to supply needed air, the amount of flow is adjusted in the Low Flow mode. However, when only one air conditioning pack is operating, and when the flaps are up during flight, the amount of flow of that air conditioning pack automatically becomes controlled in the High Flow mode. When a Pack Switch is set to "HIGH," air flow is adjusted in the High Flow mode regardless of the operating status of the other air conditioning pack.

If an air conditioning pack overheats and an eFCV closes, or if the primary and secondary control functions of the PFTC that controls each of the air conditioning packs both fail, the PACK light for the relevant air conditioning pack will illuminate. However, if an eFCV closes and an air conditioning pack does not function due to another failure, there are no functions to notify flight crewmembers of this fact with a warning light or other means or to notify mechanics of this fact by recording it in the ACMS*14.

*14 "ACMS" stands for "Aircraft Condition Monitoring System." It refers to a system that monitors and records the data of onboard subsystems during daily operations.

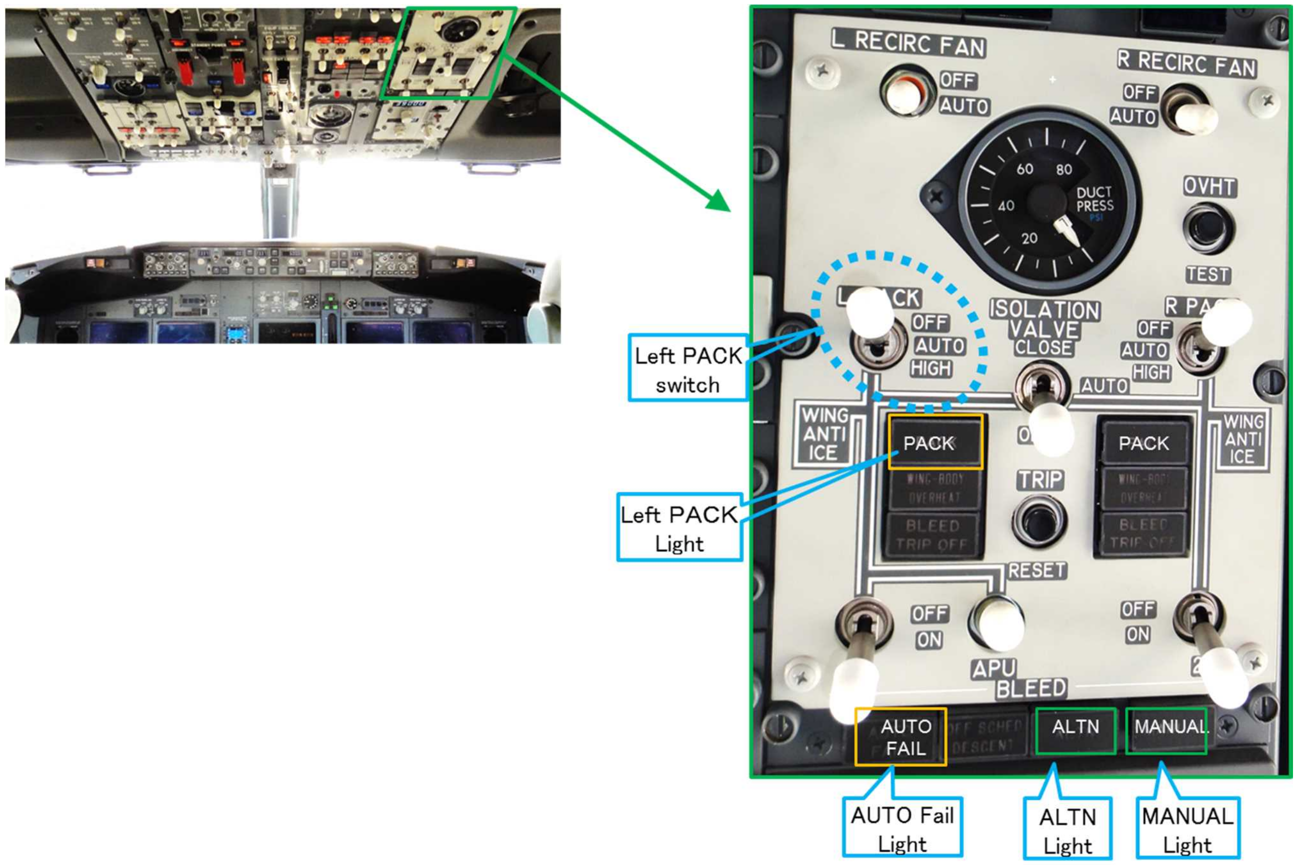

Figure 2 The Air Conditioning Pack Cockpit Control Panel

2.9.3 Regarding the Cabin Pressure Controller (CPC)

During normal operation under the AUTO pressurization mode, the cabin altitude is automatically controlled by adjusting the amount of air released outside of the aircraft, primarily through opening or closing of the OFV by the CPC. There are two identical CPC's -. For each flight leg, one CPC operates as the active controller and the other is constantly in a state in which it can substitute as a backup. The CPC's switch control with each flight. As will be discussed later in 2.11.4, when, during flight, the CPC detects a failure in the automatic system on the operating side and switches to the backup CPC, the pressurization mode switches to the alternate mode. Additionally, it is possible to switch to the ALTN (alternate) mode using the Pressurization Mode Selector switch (see Figure 3).

It should be noted that switching the Pressurization Mode Selector switch to MAN and operating the system manually by monitoring the OFV's position indicator, without relying on the CPC, is called the "manual mode."

