Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Serious Incident
Date:	13 July 2018
Location:	French Airspace; 33 NM west of Grostenquin VOR
Aircraft:	Airplane
Manufacturer:	The Boeing Company
Type:	B737-8AS
Injuries to Persons:	33 persons suffered minor injuries
Damage:	None
Other Damage:	None
State File Number:	BFU18-0975-EX

This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (*Flugunfall-Untersuchungs-Gesetz - FlUUG*) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

Published by:

Bundesstelle für
Flugunfalluntersuchung

Hermann-Blenk-Str. 16
38108 Braunschweig

Phone +49 531 35 48 - 0
Fax +49 531 35 48 – 246

Email: box@bfu-web.de
Internet: www.bfu-web.de

Content Page

Abbreviations

Glossary of Abbreviations

AAIU	Air Accident Investigation Unit	
AAO	SOP for emergency vehicle deployment	Alarm- und Abrückeordnung
ACM	Air Cycle Machine	Kühlturbine
ADIRU	Air Data Inertial Reference Unit	Trägheitsnavigationssystem
APS	Airline Pilot Standard Course	
ATC	Air Traffic Controller	Air Traffic Control Unit
ATPL(A)	Airline Transport Pilot License (Aeroplane)	Verkehrspilotenlizenz (Flugzeug)
BEA	Bureau d’enquêtes et d’analyses pour la sécurité de l’aviation civile	
BFU	German Federal Bureau of Aircraft Accident Investigation	Bundesstelle für Flugunfalluntersuchung
BITE	Built in Test Equipment	Geräteselbsttest
COO	Chief Operations Officer	Manager des operativen Geschäfts
CS	Certification Specification	Bauvorschrift über die Bauartzulassung
CPC	Cabin Pressure Controller	
CPL(A)	Commercial Pilot License (Aeroplane)	Berufspilotenlizenz (Flugzeug)
CU	Command Upgrade Course	
CVR	Cockpit Voice Recorder	
DC	Direct Current	Gleichstrom
DSP	Digital Selector Panel	
EASA	European Aviation Safety Agency	Europäische Agentur für Flugsicherheit
ECCAIRS	European Coordination Centre for Accident and Incident Reporting Systems	
ECS	Environmental Control System	
ELW	Mobile command post	Einsatzleitwagen

EM-Plan	Emergency-Plan	Notfallplan
FAA	Federal Aviation Administration	
FCOM	Flight Crew Operations Manual	
FCTM	Flight Crew Training Manual	
FDR	Flight Data Recorder	
FHFW	Airport Fire Brigade	Flughafenfeuerwehr
FL	Flight Level	Flugfläche
ft	Feet	Fuß (1 Fuß = 0,3048 m)
ft/min	Feet per minute	Fuss pro Minute
HNO	Otorhinolaryngology	Hals-, Nasen-, Ohrenheilkunde
ICAO	International Civil Aviation Organisation	Internationale zivile Luftfahrtorganisation
IuK	Information and communications team (unit of civil protection)	Information und Kommunikation (Einheit des Katastrophenschutzes)
kt	knot(s)	Knoten (1 kt = 1,852 km/h)
KTW	Patient Transport Ambulance	Krankentransportwagen
MANV	Large number of casualties	Massenanfall von Verletzten
MCP	Mode Control Panel	
METAR	Meteorological Terminal Aerodrome Routine Report	Routine Wettermeldung für die Luftfahrt
MSA	Minimum Sector Altitude	Mindestsektorenhöhe über MSL
MSL	Mean Sea Level	Mittlerer Meeresspiegel
NEF	Emergency medical physician deployment vehicle	Notarzteinsatzfahrzeug
NITS	Nature of Incident; Intentions; Time Available; Special Instructions	Art des Ereignisses; Intentionen; verfügbare Zeit, spezielle Anweisungen
NM	Nautical Mile(s)	Nautische Meile(n)
NNC	Non Normal Checklist	
NTSB	National Transport Safety Board	
NVM	Non Volatile Memory	Nichtflüchtiger Speicher
OCC	Operations Control Center	
OCC	Operators Conversion Course	
OFV	Outflow Valve	

OLRD	Senior lead paramedic supervisor (SLP-S)	Organisatorischer Leiter Rettungsdienst
PM	Pilot monitoring	Pilot, der den PF unterstützt
p/n	part number	Teilenummer
psi	pounds per square inch	(14,5 psi = 1 bar)
PSEU	Proximity Switch Electronics Unit	
QAR	Quick Access Recorder	
QDM	Quick Donning Mask	Sauerstoffmasken zum Gebrauch im Cockpit
QRH	Quick Reference Handbook	
RLST	Rescue Coordination Centre	Rettungsleitstelle
RST	Recurrent Simulator Training	
RTW	Emergency Ambulance	Rettungswagen
SEG	Civil protection deployment group	Schnelleinsatzgruppe (Einheit des erweiterten Rettungsdienstes/Katastrophenschutzes)
SEU	Single Event Upset	
SMYDC	Stall management and Yaw Damper Computer	
s/n	serial number	Serial number
THW		Technisches Hilfswerk
TMR	Triple Modular Redundancy	
TR	Type Rating	Musterberechtigung
TTR	Transition Type Rating	
VvD	Airport ground operation manager	Verkehrsleiter vom Dienst
WAL	Head of watch	Wachabteilungsleiter

Abstract

During a passenger flight from Dublin, Ireland, to Zadar, Croatia, rapid decompression in the cabin occurred at FL 370 due to miscalculation of one of the Cabin Pressure Controllers (CPC) which resulted in the opening of the Outflow Valve (OFV). While the crew conducted an emergency descent with manually closed OFV, the cabin pressure increased to the maximum differential pressure. At 9,000 ft AMSL, the aircraft levelled off and the OFV was opened manually which resulted in a second rapid decompression. Subsequently, the airplane landed at Frankfurt-Hahn Airport.

According to the last statements, 33 persons on board suffered minor injuries due to pressure fluctuation. It was not possible for the BFU to verify the number of injured persons due to differing information by the parties involved.

The Lagezentrum des Ministeriums des Inneren und für Sport des Landes Rheinland-Pfalz informed the BFU of the occurrence.

During the night, the BFU sent an external expert for field investigation to Frankfurt-Hahn Airport. The next morning, two BFU employees arrived at the airport.

After it became known that the occurrence occurred in French airspace, the French Bureau d’Enquêtes et d´Analyses (BEA) was notified. They delegate the investigation into the occurrence to the BFU.

Subsequently, the Irish Air Accident Investigation Unit (AAIU) and the US American National Transportation Safety Board (NTSB) were also notified. Both authorities appointed Accredited Representatives and experts to support the investigation. In addition, EASA and FAA were notified.

1. Factual Information

1.1 History of the Flight

At 2105 hrs, the airplane had taken off at Dublin Airport to a scheduled flight to Zadar. Six crew members and 190 passengers were on board the airplane.

The Pilot in Command (PIC) was pilot flying, the co-pilot pilot monitoring.

At 2214:24 hrs, while in French airspace at FL 370, prior to way-point BEGAR, the co-pilot radioed the air traffic control unit Reims.

According to the QAR, at 2243:30 hrs, cabin pressure altitude was 7,925 ft; the OFV began to open over a period of 9 seconds from originally 18° to fully open (104°).

According to the CVR, the crew noticed the pressure drop after 4 seconds. The Cabin Altitude Warning sounded 2 seconds later, as the cabin pressure altitude of 9,470 ft was passed. Both pilots stated that due to the pressure drop they had significant hearing problems and at that time seen the cabin pressure altitude indication climbing with a rate of more than 4,000 ft/min. They could not remember the position of the OFV or the operating condition of the auto fail and the alternate lights.

At 2243:40 hrs, at a cabin pressure altitude of 13,153 ft, the pressure switch was triggered and the OFV began to close automatically with a speed of about 19° per second until it reached an opening angle of 18°. At 2243:41 hrs, both pilots had donned their oxygen masks (QDM) and began to complete the memory items for rapid decompression. This was made more complicated because the masks were partially fogged. Meanwhile, there was no verbal communication. At the same time the cabin altitude warning horn sounded. Over a time period of approximately 25 seconds, the position of the OFV oscillated four times between 18° and 28° open (Fig. 12) while the cabin pressure altitude increased to 14,639 ft.