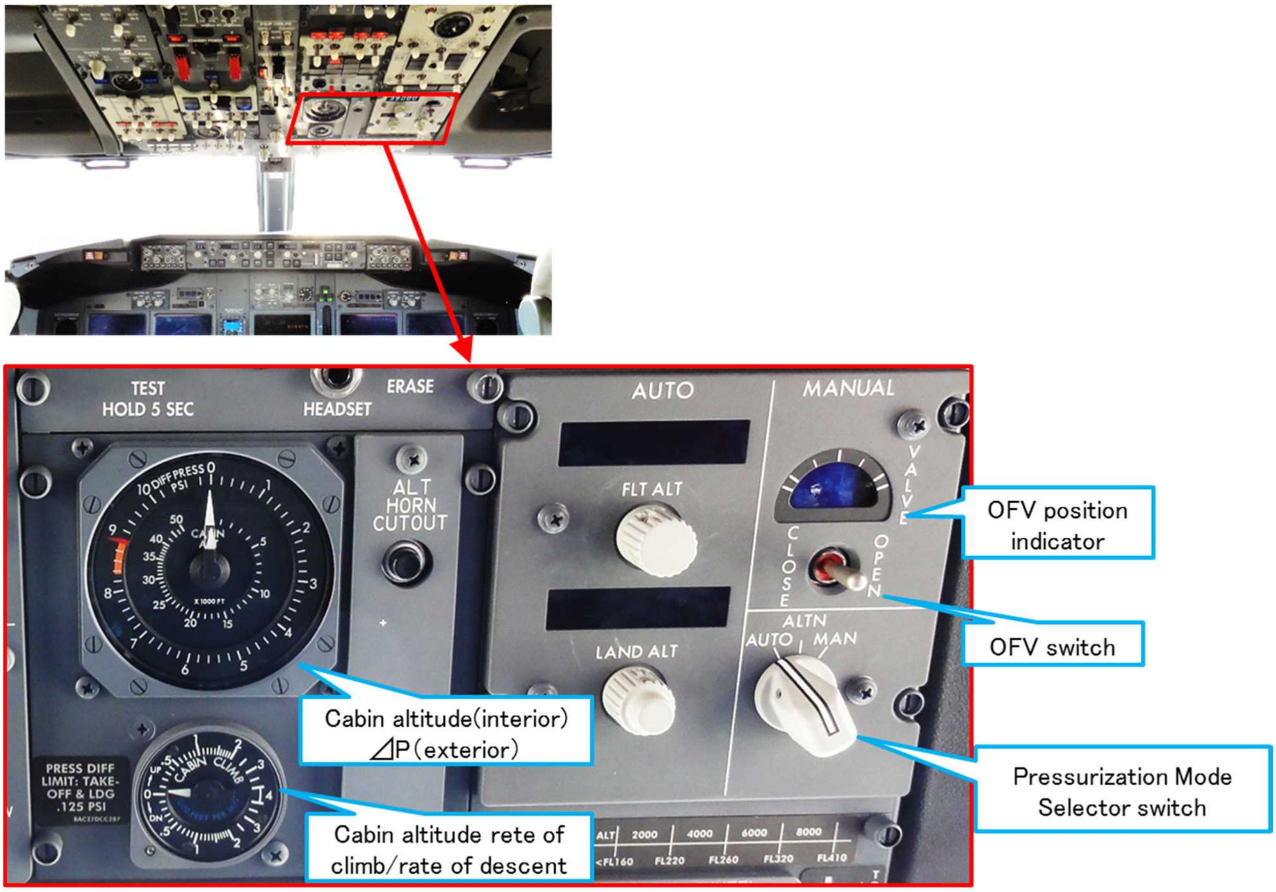

Figure 3 Cockpit Panels Relating to Cabin Altitude and Pressurization Mode Operation

2.9.4 eFCV Mechanism

An eFCV is a flow control valve that operates pneumatically and controls electronically. Switching a cockpit Pack Switch (Figure 4 ①) to AUTO or HIGH opens the eFCV's butterfly valve (Figure 4 ②) and begins the supply of air to the air conditioning pack. Inside the eFCV is a reference regulator that adjusts air pressure used for control inside the eFCV (hereinafter referred to as "the Supply Pressure") (Figure 4 ③). The reference regulator is in a fully open state when the Bleed Pressure is low, including when the aircraft is parked with the engines off. However, it maintains the Supply Pressure within a specified range by closing in response to increases in the Bleed Pressure. When the Supply Pressure is maintained within the specified range, the outflow from the vent is changed (Figure 4 ⑤) by electronic control by the PFTC (Figure 4 ④) and the opening position of the eFCV's butterfly valve is controlled as a result. On the other hand, when the Supply Pressure exceeds the normal range, the outflow from the vent increases beyond the adjustment range of the PFTC's electronic control, the eFCV's butterfly valve closes, and the amount of air supplied to the air conditioning pack is decreased.

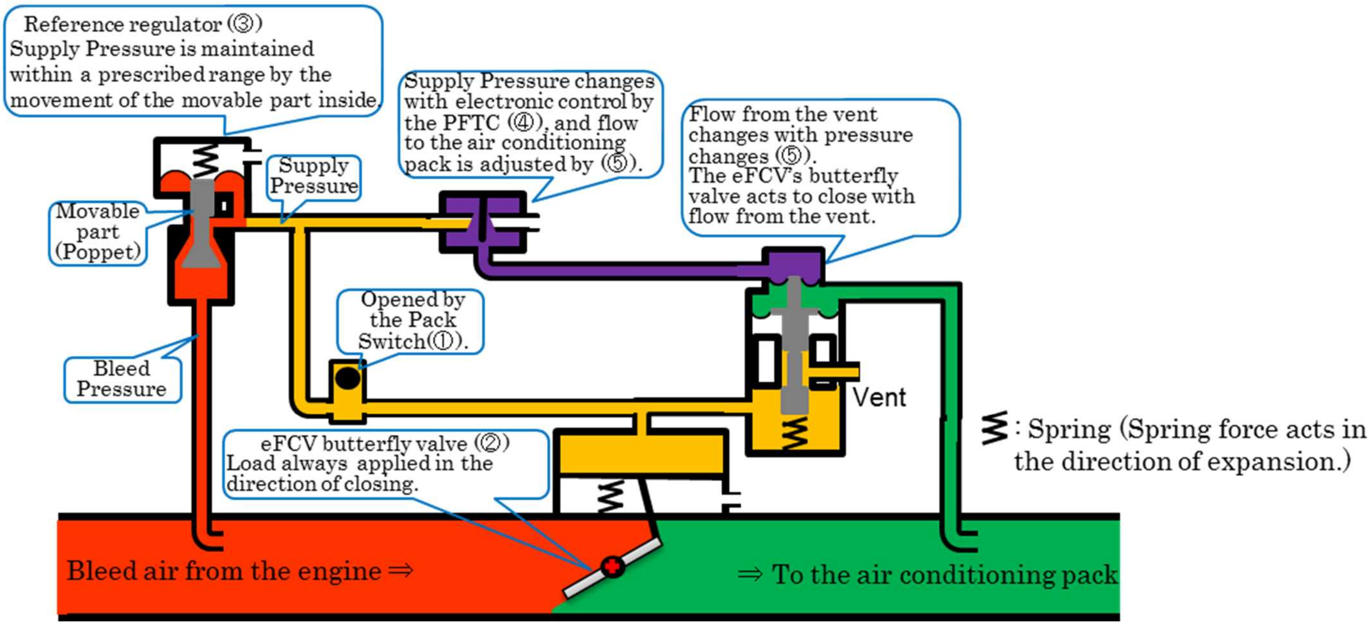

Figure 4 eFCV Outline

2.9.5 eFCV and Reference Regulator Equipment Positions

As is shown in Figure 5, eFCVs are installed in the left and right Environmental Control System (ECS) bays located in the bottom center of the fuselage. The reference regulator is located on the bottom of its eFCV.

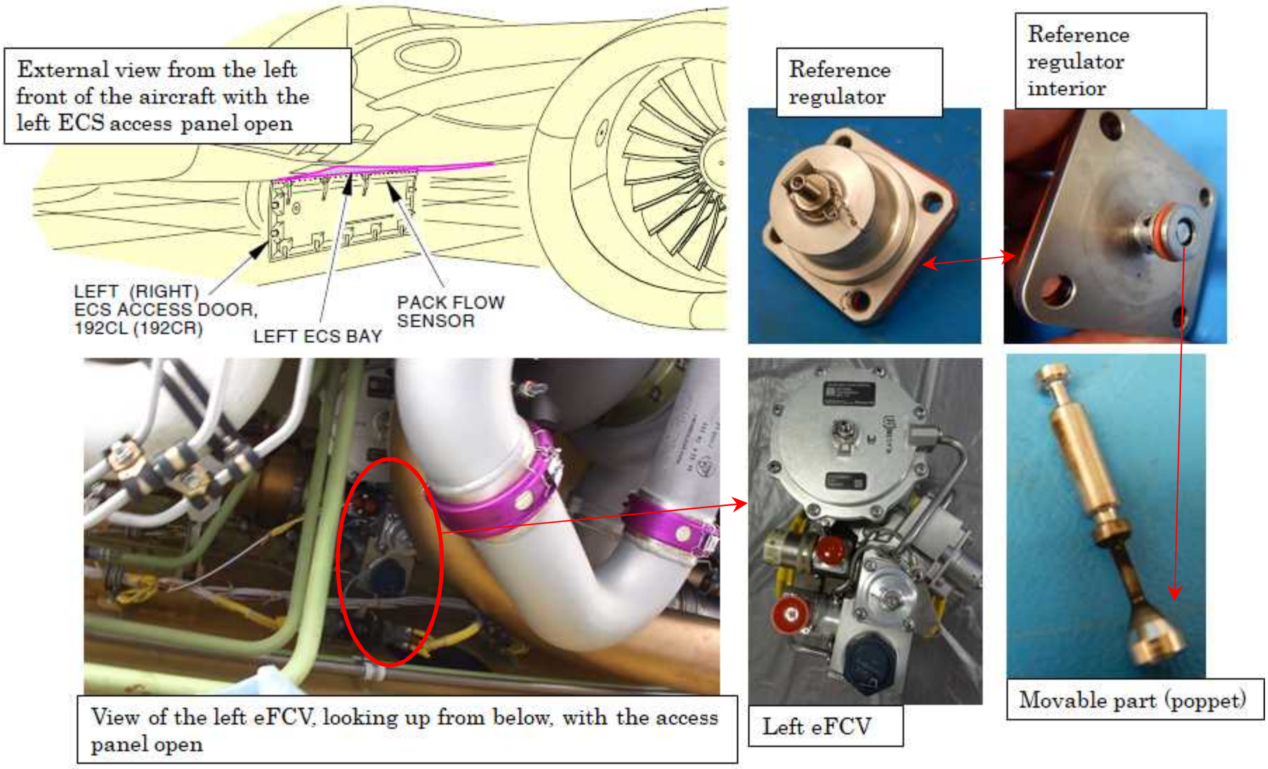

Figure 5 Left eFCV Equipment Positions
(The same equipment is installed with the same facing on the right side.)

2.10 Troubleshooting

2.10.1 Investigation of Equipment Components Relating to the Failure

From the state of operation of the air conditioning packs described in 2.1.1, it was found that the left eFCV closed as the Aircraft was in its takeoff run and the right eFCV closed immediately after takeoff, that both eFCVs opened about eight minutes later, and that the left then repeatedly opened and closed intermittently. Additionally, as was described in 2.8, it was found that a phenomenon occurred whereby the left eFCV temporarily closed on one flight on each of the dates of May 18, May 20, and May 25 as well as all seven flights that took place that took place on May 26, the day prior to the serious incident.

The self-diagnostic functions of each PFTC and CPC that control air-conditioning and pressurization were checked, but there were no records indicating a failure. Additionally, when the operations of the air-conditioning and pressurization systems were checked through engine ground tests and flight tests, the failure was not reproduced.

To identify the cause, the eFCVs and equipment relating to the eFCVs operation were removed from the Aircraft, and a detailed investigation was conducted at the facilities of each designer/manufacturer with the cooperation of the National Transportation Safety Board (NTSB) of the United States and the Transportation Safety Board (TSB) of Canada. The results were as shown in Table 2. It deserves noting that all of the removed equipment items had been installed in the Aircraft since the time of the Aircraft's manufacture and had no history of failure.