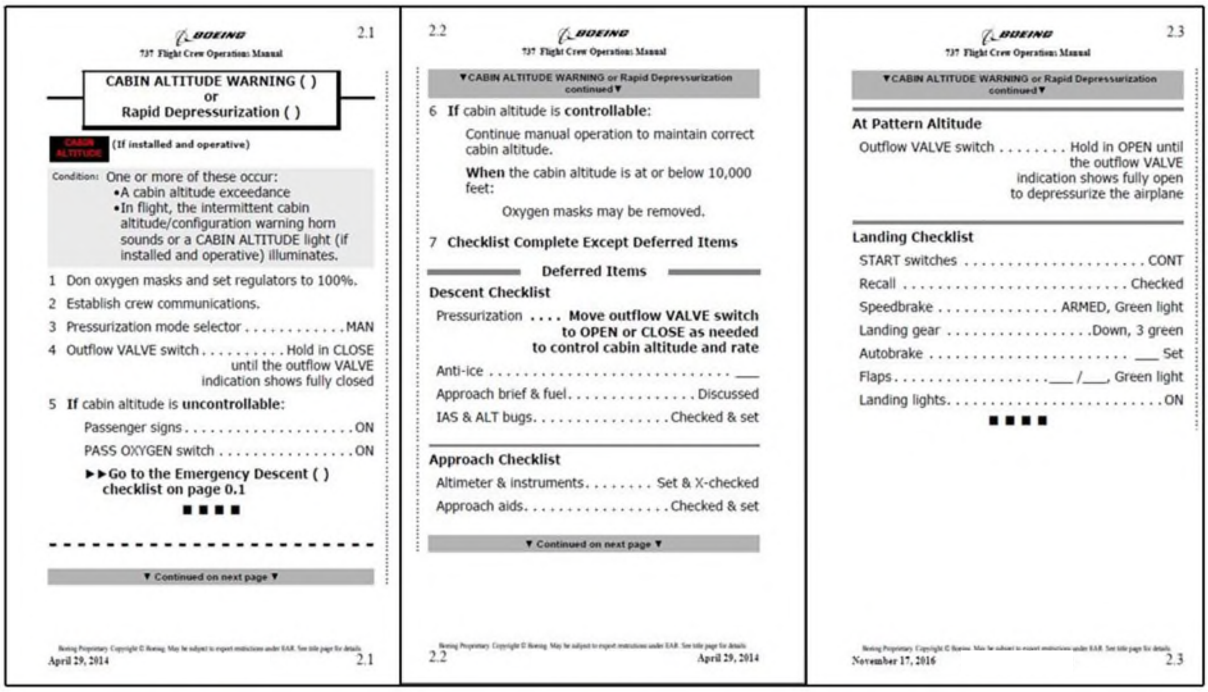
At 2244:00 hrs, the fasten seatbelt signs in the cabin were activated. At 2244:02 hrs, the co-pilot switched the OFV to manual control mode and then closed the OFV to position 9.3° open. During the last 32 seconds, the cabin pressure altitude had increased with a mean rate of 12,950 ft/min to 14,830 ft. After the OFV was closed, it began to decrease again. At 2244:13 hrs, the PIC used the cabin PA system and called three times “Emergency Descent” and then said to the co-pilot “Valve manual close”, which he answered with “OK”. At 2244:17 hrs, the PIC initiated emergency descent. At the time, the cabin pressure altitude had already decreased by 2,000 ft.

According to the air traffic control radar recording, the airplane passed FL 367 at 2044:31 hrs with a groundspeed of 470 kt, a south-eastern heading, and FL 220 selected at the MCP. At 2244:36 hrs, ATC Reims received the Mayday call and was informed about the emergency descent to FL 100.

At 2245:17 hrs, the OFV was manually closed completely. Over the next 12 minutes the cabin pressure altitude decreased with a maximum descent rate of 3,300 ft/min. At 2245:22 hrs, the co-pilot began to complete the Cabin Altitude Warning or Rapid Decompression Checklist (Fig. 1).

The radar controller instructed the flight crew at 2246:08 hrs, at a QNH of 1,019 hPa, to turn left to a heading of 050°. During the turn towards the new heading, at 2246:29 hrs, the airplane passed FL 274 with a groundspeed of 500 kt and the preselected FL 100 (MCP). At 2246:36 hrs, the radar controller asked the flight crew about their intentions. The crew answered that they wanted to continue with the prevailing heading and descend to FL 100. They requested the relevant Minimum Safety Altitude (MSA) for the region and the descent clearance to 9,000 ft, which the radar controller approved

At 2247:44 hrs, the co-pilot read items 3 and 4 of the Cabin Altitude Warning or Rapid Decompression checklist: *“Pressurization mode selector: MAN; Outflow Valve Switch: Hold in CLOSE until the outflow valve indication shows fully closed”*. The PIC acknowledged this and the co-pilot began to complete item 5 *“If cabin altitude is uncontrollable: Passenger Signs: ON; Passenger oxygen switch: ON“.*



BOEING 2.1
737 Flight Crew Operations Manual

CABIN ALTITUDE WARNING ( )
or
Rapid Depressurization ( )

CABIN ALTITUDE (If installed and operative)

Condition: One or more of these occur:
- A cabin altitude exceedance
- In flight, the intermittent cabin altitude/configuration warning horn sounds or a CABIN ALTITUDE light (if installed and operative) illuminates.

1 Don oxygen masks and set regulators to 100%.
2 Establish crew communications.
3 Pressurization mode selector . . . . MAN
4 Outflow VALVE switch . . . . Hold in CLOSE until the outflow VALVE indication shows fully closed
5 **If** cabin altitude is **uncontrollable:**
Passenger signs . . . . ON
PASS OXYGEN switch . . . . ON
►►Go to the Emergency Descent ( ) checklist on page 0.1

■ ■ ■ ■

▼ Continued on next page ▼

Boeing Proprietary Copyright © Boeing. May be subject to export restrictions under EAR. See title page for details.
April 29, 2014 2.1

2.2 BOEING
737 Flight Crew Operations Manual

▼CABIN ALTITUDE WARNING or Rapid Depressurization continued▼

6 **If** cabin altitude is **controllable:**
Continue manual operation to maintain correct cabin altitude.
When the cabin altitude is at or below 10,000 feet:
Oxygen masks may be removed.

7 **Checklist Complete Except Deferred Items**

Deferred Items

Descent Checklist
Pressurization . . . . **Move outflow VALVE switch to OPEN or CLOSE as needed to control cabin altitude and rate**
Anti-ice . . . . ___
Approach brief & fuel. . . . . Discussed
IAS & ALT bugs. . . . . Checked & set

Approach Checklist
Altimeter & instruments. . . . . Set & X-checked
Approach aids. . . . . Checked & set

▼ Continued on next page ▼

Boeing Proprietary Copyright © Boeing. May be subject to export restrictions under EAR. See title page for details.
2.2 April 29, 2014

BOEING 2.3
737 Flight Crew Operations Manual

▼CABIN ALTITUDE WARNING or Rapid Depressurization continued▼

At Pattern Altitude
Outflow VALVE switch . . . . Hold in OPEN until the outflow VALVE indication shows fully open to depressurize the airplane

Landing Checklist
START switches . . . . CONT
Recall . . . . Checked
Speedbrake . . . . ARMED, Green light
Landing gear . . . . .Down, 3 green
Autobrake . . . . ___ Set
Flaps. . . . . ___/___, Green light
Landing lights. . . . . ON

■ ■ ■ ■

Boeing Proprietary Copyright © Boeing. May be subject to export restrictions under EAR. See title page for details.
November 17, 2016 2.3

Fig. 1: Non-Normal Checklist Cabin Altitude Warning or Rapid Depressurization Source: FCOM Boeing 737

Reims Radar informed the flight crew about the MSA of 5,000 ft AMSL and at 2248:02 hrs transferred them to Langen Radar. When the radar controller asked the PIC about the reason for the emergency he answered: “We have emergency descent we are descending nine thousand feet and eh requesting heading towards eh Frankfurt […]“, The controller answered: “[…] that is copied, continue present heading there is no traffic in your way so nine thousand feet is fine.”.

At 2248:07 hrs, the cabin pressure altitude passed mean sea level while the airplane descended through FL 190. The co-pilot continued to complete the procedures of the Emergency Descent checklist (Fig. 2), as instructed by the PIC.

Boeing

737 Flight Crew Operations Manual

0.1

Emergency Descent ( )

Condition: One or more of these occur:
- Cabin altitude cannot be controlled
- A rapid descent is needed.

1 The pilot flying will advise the cabin crew, on the PA system, of impending rapid descent or confirm that the Emergency Descent PA has been made by PRAM. The pilot monitoring will advise ATC and obtain the area altimeter setting.

2 Passenger signs . . . . ON

3 **Without delay**, descend to the lowest safe altitude or 10,000 feet, whichever is higher.

4 ENGINE START switches (both) . . . . CONT

5 Thrust levers (both) . . . . Reduce thrust to minimum or as needed for anti-ice

6 Speedbrake . . . . FLIGHT DETENT

If structural integrity is in doubt, limit speed as much as possible and avoid high maneuvering loads.

7 ⚠ Set target speed to Mmo/Vmo.

8 **When** approaching the level off altitude:

Smoothly lower the SPEED BRAKE lever to the DOWN detent and level off. Add thrust and stabilize on altitude and airspeed.

▼ Continued on next page ▼

Boeing Proprietary. Copyright © Boeing. May be subject to export restrictions under EAR. See title page for details.

June 15, 2017 0.1

0.2

Boeing

737 Flight Crew Operations Manual

▼ Emergency Descent ( ) continued ▼

9 Crew oxygen regulators. . . . . Normal

Flight crew must use oxygen when cabin altitude is above 10,000 feet. To conserve oxygen, move the regulator to Normal.

10 ENGINE START switches (both) . . . . . . As needed

11 The new course of action is based on weather, oxygen, fuel remaining and available airports. Use of long range cruise may be needed.

Note: To avoid landing with the cabin pressurised, if the Pressurization Mode selector is in Manual refer to FCOM Vol 1 - Supplementary Procedures - Manual Mode Operation for further guidance on how to manage cabin pressurisation.

■ ■ ■ ■

Boeing Proprietary. Copyright © Boeing. May be subject to export restrictions under EAR. See title page for details.

0.2 April 25, 2013

Fig 2: Non-Normal Checklist Emergency Descent Source: FCOM Boeing 737

The flight crew received the new heading of 040° from Langen Radar at that time. The co-pilot read: “Emergency Descent; CONDITION: one or more of these occur: Cabin altitude cannot be controlled; A rapid descent is needed“, and then asked: “This is correct, do you agree?” The PIC answered: “Understood, yea […]“. According to the radar data, at 2249:15 hrs, the airplane passed FL 156 and the PIC informed the controller that he would now reduce speed to 250 kt. The controller answered: “Ja that’s fine and eh you eh intend to go to Frankfurt International, correct?” The PIC replied: “Affirm eh could you just check please for us the night-time […] so open and ah we get the weather from you […]”. The controller said: “Ja, they will be opened and eh just give me a call when you are ready to copy Frankfurt weather.”

At 2252:05 hrs, at 9,900 ft, the PIC said: “Cabin altitude is […] 24 000 ft. […] It’s kind of stabilizing, it’s coming down slowly. […] Basically, I’m not too sure why we had this depressurization.“ According to the QAR data, cabin pressure altitude was at the time about 7,000 ft below MSL. At 2252:15 hrs, the aircraft reached 9,500 ft AMSL and 18 seconds later the PIC said: “Now, it‘s still reducing […] It‘s coming down […] It‘s catching us up.“. At 2254:28 hrs, the PIC transferred the controls to the co-pilot and then said: “Cabin altitude now is 25 000 ft.“ The co-pilot answered with “OK?” The PIC replied: “[…] Frankfurt is open, it’s a good opportunity.” And then: “Now it says the cabin altitude is climbing – it says 33,000 ft […] it’s not working. What we have to do is opening the valve completely. We need to open the valve to depressurize.”

According to the radar data at this time, the airplane was at FL 89 with a speed of 260 kt. The FDR analysis showed that up until this time cabin pressure altitude was approximately 7,000 ft below MSL, for 4:20 min. maximum cabin differential pressure was 8.72 psi and the two pressure relief valves were in the open position. After the OFV had been opened completely, cabin pressure altitude increased over 2 min. with a maximum rate of climb of about 20,000 f/min and at 2256:04 hrs, reached the altitude of the aircraft.

Shortly afterward, the purser called from the cabin. After the PIC had explained the circumstances he asked about the situation in the cabin and was informed that cabin crew and passengers were using oxygen masks and that everyone was “more or less okay”. At 2257 hrs, the flight crew removed their oxygen masks at an altitude of 9,000 ft AMSL. Langen Radar advised a heading of 010°. Subsequently, the PIC conducted a so-called NITS[1] briefing with the purser during which the purser told him that one of his colleagues from the aft cabin had reported a loud hissing sound. He asked whether there was a possibility of evacuation after landing which the PIC negated.

At 2300 hrs, the radar controller enquired once again about the kind of emergency, the number of persons on board, and the remaining fuel. The PIC subsequently reduced the emergency from Mayday to Pan in reference to the stable situation after rapid decompression and requested the prevailing weather conditions at Frankfurt-Hahn Airport. The radar controller made sure the flight crew indeed wanted to fly to Frankfurt-Hahn Airport and not to Frankfurt-Main Airport. At 2301 hrs, he advised the flight crew of the new heading of 270° (Fig. 3), the prevailing weather conditions, and the expected landing direction. On enquiry, the PIC declined further assistance after landing.

[1] NITS Briefing: Nature of incident, Intentions, Time available, Special instructions. A briefing which in certain circumstances is performed for the cabin crew to inform them of the current situation, the course of action and the resulting consequences.

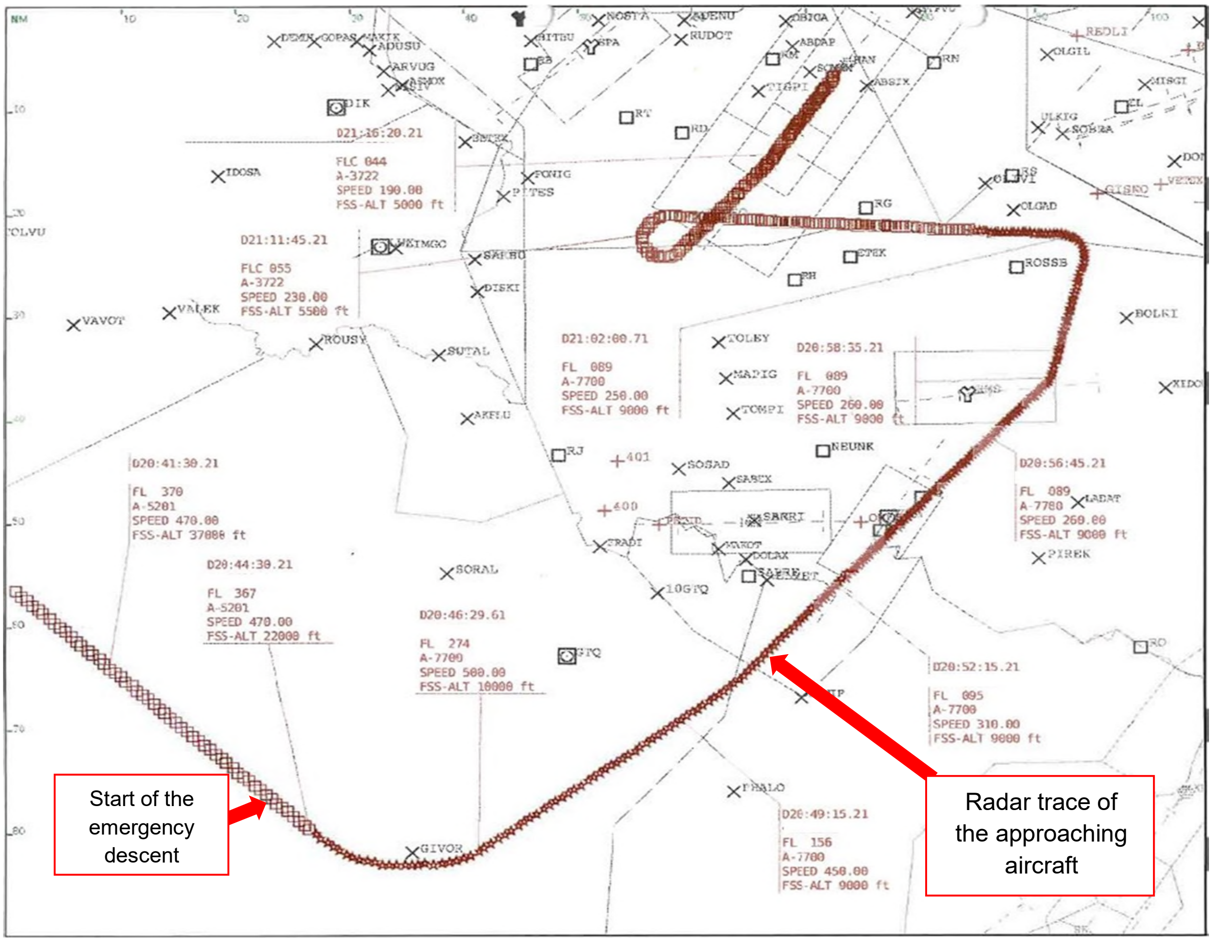


Fig. 3: Secondary radar recording of the approach to Frankfurt-Hahn Airport

Source: Air navigation service provider

At 2303 hrs, the PIC informed the passengers via the PA system about the pressure loss and the subsequent diversion to Frankfurt-Hahn Airport, and then began with the approach preparations and briefing. He told the co-pilot that he considered Hahn a good alternate aerodrome because of it being the maintenance base of the operator; he also believed that the OFV had caused the problem, and he did not think they needed rescue personnel assistance on the ground. He asked the purser once again whether passengers had said they needed medical assistance. He received the information that there was one passenger whose ear was bleeding. At 2310 hrs, the PIC requested via ATC an ambulance to the parking position of the airplane.