Table 2 List of Equipment Items Relating to the Failure and Investigation Results

Equipment item name / Part No. (P/N)	Installation position (left or right)	Serial No. (S/N)	Existence of findings based on the investigation's results
eFCV	Left	155	Yes (see 2.10.2)
63396754-1	Right	125	Yes (see 2.10.2)
ACAU	Left	F13940	No
65-52810-64	Right	F13947	No
PFTC	Left	00031	No
51090248-002	Right	00059	No
Flow sensor	Left	00081	No
51090306-002	Right	00392	No
Pressure sensor	Left	06128	No
1153222-2	Right	06120	No

2.10.2 Investigation of the Aircraft's eFCVs

The investigation of the left and right eFCVs resulted in the findings provided in Table 3.

		Left eFCV (S/N:155)	Right eFCV (S/N:125)
Functional test	Unit test	There were no particularly noteworthy problems.	
	System-level test	After the eFCV was exposed to a high-humidity environment, the five equipment items of the left air conditioning pack that were removed from the Aircraft (provided in Table 2) were mounted on a test rig for development testing of the designer/manufacturer and tested, but the failure was not reproduced.	Not conducted

Teardown inspection	Visual inspection	When the reference regulator was disassembled and visually inspected, black grime was found along the air passage. Additionally, a small number of abrasions were found on the movable part within the reference regulator.	
	Material (composition) analysis	When particles attached to the movable part within the reference regulator were analyzed, atmospheric dust and other constituents were detected.	

Table 3 Results of the Investigation of Each eFCV

2.10.3 Regarding a Similar Failure on Another Aircraft Equipped with eFCVs

Following the serious incident, it was reported that there was an air-conditioning and pressurization failure caused by the closing of both eFCVs during takeoff and initial climbing that resembled that which occurred in the Aircraft on an aircraft equipped with the eFCVs described in 2.5.2.

When a system-level test similar to the one described in 2.10.2 was conducted using the eFCVs removed from the aircraft, which is operated by another airline, due to the similar accident, a reference regulator, which is an internal component of the eFCV, remained stuck open, and the failure whereby the eFCV closed was recreated. Moreover, when a system-level test that simulated an open reference regulator was similarly conducted using an eFCV owned by an eFCV designer/manufacturer, the phenomenon whereby the eFCV fully closed was recreated.

2.11 Additional Information

2.11.1 Procedure When the Cabin Altitude Warning Activates

According to the Company's Airplane Operations Manual, the procedure to follow when the Cabin Altitude Warning activates is as follows.

Condition: When at least one of the following conditions occurs:

・Excess of Cabin Altitude

・The Intermittent Cabin Altitude / Configuration Warning Horn sounds and the CABIN ALTITUDE Light comes on during flight

1 Wear Oxygen Mask and set the Regulator to 100%.

2 Establish Crew Communication.

3 PACK switches (both) . . . . HIGH PM

4 Pressurization mode selector . . . . . MAN PM

5 Outflow VALVE switch . . . . Hold in CLOSE until the outflow VALVE indication shows fully closed PM

(Omission)

7 If the Cabin Altitude can be controlled:

Maintain the Desired Cabin Altitude with Manual Operation.

If the Cabin Altitude is 10,000 feet or less:

Removal of Oxygen Mask is permitted.

2.11.2 Regarding High Flow Operation for Only One Air Conditioning Pack

According to the Company's Airplane Operations Manual, the following is mentioned regarding operation of only one air conditioning pack. (Excerpt)

Air Conditioning Pack

The flow of Bleed Air to each Air Conditioning Pack from the Main Bleed Air Duct is controlled by each Pack Valve. Ordinarily, the Left Pack uses Bleed Air from the No. 1 Engine and the Right Pack uses Bleed Air from the No. 2 Engine. The system is capable of maintaining Cabin Pressurization and Temperature at Maximum Cruising Altitude on just one Pack operating at High Flow.

(Rest omitted)

2.11.3 Regarding Automatic Control of Pressurization by the Cabin Pressure Controller (CPC)

According to the Maintenance Manual, when the pressurization mode is AUTO or ALTN, pressurization is automatically controlled as follows. (Excerpt)

(Previous section omitted)

Climb

(Part omitted)

The maximum cabin pressurization rate of change for depressurization is 600 slfpm.

Cruise

(Part omitted)

In the cruise phase, the system maintains a constant cabin altitude. The cabin altitude will be adjusted to the landing field elevation for flights with a flight altitude of 18,500 feet or less. For flights with a flight altitude above 18,500 feet, the cabin altitude will increase to such a status that differential pressure (ΔP) is within a safe limit.

These are the pressure schedules:

FLIGHT ALTITUDE	*Differential pressure(ΔP)*
SEA LEVEL TO 18,500	*LANDING FIELD ELEVATION*
18,500 TO 28,000	*7.45 +/- 0.2 psid*
28,000 TO 37,000	*7.80 +/- 0.2 psid*
37,000 AND ABOVE	*8.35 +/- 0.2 psid*

NOTE: *Deviations from flight altitude may cause the pressure to go as high as 8.45 psid to maintain a constant cabin altitude.*

(Part omitted)

NOTE: *When the cabin altitude increases to more than 10,000 feet, the cabin altitude warning alarm will sound. You can push the ALT HORN CUTOUT switch to deactivate the alarm.*

Descent

(Part omitted)

The maximum cabin pressurization rate of change for pressurization is 350 slfpm.

(rest omitted)

2.11.4 Regarding Conditions for Illumination of the AUTO FAIL Light

The AUTO FAIL light (Caution) will come on if a failure in cabin pressure control occurs while operating in the AUTO pressurization mode, and the mode will switch to alternate automatic pressure control and the ALTN light (green) will come on if there is a switch to the backup CPC. Both lights are on the cockpit's P5-10 Air Conditioning control panel.

According to the Aircraft Maintenance Manual, the conditions for illumination of the AUTO FAIL light are as follows.

(First section omitted)

These things cause the auto fail indication:

- *Power loss*
- *Cabin altitude rate of change is too high (>2,000 slfpm) and the outflow valve has not responded correctly*
- *Cabin altitude is too high (>15,800 ft) and the outflow valve has not responded correctly*
- *Wiring failures*
- *Outflow valve component failures*
- *CPC failures*
- *Cabin differential pressure is too high (>8.75 psi) and the outflow valve has not responded correctly*

(omitted)

The system automatically changes pressurization control to the backup controller if the active controller fails.