During the continued approach the PIC said: “[…] valve now is completely open. Very strange, because cabin altitude reached over 30,000 ft.” The co-pilot replied: “I know how did that happen?“ At 2314 hrs, after the airplane had been established on approach to Runway 03 of Frankfurt-Hahn Airport it was transferred to the tower controller. At 2319 hrs, the landing occurred without further incident. At 2322 hrs, after having reached the parking position the engines were shut off. The PIC asked the passengers who needed medical assistance to remain seated and to reach out to the cabin crew. The purser reported that another two passengers did not feel well.

A total of 33 persons were medically treated on site by rescue personnel or transported to hospital.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Total in aircraft	Other
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	2	31	33	NA
None	4	159	163	NA
Total	6	190	196	NA

1.2 Damage to Aircraft

The field investigation determined no damage at the aircraft.

1.4. Other Damage

There was no other damage to persons or property.

1.5 Personnel Information

Pilot in Command

The 29-year-old PIC was a British citizen, who held an Airline Transport Pilot License (ATPL(A)) initially issued by the Irish civil aviation authority in accordance with ICAO and EASA standards. The type rating for the B737-300-900 was valid until 30 April 2019.

His Class 1 Medical Certificate was valid until 15 October 2018.

He had a total flying experience of 4,867 hours; of which 4,647 hours were flown on type. In the last 72 hours he had flown 14:37 hours. In the last 24 hours prior to the occurrence flight, he had slept for 7:30 hours.

Co-pilot

The 36-year-old co-pilot was a Croatian citizen, who held a Commercial Pilot License (CPL(A)) including ATPL theory knowledge credit initially issued by the Irish civil aviation authority in accordance with ICAO and EASA standards. The type rating for the B737-300-900 was valid until 28 February 2019.

His Class 1 Medical Certificate was valid until 3 October 2018.

He had a total flying experience of 2,447 hours; of which 2,244 hours were flown on type. In the last 72 hours he had flown 14:37 hours. In the last 24 hours prior to the occurrence flight, he had slept for 8:00 hours.

The flight crew had conducted all flights on the day of the occurrence and the two previous days together.

1.6 Aircraft Information

Manufacturer:	Boeing
Type:	B737-8AS
Manufacturer's Serial Number (MSN):	35038
Year of Manufacture:	2011
MTOM:	66,900 kg
Engines:	CFM International, CFM56-7B26

The aircraft had an Irish certificate of registration and was operated by an Irish operator.

At the time of the occurrence, the aircraft had a total operating time of 24,038 hours at 12,575 cycles. According to the documentation provided, the Technical Log and the Hold Item List of the airplane did not show any irregularities in the weeks leading up to the occurrence concerning the Environmental Control System.

1.6.1 Environmental Control System

1.6.1.1 System Description

The Environmental Control System (ECS) of the aircraft essentially consists of the pressurised airframe, two Air Cycle Machines (ACM) for fresh air and temperature, as well as one OFV for airflow and pressurisation. The position of the OFV is regulated by two Cabin Pressure Controllers (CPC), of which one actively controls the OFV and the other is on standby. The CPCs measure the cabin pressure directly at the controller via a pressure sensor and receive another data input from the DSP, the ADIRUs, the SMYDCs and the PSEUs. The role of the CPCs (Master or Slave) changes with each flight leg.

The OFV is a two-part valve which is located in the lower right fuselage area. It is equipped with three electrical motors which change the position of the two valve plates via joint mechanical activation. Two of the motors (Auto-Motor 1 and 2) are controlled by the CPCs, whereas the third (Manual-Motor) is controlled via the toggle switch for manual mode. The Auto-Motors are supplied by DC Bus 1 and 2 and the Manual-Motor with 28V DC via the Battery Bus.

In case of cabin pressure control system failure two Overpressure Relief Valves and one Negative Pressure Relief Valve protect the pressurised cabin against high differential pressures. The OFV is also equipped with two so-called pressure switches, which function independent of each other and close the OFV if the cabin pressure altitude exceeds 14,500 ft. These pressure switches are located in the electronics box portion of the OFV, and are separate from the pressure sensors (located on the CPCs), that are used to measure cabin pressure during automatic regulation.

Fig. 4: Outflow valve in open position (arrow) Source BFU

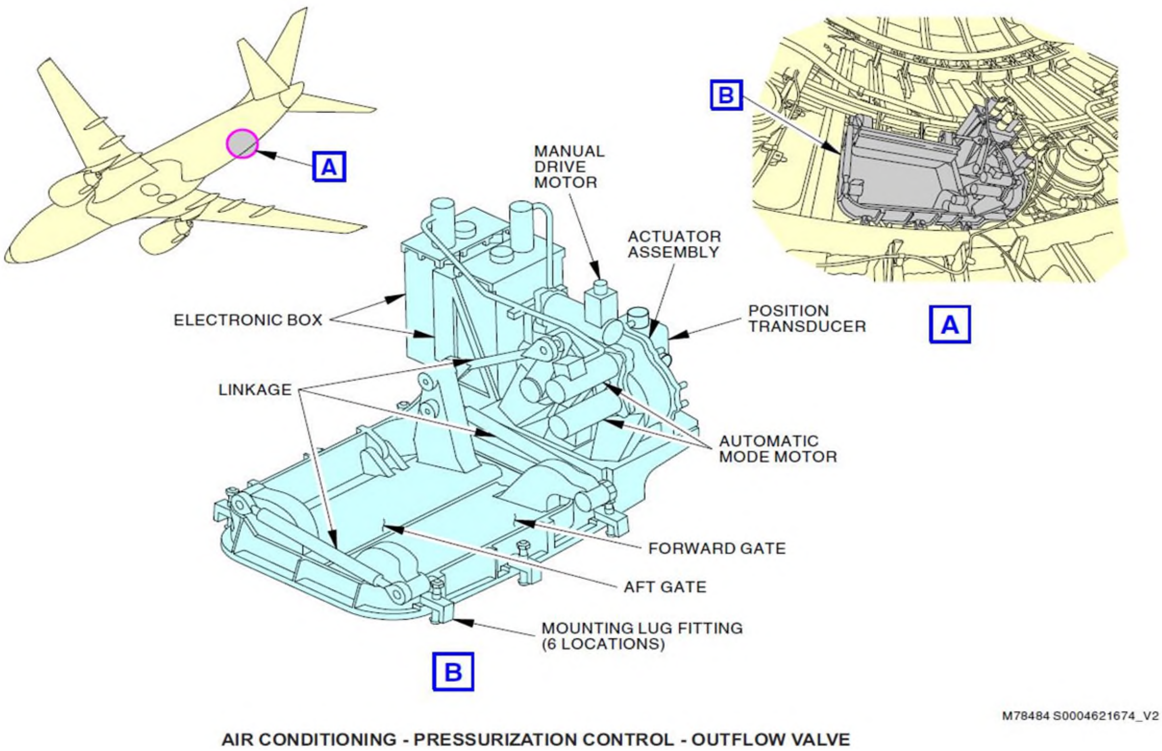


Fig. 5: Mounting position and schematic depiction of the OFV Source: AMM Boeing 737

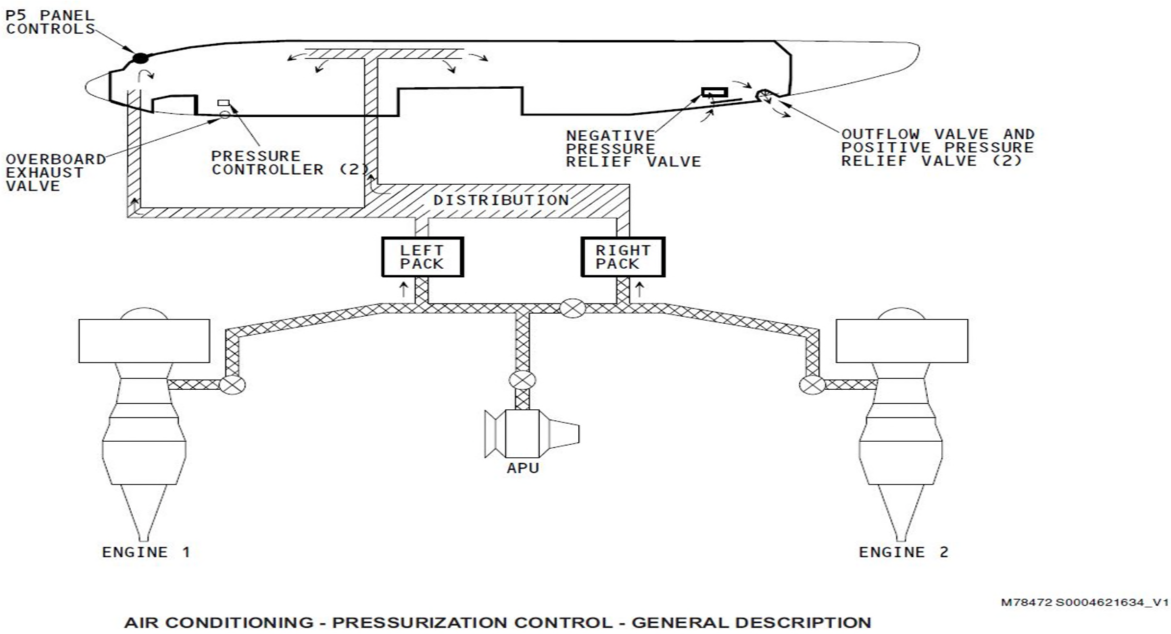


Fig. 6: Schematic depiction of the environmental control system Source: AMM Boeing 737

The Digital Cabin Pressure Control Systems is controlled by the Digital Selector Panel (DSP) located at the front right overhead panel.