(omitted)

The ALTN light shows that the backup system is active. The AUTO FAIL light gose off when you select the ALTN position on the mode selector.

(Rest omitted)

3. ANALYSIS

3.1 Airman Competence Certificate and Aviation Medical Certificate

The Captain and FO held both valid airman competence certificates and valid aviation medical certificates.

3.2 Airworthiness Certificate

The Aircraft had a valid airworthiness certificate and had been maintained and inspected as prescribed.

3.3 Relationship with Meteorological Conditions

At each time point during the times the Aircraft was parked between the Aircraft's arrival at Tokushima Airport two days prior to the serious incident until the occurrence of the serious incident, the temperature was in a range of between 20 and 26℃ and the dew point was in a range of between 19 and 23℃; thus, the weather conditions were marked by high humidity. Accordingly, it is somewhat likely that condensation occurred when the temperature temporarily dropped while the Aircraft was parked at night and that drops of condensed water flowed into the reference regulators positioned on the bottom of the eFCVs as described in 2.9.5.

3.4 Occurrence Time of the Serious Incident

As was described in 2.1.1, the left air conditioning pack shut down at 8:21:47, the right air conditioning pack also shut down at 8:22:25, and an excessive cabin altitude warning device activated at 8:27:42, which was immediately after the cabin altitude passed 10,000 ft. Accordingly, it is highly probable that the time at which both air conditioning packs were shut down (8:22:25) was the time that the serious incident occurred.

3.5 Reason the Air Conditioning Packs Stopped

(1) From the troubleshooting described in 2.10, it is probable that the air conditioning packs shut down because the eFCVs that control the flow of air to the air conditioning packs fully closed.

(2) From the eFCV mechanism that was described in 2.9.4 as well as the eFCV investigation that was described in 2.10.2 and 2.10.3 and the case of a similar failure on another aircraft, it is probable that the eFCVs fully closed because the reference regulators were stuck open. If a reference regulator is stuck open, the function of the reference regulator, which adjusts the Supply Pressure to correspond to increases in the Bleed Pressure, is lost and the eFCV's butterfly valve closes as a result of the excessive Supply Pressure.

(3) It is probable that the air conditioning packs regained their function and began operating again because the high Supply Pressure mentioned in (2) above occurs when the Bleed Pressure increase due to engines high power operation, and because the eFCVs will subsequently return to their normal state when, as the Bleed Pressure decrease with aircraft's descent or deceleration, the Supply Pressure also decrease.

(4) It is somewhat likely that the attached atmospheric dust and other substances that were described in the teardown inspection mentioned in 2.10.2 and the flowing water drops mentioned in 3.3 were contributing factors to the reference regulators' being stuck open.

3.6 Factors Contributing to the Shutdown of Both Air Conditioning Packs

Because the possibility that the PFTC and other control equipment contributed to the shutdown of both air conditioning packs and the possibility that the failure of one pack had an effect on the other pack cannot be confirmed from the results of the troubleshooting described in 2.10, it is probable that the following factors contributed to the shutdown of both air conditioning packs at the time of takeoff.

(1) Grime and abrasions similarly existed inside the reference regulators of both eFCVs. It is probable that this was because both eFCVs had been installed in the Aircraft since its manufacture and had been in operation in the same environment, and that as a result the reference regulators of both eFCVs were similarly prone to becoming stuck open.

(2) It is probable that both air conditioning packs shut down during takeoff on the day of the serious incident because, under conditions in which the reference regulators of both eFCVs were similarly prone to becoming stuck open, the reference regulators became stuck due to high humidity resulting from weather conditions marked by showers and mist while the

Aircraft was parked on the two previous days, said stuck condition continued until the first flight of the following day (specifically, the flight of the serious incident), and both engines power increased when the Aircraft was taking off with the reference regulators in a stuck condition, resulting in a situation in which the air conditioning packs shut down simultaneously for the reason described in 3.5 (2).

(3) As was mentioned in 2.8, instances in which the left air conditioning pack had shut down were frequently recorded in the FDR in the time leading up to the serious incident in which both air conditioning packs shut down. The FDR contained a record for the most recent period of approximately ten days, and it is somewhat likely that the air conditioning pack had been repeatedly shutting down even before that period. However, it is probable that because, as was mentioned in 2.9.2, the Aircraft was not equipped with a function that notifies flight crewmembers or mechanics even if an eFCV closes and an air conditioning pack shuts down, the frequent failure of the left air conditioning pack was not noticed and the pack remained in operation without repair, and this led to the situation in which the two systems, left and right, malfunctioned simultaneously during the flight of the serious incident.

3.7 History of the Flight

From the statements of the relevant parties mentioned in 2.1.2 and the eFCV malfunction factors mentioned in 3.5, the operational circumstances whereby the cabin altitude fell rapidly and rose rapidly after both air conditioning packs shut down are analyzed for each flight phase as follows. As a result, it is probable that the failure was limited to the left and right eFCVs and that the CPC and other equipment that control pressurization were functioning properly.

(1) It is highly probable that the cabin altitude warning device activated when the cabin altitude reached approximately 10,000 ft because the left and right air conditioning packs sequentially shut down for the reason described in 3.5 (2) when the engines power increased during takeoff and pressure to the cabin increased under conditions in which it was not being maintained. (See Appendix Figure 2 ①)

It is probable that, until the warning device activated, there were no warnings to notify the flight crewmembers of the abnormal pressure, and that flight crewmembers could not know about the abnormal pressure without reading the abnormal cabin altitude on the Cabin Altitude Panel (see Figure 3).

(2) The flight crewmembers canceled ascent when the cabin altitude warning activated, transitioned to level flight at FL160, and slowed to 250 kt. It is probable that, as a result, the left and right air conditioning packs restarted for the reason described in 3.5 (3) because the Bleed Pressure decreased together with the decrease both engine power. (See Appendix Figure 2 ②)

(3) It is probable that, although both air conditioning packs had restarted and pressurization began, the OFV was temporarily left open to prevent a rapid descent in cabin altitude because, as was mentioned in 2.11.3, a lower limit was set for the automatically controlled rate of descent of cabin altitude. (See Appendix Figure 2 ③)

(4) It is probable that, after the Aircraft transitioned to level flight at FL160, the left air conditioning pack shut down again because the Bleed Pressure increased together with the engine power. (See Appendix Figure 2 ④)

(5) Although the flight crewmembers executed the Cabin Altitude Warning checklist mentioned in 2.11.1, switched both PACK switches to HIGH, and operated the switch to close

the OFV by switching the pressurization mode to MAN (manual), the OFV was already in a fully closed condition. (See Appendix Figure 2 ⑤)

(6) It is probable that, as a result of the descent to 13,000 ft, the Bleed Pressure decreased together with the engine power and the left air conditioning pack restarted. (See Appendix Figure 2 ⑥)

It is probable that the amount of air flowing into the cabin increased suddenly with the operation of both air conditioning packs because both PACK switches were operating at HIGH with the OFV fully closed. As a result, during the approximately two minutes that the Aircraft descended to 13,000 ft, pressurization progressed rapidly and there was a rapid descent in cabin altitude at rete of -3,500 fpm on average. During this time, the cabin altitude warning stopped, as the cabin altitude reached approximately 9,000 ft. (See Appendix Figure 2 ⑦)

(7) It is probable that, when the Aircraft transitioned to level flight at 13,000 ft, the left air conditioning pack shut down again because the Bleed Pressure increased in the same manner described in (4) above. (See Appendix Figure 2 ⑧)

(8) The FDR record showed that, during the Aircraft's approximately ten minutes of level flight at 13,000 ft, the right air conditioning pack was working and operating at High Flow, but the cabin altitude was gradually rising and pressurization was not being maintained. Given that, as was described in 2.11.2, pressurization is ordinarily maintained with High Flow operation by one air conditioning pack, It is somewhat likely that, although the right eFCV was partially open but regulating incorrectly due to the reference regulator issues described earlier in the report. It is not likely that it was full closed as the limit switch was not faulty any other point during the event or during the subsequent component evaluations and because the cabin altitude was climbing slowly during this time and not rapidly as would be the case if there was no cabin air inflow. (See Appendix Figure 2 ⑨)

(9) It is probable that, as a result of the descent to 9,000 ft, the Bleed Pressure decreased together with the engine power and the left air conditioning pack restarted again. (See Appendix Figure 2 ⑩)

Similar to the situation described in (6) above, the operation of both air conditioning packs while the outflow valve was fully closed in manual mode resulted in a state of rapid pressurization. Moreover, it is probable that both air conditioning packs continued operating, even after the Aircraft transitioned to level flight at 9,000 ft, because the Bleed Pressure did not rise high enough to result in the left air conditioning pack's shutting down in the manner described in (7) above, and thus the situation became one in which the most rapid pressurization on the flight was occurring. Consequently, for a period of approximately four minutes that lasted from after the Aircraft descended to 9,000 ft and transitioned to level flight until the pressurization mode was switched to AUTO and the OFV opened, pressurization continued rapidly and the cabin altitude rate of descent was below -4,000 fpm on average and for a moment fell below -8,000 ft （⊿P=8.967 psid）. (See Appendix Figure 2 ⑪)

(10) As was mentioned in (6) and (9) above, during the Aircraft's descended to 13,000 ft and then to 9,000 ft, the cabin altitude fell at a rapid rate of descent below -3,500 fpm on average for approximately two minutes in the case of the former and below -4,000 fpm on average for approximately four minutes in the case of the latter. This value falls far below the maximum cabin pressurization rate of change for pressurization when pressurization is automatically controlled of -350 slfpm that was provided in 2.11.3. It is probable that was the time when passengers felt pressure in their ears, and that some passengers suffered injury to their ears.

(11) It is probable that, when the cabin altitude was descending rapidly, automatic control of pressurization by the CPC that was mentioned in 2.11.3 started when the Pressurization Mode Selector switch was switched from MAN to AUTO in a state which the cabin altitude was below -8,000 ft at a flight altitude of 9,000 ft, and the OFV opened because the cabin and outside differential pressure (delta P) raised to 8.967 psid. In addition, it is likely that one or both PPRV's activated thus contributing to the rapid cabin altitude increase. (See Appendix Figure 2 ⑫)

(12) For one minute around the time that the OFV opened to a maximum of 75%, the cabin altitude rapidly rose above 9,500 fpm on average. (See Appendix Figure 2 ⑬)

It is probable that the "white mist" that appeared in the statement of the Chief Purser, mentioned in 2.1.2 (3), was caused when water vapor in the air condensed because, when the OFV opened to a maximum of 75% along with the likely activation of the Positive Pressure Relief Valves released air from cabin outside, the air pressure in the cabin fell rapidly and the temperature dropped under conditions in which a large amount of air was flowing in from the top of the cabin due to pressurization resulting from the restoration of air conditioning pack functions.

(13) AUTO FAIL was issued when the operating CPC detected a failure from an excessive rise in the cabin altitude that greatly exceeded 2,000 fpm and the outflow valve has not responded correctly, which is one of the conditions for illumination of the AUTO FAIL light that was mentioned in 2.11.4. Subsequently, the pressurization mode switched to ALTN (alternate) and the green ALTN light came on with the switch to the backup CPC that was standing by. (See Appendix Figure 2 ⑭)

It should be noted that, as was mentioned in (6) and (9) above, excessive changes in the cabin altitude above 2,000 fpm were observed at the times of descent to 13,000 ft and descent to and level flight at 9,000 ft; however, no warning was issued at those times because the pressurization mode was set to MAN (manual). Additionally, although an excessive rise in the cabin altitude was also observed when the Aircraft was taking off and climbing while in the AUTO pressurization mode, without pressurization being maintained, AUTO FAIL was not issued because, even at its largest, the rise in cabin altitude was about 1,900 fpm and did not exceed 2,000 fpm.