The following parameters are indicated on analogue instruments:

- Cabin pressure altitude
- Differential pressure
- Cabin rate of climb or descent
- OFV position

The modes of the OFV, flight and landing altitude can also be selected. In this panel the cabin altitude warning system is integrated.

The pointer of the analogue Cabin Pressure Indicator does not have a zero dead stop. In case the cabin is operated with positive pressure, mirroring a flight altitude below MSL, after passing MSL, it moves further counter clockwise to enter the altitude scale again from the portion, that represents high cabin altitudes.

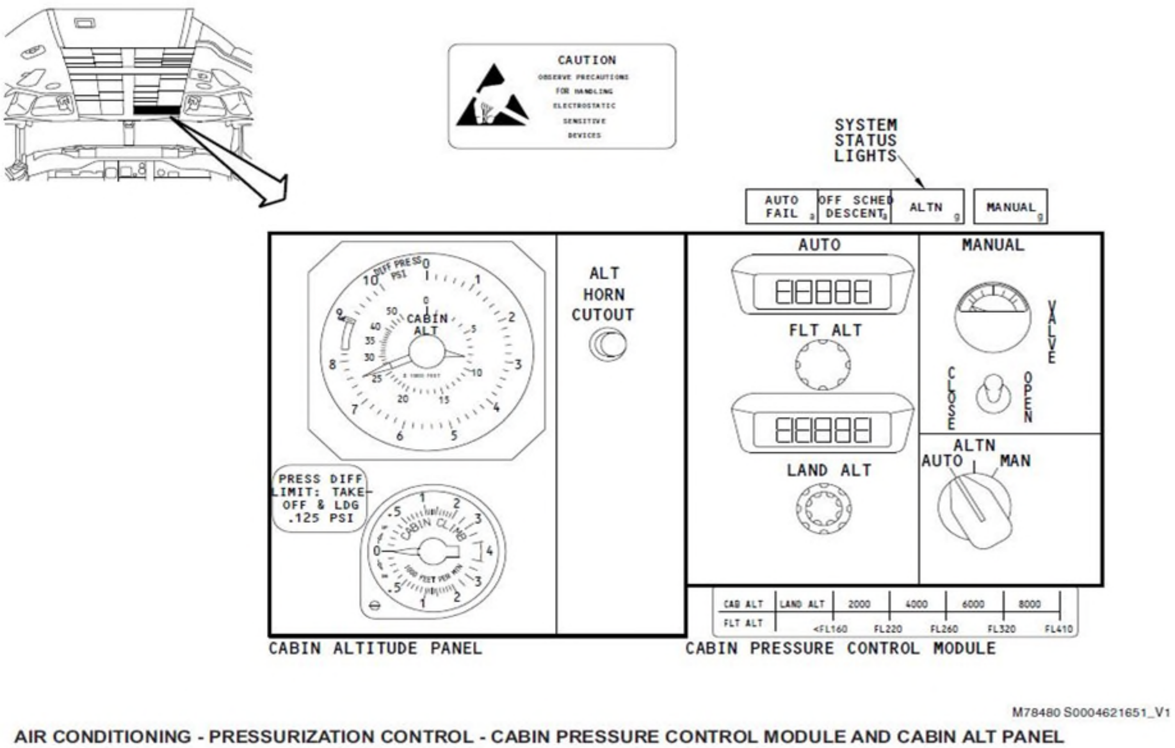


Fig. 7: Cabin pressure control module and cabin alt panel — Source: Manufacturer

1.6.1.2 Operating Mode

In automatic mode, the ECS regulates the maximum cabin pressure rate of change in a range comfortable for passengers, during climb and descent. During cruise flight, the system keeps a constant differential pressure which depends on the respective altitude or flight level between pressurised cabin and the environment by controlling the opening of the OFV. During cruise flight at FL 370 this is 7,8±0,05 psi. Descent mode is triggered automatically if the differential pressure is more than 0.25 psi between the cruising altitude preselected at the DSP and the outside pressure at the actual altitude. At a cabin pressure altitude between 15,000 ft and 8,000 ft, the system controls the pressure change during descent in automatic mode depending on the operator option selected, in this case to a maximum rate of descent of 350 ft/min. After landing, the OFV opens to depressurise the cabin.

The automatic control of the OFV's position via the CPCs occurs electronically. The active CPC compares the actual cabin pressure with the calculated reference pressure for the respective flight phase and altitude. Is there a difference between the two values, the CPC generates a corresponding opening or closing command signal for one of the two auto motors of the OFV. The actual position of the OFV is send to the CPC and compared with a calculated reference position of the OFV. If a CPC detects a malfunction in its own control circuit, it ends the active control, the Auto Fail and Alternate indications at the DSP are illuminated and the second CPC becomes active.

For manual mode operation the corresponding switch at the DSP has to be switched to MAN mode. At a spring-loaded toggle switch kept in neutral, the position of the OFV can be varied manually. The OFV position is indicated at an analogue indication located above this switch.

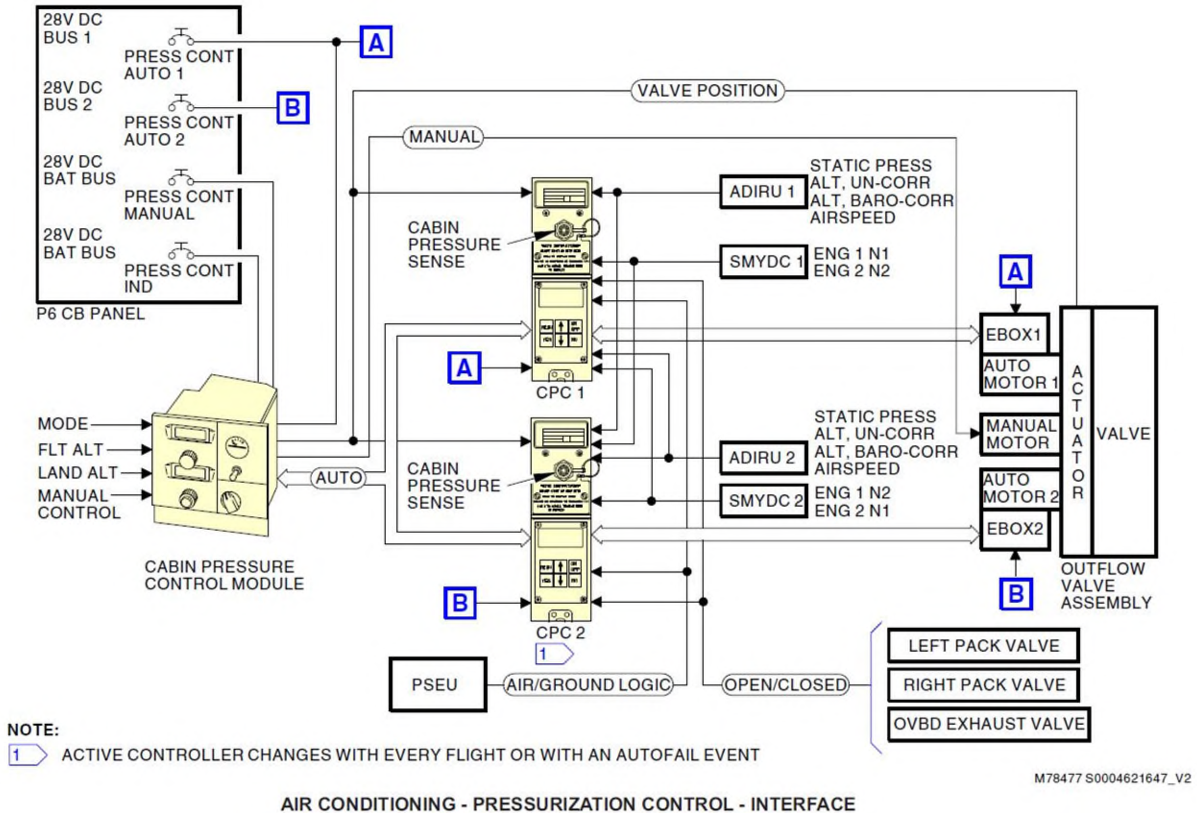


Fig. 8: Schematic depiction of the environmental control system Source: AMM Boeing 737

1.7 Meteorological Information

At the time of the occurrence, it was night and visual meteorological conditions prevailed. There was no wind, visibility was more than 10 km and the lowest cloud base was higher than 5,000 ft. The relevant METARs for Frankfurt-Hahn read:

METAR EDFH 132050Z 00000KT CAVOK 17/12 Q1021=

METAR EDFH 132120Z VRB01KT CAVOK 17/12 Q1021=

1.8 Aids to Navigation

The air navigation service provider provided the BFU with the secondary radar data of the aircraft of the relevant time period (Fig. 3). The recording started at 2240:05 hrs and ended at 2320 hrs.