4. PROBABLE CAUSES

It is highly probable that this serious incident occurred when, as the aircraft was being continuously operated without a malfunction involving temporary shutdowns of the left air conditioning pack being perceived by the flight crewmembers or mechanics, the left air conditioning pack shut down during takeoff and then the right air conditioning pack, which had the same service hours and service environment, also shut down, and as a result pressurization was not maintained.

It is probable that the left and right air conditioning packs shut down because, in both cases, the reference regulators inside the valves that control airflow to the air conditioning packs (eFCV) were stuck, and as a result the eFCVs closed from the rising Bleed Pressure and air was not supplied to the air conditioning packs.

5. SAFETY ACTIONS

5.1 Safety Actions Taken by the Aircraft and Equipment Manufacturers

The Aircraft's manufacturer (The Boeing Company) and equipment manufacturer for the eFCV (Honeywell) implemented the following measures.

(1) Upgrade of ACMS software

The Company upgraded the ACMS's software so that it can monitor when an eFCV is closed for three seconds or longer, either the left side or the right side, after takeoff, and The Boeing Company informed other operators about a similar method.

(2) Introduction of double packings on the reference regulator poppet and increased clearance between the reference regulator poppet and guide.

Honeywell recommended that this revised reference regulator (eFCV P/N: 63396754-1 Series 3) be implemented as an interim measure only to reduce the probability of reference regulator failures.

(3) The eFCV (P/N: 63396754-2) developed for the Boeing 737 MAX aircraft has a fail-safe design in which the eFCV will open even if there is a failure caused by a reference regulator's becoming stuck open and Supply Pressure rises excessively. Because using this eFCV will eliminate failures occurring when an eFCV accidentally closes, Honeywell recommended upgrading to this eFCV and The Boeing Company proposed this improvement to operators.

5.2 Safety Actions Taken by the Company

The Company implemented the following measures to prevent recurrence of similar incidents.

(1) Addition of a function to notify flight crewmembers of an eFCV in a closed condition (provisional measure)

With the upgrade to the ACMS software mentioned in 5.1 (1), an eFCV in a closed condition can be detected by the ACMS. The Company added a function that uses this signal to notify the flight crewmembers when an eFCV is closed as follows.

(a) Notice is outputted directly from the ACMS by the cockpit printer.

(b) The open/close condition of the eFCVs can be observed at any time on the cockpit's Multi-Purpose Control Display Unit (MCDU).

(c) When information on an eFCV's closing is communicated from the ACMS through the ACARS*15 to the ground maintenance support department, the information is automatically uplinked from the ground and printed out in the cockpit together with a chime.

(2) The Company prohibited use of the Minimum Equipment List*16, which permits operating on only one air conditioning pack, until permanent measures are implemented. (Provisional

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*15 "ACARS" stands for "Aircraft Communication Addressing and Reporting System." It is a data communication device that links an aircraft with the ground. It links the aircraft with the operator's host computer by ground VHF stations or communications satellites. Presently, in Japan, it is mainly used to assist operations.

*16 "Minimum Equipment List" (MEL) refers to a standard established by the operator that defines the scope within which criteria for determining whether or not an aircraft's operation is permissible when a piece of equipment, etc., is not functioning normally will not impair aircraft safety. It defines the min
imum quantities and conditions
that will permit operation.

measure)

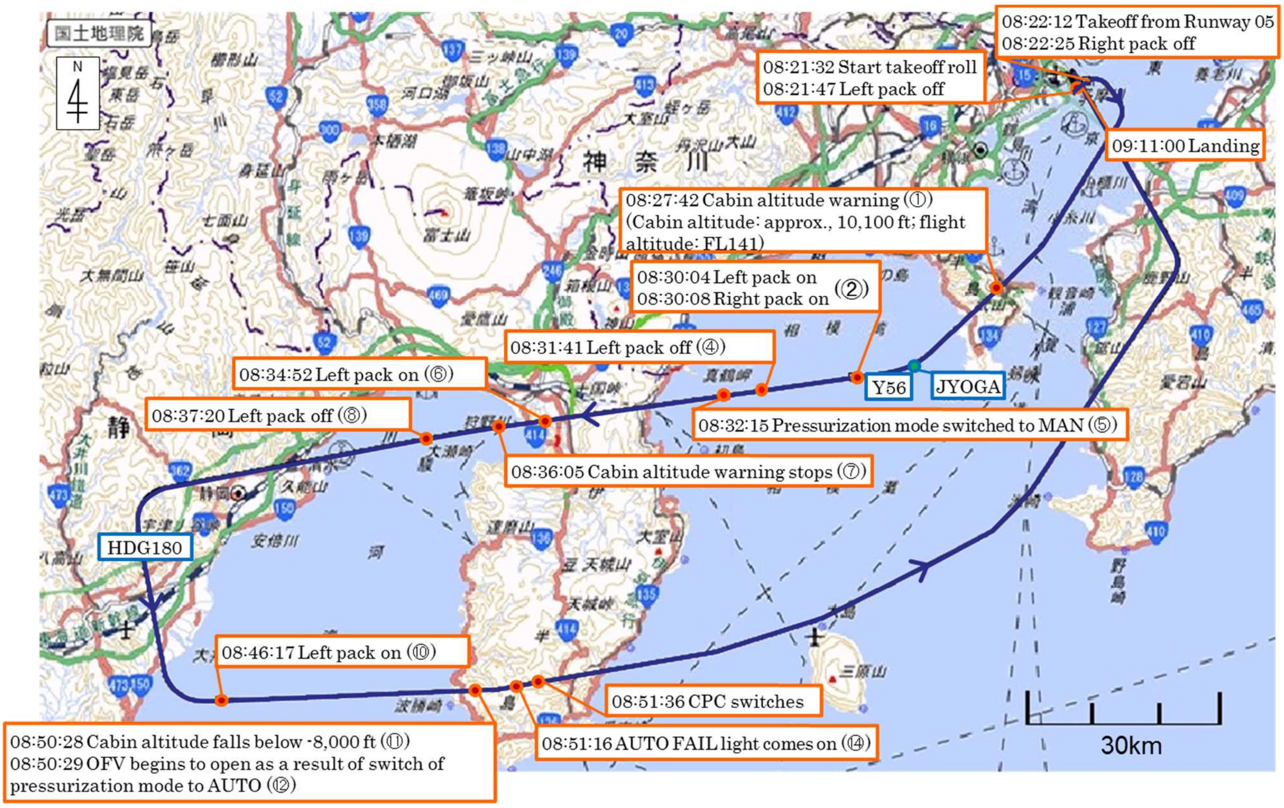
(3) The Company prohibited use of the MEL for the ACMS, ACARS, and VHF communications in order to guarantee monitoring of eFCV closings by the ACMS and notification of flight crewmembers as described in (1) above. (Provisional measure)