1.9 Radio Communications

The transcript of the radio communications between flight crew and the German air traffic control unit were made available for the investigation. The transcript started at 2248:21 hrs and ended at 2315:52 hrs. Radio communications were carried out in English on frequency 129,675 MHz. The relevant passages were included in this report as excerpts.

1.10 Aerodrome Information

Frankfurt-Hahn Airport is located 5.5 NM west of the town Kirchberg (Hunsrück). Aerodrome elevation is 1,649 ft above MSL. It had one runway with the orientation 032°/212°, a length of 3,800 m and a width of 45 m. Both landing directions were approved for visual and instrument approach procedures. The airport was in service 24 hours a day.

On the day of the occurrence, runway 03 was in service.

1.11 Flight Recorders

The airplane was equipped with a Honeywell HFR5-D (P/N 980-4750-003, S/N FDR-04718) FDR and a Honeywell SSCVR (P/N 980-6022-001, S/N CVR120-14265) CVR. Both recorders were undamaged. The BFU read out and analysed both recorders using a Honeywell RPGSE computer.

Data quality was good. The time parameter of the FDR was GPS coupled UTC. Synchronisation of the timeline of FDR and CVR occurred at the activation of the push-to-talk button of the co-pilot at COM1 at 2044:41 UTC.

The QAR data was also available. Both cabin pressure controllers (Nord Micro 21933-01AC) were seized. In the presence of a BFU employee, they were read out and analysed at the manufacturer's facilities (Fig. 9 and 10).

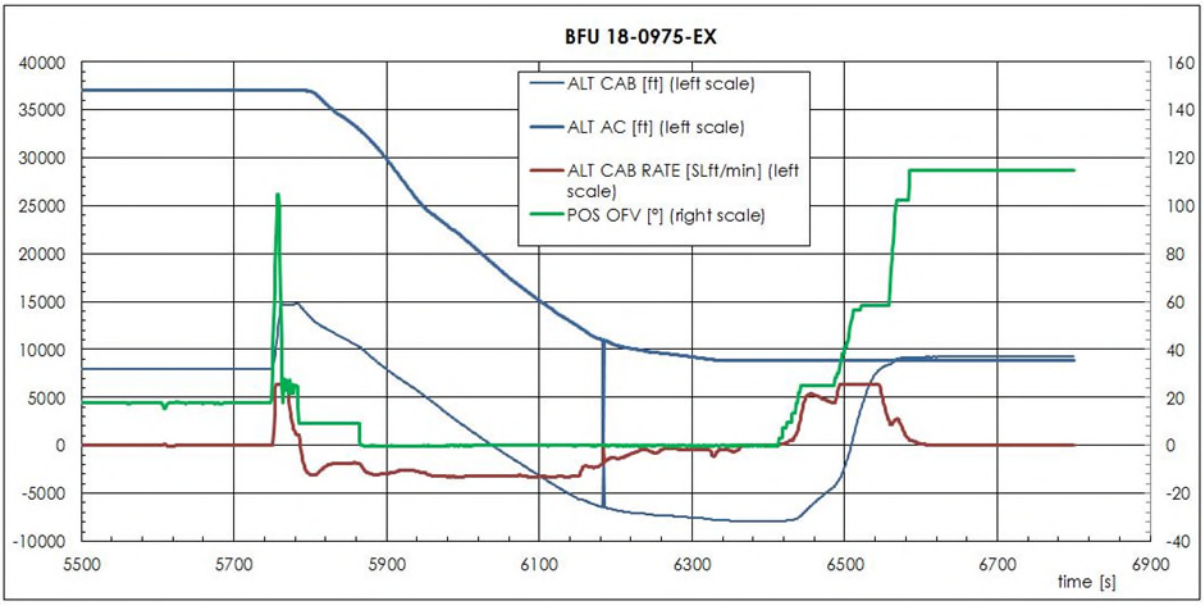


Fig. 9: Operating parameters pressurized cabin 1/2 Source: Nord Micro

Thick blue line: aircraft altitude; thin blue line: cabin pressure altitude; green line: OFV position; red line: cabin rate of climb or descent

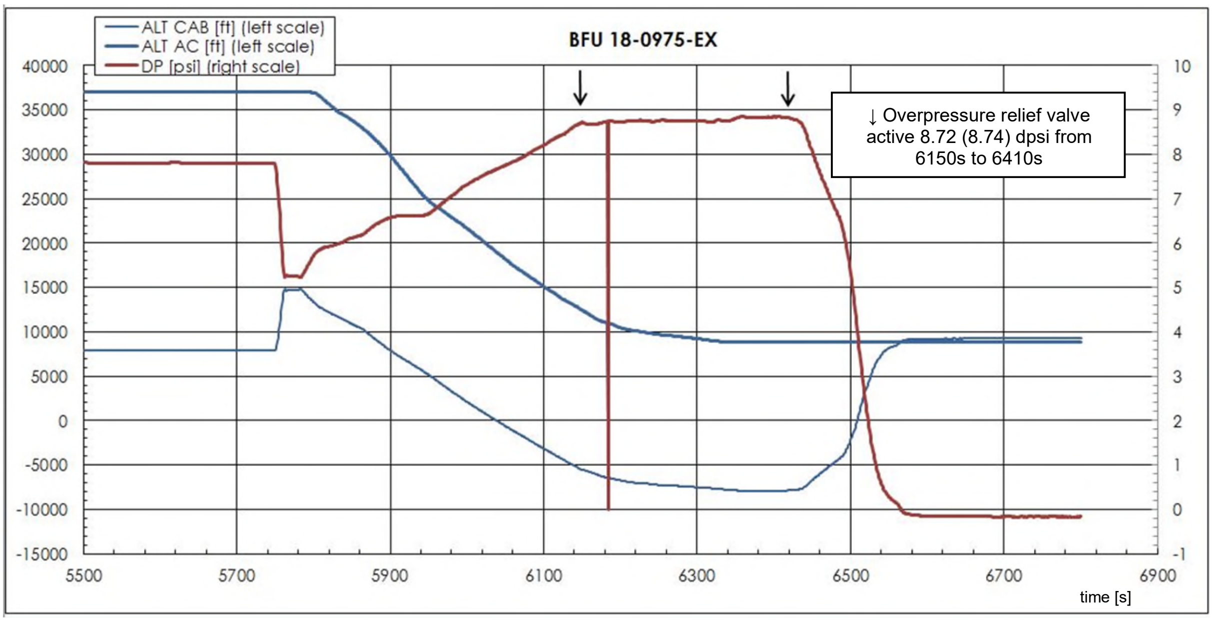


Fig. 10: Operating parameters pressurized cabin 2/2 Source: Nord Micro

Thick blue line: aircraft altitude; red line: differential pressure; thin blue line: cabin pressure altitude

1.12 Findings on the Aircraft

At the day of the occurrence, BFU investigators visually examined the airplane at daylight. No external damage could be detected. In the cockpit two oxygen masks had been removed from their storage; in the cabin and lavatories the Passenger Service Units were open and the masks had fallen out.

The OFV was subject to a functional test in manual mode; there was no indication of mechanical malfunction.

The read-out of the Built-In Test Equipment (BITE) of the two at that time still installed CPCs showed concordant messages:

- MANUAL SWITCH
- CAB RATE HI
- CAB ALT 10000 FT
- CAB ALT 13500 FT
- CAB PRES SW ACTIVE

In addition, CPC 1 showed the message “NO AUTO FAIL”.