(4) The Company installed double-packings eFCV (P/N : 63396754-1 Series 3) with O-rings on the reference regulator poppet and increased clearance between the reference regulator poppet and guide that was mentioned in 5.1 (2) and confirmed that no abnormalities occurred in the reference regulators.

(5) Following the measure described in (4), it became possible to equip its aircraft with the eFCV (P/N: 63396754-2) mentioned in 5.1 (3), and the Company installed them.

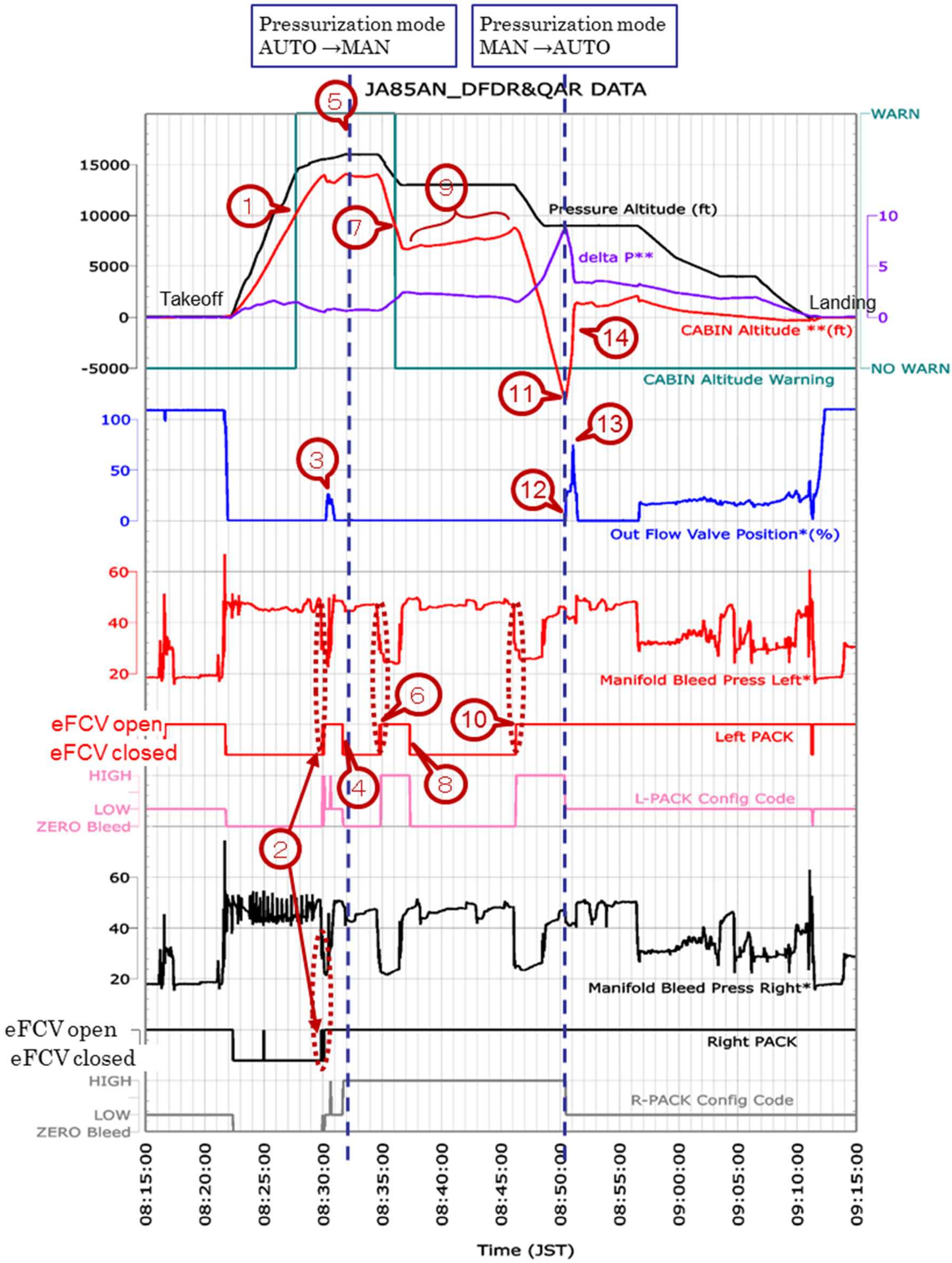
It should be noted that, with the introduction of this eFCV, the eFCV will not close even if the reference regulator is stuck open, and therefore the provisional measures mentioned in (1) to (3) above were cancelled.

Attached Figure 1 Estimated Flight Path



Items ①, ②, ④ to ⑧, ⑩ to ⑫, and ⑭ correspond to the items mentioned in 2.1.1 and 3.7 of the main text.

Attached Figure 2　FDR and QAR Records



Items ① to ⑭ correspond to the items mentioned in 2.1.1 and 3.7 of the main text.
*: QAR data
**: Data obtained from calculation based on QAR data converted the Cabin Press recorded in the QAR using the average ocean surface air temperature (21℃) and atmospheric pressure (29.73 inHg) at the time. Additionally, ⊿P was calculated from the difference between the Cabin Press value and the outside atmospheric pressure obtained from flight altitude.)

: Place where a correlation between falling Manifold Bleed Press and pack "on" is observed.

Attached Figure 3　Three Angle View of the Boeing B737-800

Unit: m