The following ECS components of the aircraft were examined at the manufacturer:

- Cabin Pressure Controller 1
- Cabin Pressure Controller 2
- Outflow Valve
- E-Box 1
- E-Box 2
- Gearbox
- Digital Selector Panel

The individual components were tested and several flight simulations conducted with the complete system in order to determine the cooperation of the components.

After the examination, the manufacturer came to the following conclusion:

[...] Both CPCs, the OFV and the DSP were tested. The result was that no malfunction was determined.

The analysis of the occurrence was based on the QAR data and the NVM data of the CPCs. […]

The analysis of the main reason for the movement of the OFV showed that it is highly likely that the opening of the OFV was caused by a damaged data record from a Single Event Upset. In the scope of a software analysis, it was possible to prove the sensitivity of this type of CPCs to SEUs. […]

A Single Event Upset (SEU) is a so-called “soft error” in connection with the function of semiconductor components, which in aerospace are mostly caused by ionising radiation at great altitudes. Charged particles emit energy when passing through semiconductor components, for example. This may cause the charge distribution in the component to change and may result in a so-called Bitflip (switch of the p-n transition). The results of calculations such a component may process at the time may be affected. The SEU does not cause any damage on the component and does affect it only at the time it occurs.

Actions to minimise SEUs can be of a physical nature by shielding the components against radiation or functional by implementing so-called Triple Modular Redundancy (TMR). TMR means that the relevant calculations occur trifold and the results are compared at the end by a so-called Comparator so that wrong results can be realised and eliminated.

The detailed read-out of the QAR data showed for CPC 2 a wrong calculation of the reference position of the OFV at correct measured cabin pressure altitude. Figure 11 is an exemplary depiction of them at the time of passing a cabin pressure altitude of 10,000 ft and at the deactivation of CPC 2. While the calculation of the reference cabin pressure altitude in relation to the actually measured cabin pressure altitude occurred accurately, the result was not the expected closing signal but a control command for a wider opening of the OFV when the reference position of the OFV was calculated.

event	aircraft altitude [ft]	cabin altitude [ft]	reference cabin altitude [ft]	measured OFV position [°]	reference OFV position [°]	CPC in control
10000 ft warning CPC1	36996	10555	NA	91.5	NA	2
10000 ft warning CPC2	36996	10560	10187	92.4	99.3	2

event	aircraft altitude [ft]	cabin altitude [ft]	reference cabin altitude [ft]	measured OFV position [°]	reference OFV position [°]	CPC in control
high cabin rate fail	36996	11296	10914	104.5	110.0	2

Fig. 11: QAR data, incorrect calculation of the OFV reference position Source: Nord Micro

Using mathematical simulation, the manufacturer was able to identify the two calculation processes by which SEU impact of a parameter resulted in the documented malfunction. Both calculation processes are part of the CPC function control of the OFV. They affect the command signal of the OFV and the calculation of the OFV reference value. These calculations showed that a total of 14 parameters were at risk of SEUs. The probability of one of the parameters being affected by SEU was between 10^{-5} and 10^{-13}.

In addition, the manufacturer came to the following findings:

[…] The oscillation after the first pressure switch activation was caused by repeated control transitions between the pressure switch and the automatic control of CPC1. At the time of the first deactivation of the pressure switch, the cabin rate of descent was 3,420 ft/min. In this situation, the command variable of the CPC was 350 ft/min. Accordingly, the CPC commanded reopening of the OFV and the pressure switch was triggered again. This resulted in damped oscillation and the system reached normal operating mode after a few cycles with a cabin rate of descent of 350 ft/min.

Before normal operating mode was reached the crew switched the system to manual mode and closed the OFV for about 9 minutes completely. After the crew had conducted an emergency descent they opened the OFV completely. […]

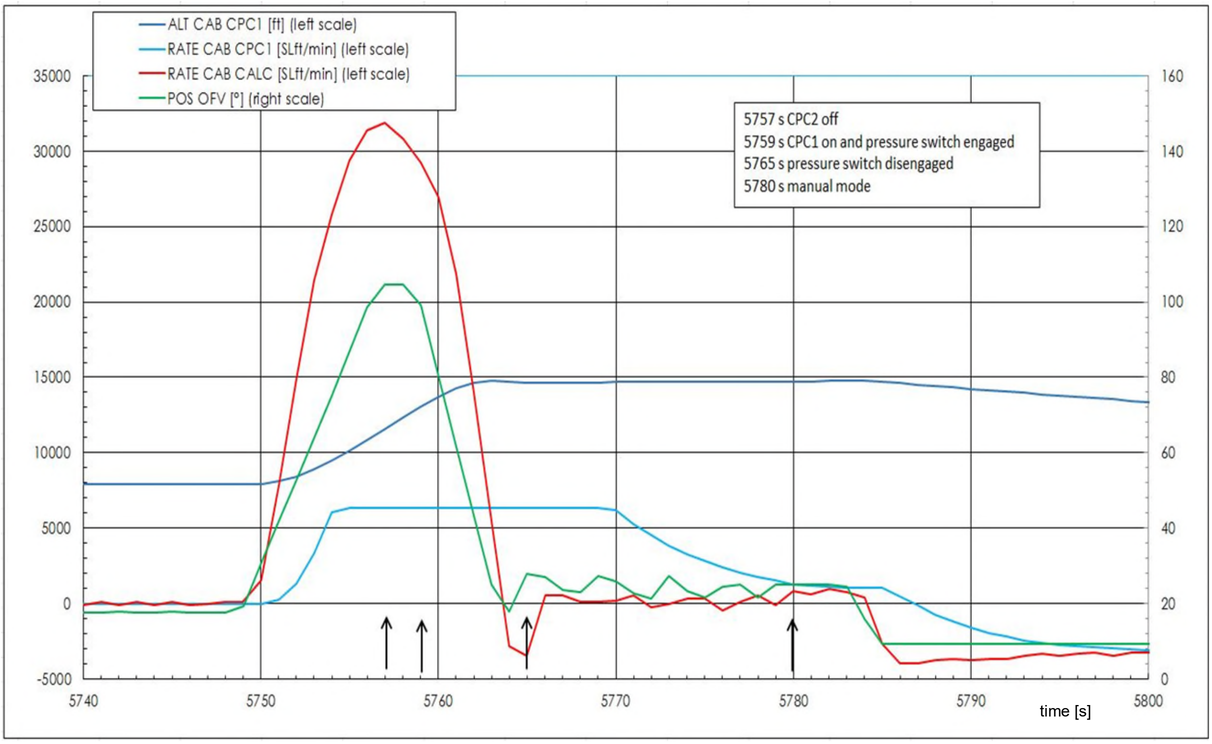


Fig. 12: Oscillation of the OFV after pressure switch activation Source: Nord Micro

Blue line: cabin pressure altitude CPC1; red line: calculated cabin rate of climb and descent; green line: OFV position; light blue line: cabin rate of climb and descent stored in the CPC

According to the statement of the aircraft manufacturer, the occurrence probability of SEU is 3.5×10^{-8} per flight hour, if the worst comes to the worst. This means one occurrence per 28.4 million flight hours. In addition, they came to the conclusion that 2.7% of all rapid decompression occurrences are the result of CPC malfunctions caused by SEU. Accordingly, the manufacturer reckons with nine more similar occurrences during the expected service life of this entire fleet. Due to the high redundancy in ECS this failure probability corresponds with the valid certification requirements.

There are three redundancy levels in the ECS: two CPCs, of which one is sufficient to operate the pressurised cabin, two pressure switches at the OFV, which close it in case the cabin pressure altitude exceeds 14,500 ft and the crew, which can control the OFV position manually via the DSP.

The Applicable Means of Compliance (AMC) to EASA certification requirements "CS-25 Large Aeroplanes" described in chapter AMC 25.1309 System Design and Analysis necessary safety levels in case of a system failure. To meet the requirements, the impact of a failure as well as the failure probability was taken into account.

While in this case the impact of a total system loss, according to AMC 25.1309 7.a.(3), has to be considered as major (*[…] significant increase in crew workload, […] or physical distress to passengers or cabin crew, possibly including injuries.*), the occurrence probability of $3{,}5x10^{-8}$, is classified as extremely remote (AMC 25.1309 7.c.(iii)), resulting in an acceptable safety level (AMC 25.1309 8).

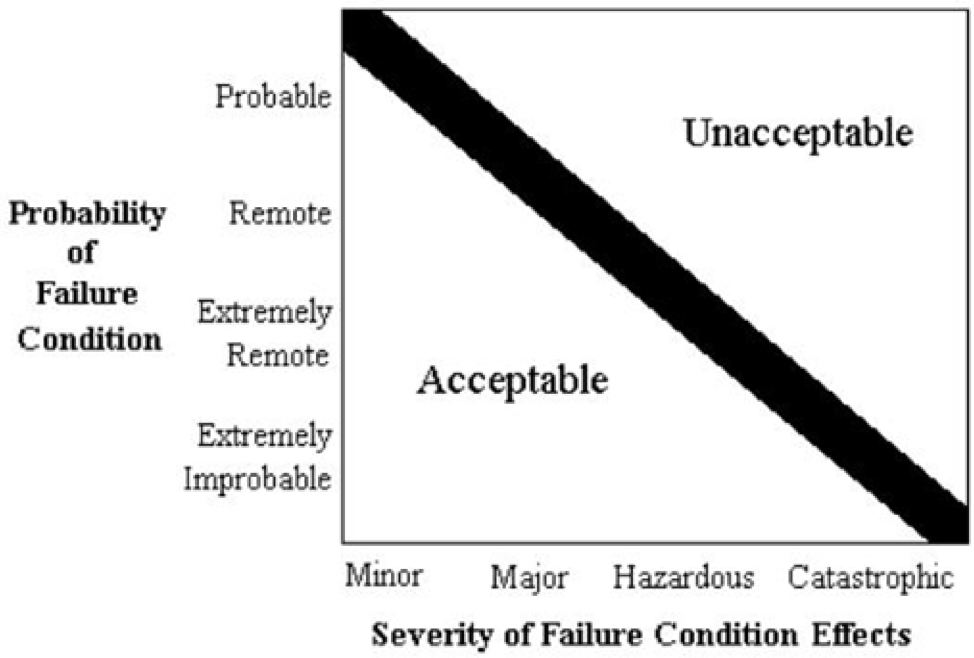


Fig. 13: Relationship between probability and severity of failure condition effects Source: EASA CS-25

Furthermore, AMC 25.1309 9.b(5)(iii) stated:

[…] However, quantitative assessments of the probabilities of crew or maintenance errors are not currently considered feasible. If the failure indications are considered to be recognizable and the required actions do not cause an excessive workload, then for the purpose of the analysis, the probability that the corrective action will be accomplished, can be considered to be one.

1.13 Medical and Pathological Information

Up until the writing of this report, it was not possible to determine the final number of injured persons, because different sources reported different numbers. Initially, the Bundespolizei (German federal police) stated 15 persons were injured. By the next morning the number had increased to 21, which the operator quoted. According to the documentation of the rescue personal, 15 patients were treated on site and another 28 were transported with rescue vehicles to 4 hospitals. The final report of the Bundespolizei stated a total of 33 injured persons.

An enquiry of the hospitals treating passengers showed the following injuries

- Tube ventilation disorder
- Retrotympanic hematoma
- Epistaxis (nosebleed)
- Barotraumata

As far as could be determined, there was no ruptured eardrum. All passengers were treated as ambulant patients, there was no inpatient admission.

The BFU consulted an Otorhinolaryngologist of the Zentrum für Luft- und Raumfahrtmedizin der Luftwaffe at Fürstenfeldbruck.

He came to the conclusion that it is highly likely that the injuries of the middle ear were caused by the re-pressurisation of the cabin during the overpressure phase of the descent. The injuries were all caused by an untimely pressure balance between the individual sections of the human acoustic and equilibrium organs.

The anatomically existing compensation tubes covered with mucous membranes are able to transfer and therefore compensate rapidly occurring underpressure, as is the case with rapid decompression. With a sudden occurrence of overpressure, the mucous membranes are “pushed together” which results in a valve mechanism and therefore closure of the compensation tubes. This can only be bypassed to a certain extent by swallow and pressure manoeuvres of the person involved. If the pressure differential continues the result is that at the border of two parts of the human acoustic and equilibrium organs pressurised with different pressures, pressure differences occur which cause tearing of small blood vessels including haemorrhaging into the surrounding area, among other things. Because of this and in combination with the fact that due to the pressure differential the eardrum no longer swings freely the results are conductive hearing losses.

The injuries of the sinuses and the cases of nosebleeds are in general caused by the same mechanism, but according to the expert, can also be caused by rapid decompression and excess pressurisation. However, the mechanism of re-pressurisation is more likely.

1.14 Fire

There was no evidence of fire in flight or after landing.

1.15 Survival Aspects

The on-duty Wachabteilungsleiter (head of watch) of the airport fire brigade Frankfurt-Hahn Airport stated that the first report of the air navigation service provider passed on to the fire brigade at about 2310 hrs read: *Landung eines Flugzeuges nach Emergency Descent; weiteres unklar; ggfs. ein Verletzter (landing of an airplane after emergency descent, everything else unclear, possibly one casualty).* Accordingly, one Patient Transport Ambulance of the medical service provider of the airport and one mobile command post of the fire brigade were sent to the parking position of the aircraft with the dispatch keyword "medical emergency".

At the same time, the Airport Ground Operations Manager on duty, who was also the Handling Agent for the operator and in telephone contact with their OCC, was at the site. After the rescue personnel had entered the aircraft and realised that several passengers were requiring treatment, they reported this to the airport control room. They also requested that the Rettungsleitstelle Bad Kreuznach (rescue coordination centre) triggers a MANV[2] situation and to activate the remaining nine fire fighters of their shift. In addition, the COO of the airport was also informed. He then acted as responsible Airport Ground Operations Manager. They dispensed with upgrading the emergency category from local standby to full emergency, according to the EM-Plan of Frankfurt-Hahn Airport, because they had no use for fire fighters of brigades outside the airport. At 2331 hrs, the rescue coordination centre Bad Kreuznach alerted an emergency medical physician deployment vehicle and an emergency ambulance with the dispatch keyword "acute hearing loss" to assess the situation.

[2] MANV: Large number of casualties

Shortly after the emergency physician had arrived, he confirmed the “MANV” dispatch keyword, which the rescue coordination centre activated at 2357 hrs. The Organisatorischer Leiter Rettungsdienst (Senior Lead Paramedic Supervisor; SLP-S) was alerted and received the information that several passengers required ENT-medical treatment after decompression in the cabin. He decided to alert other vehicles individually, but aberrant from the standardised Alarm- und Abrückeordnung (SOP for emergency vehicle deployment) of the airport mission concept of the Landkreis Rhein-Hunsrück (administrative district), because they would not need the additional fire brigade resources at a situation with medical focus.

When the alerted additional rescue and disaster control personnel arrived, passenger transfer to an airport terminal was already in progress. Several medical teams simultaneously performed classification and treatment. Using the PA system, the passengers were informed about this; participation was voluntary. The crew members were also examined. Each team used the classification lists the administrative district provided. The classified injured persons were not marked with casualty cards. Bracelets to differentiate and mark injured and non-injured passengers were not used. Classified passengers were not consistently separated from the ones who had not been. Furthermore, passengers, already classified as injured, changed their mind in the scope of the event and refused further treatment. Therefore, the different groups mixed. During the initial phase, the personnel on site did not have passenger lists available.

The SLP-S carried out the organisation on site, supported by fire fighters of the airport fire brigade. The Airport Ground Operations Manager of Frankfurt-Hahn Airport was on site, but did not play any significant role. He was still the Handling Agent for the operator and was responsible for the telephone communication with the operator’s OCC in Ireland.

After the passenger lists had arrived and the Bundespolizei had completed the immigration requirements, the 28 passengers requiring treatment were transported to 4 different hospitals with ENT-medical departments within a radius of 100 km. Six of the patients did not arrive at the hospital for which they had been intended, according to the documentation. The BFU enquired during the safety investigation and learned that they had been taken to another hospital. The reason remained unclear.

About three hours after the mission began, the last passengers were taken to hospital.

The rescue personnel involved stated that the language barrier, the injury severity, which by the passengers’ subjective perception was rather minor, the long transportation distance to the closest suitable hospitals and the unclear situation as to the assumption of costs for transport and medical treatment were the main factors for the delayed processing.

The passengers not requiring treatment remained at the terminal and were taken to other airport facilities during the night. The Handling Agent stated that accommodation at local hotels did not take place because there were not enough in the direct vicinity of the airport.

Up until the next morning, the operator's OCC in Ireland had no information that passengers had been taken to hospital.

After the operator's local representative had arrived on site the next morning, the organisation of the transport of passengers and the support of necessary medical actions occurred. Some passengers continued their trip by land; 166 passengers by air transport.

1.16 Tests and Research

NA

1.17. Organisational and Management Information

1.17.1 Flight Crew Training

The topics of Rapid Depressurisation and Emergency Descent were regularly covered during training of the operator's pilots.

This training was based on the documentation of the aircraft manufacturer (FCOM 1, FCOM 2, FCTM, and QRH) and the operator which should ensure recurring training in all phases of the professional career of the pilots. Accordingly, the topics mentioned above were covered in the Operators Conversion Course (OCC), Airline Pilot Standards Course (APS), Type Rating (TR), Transition Type Rating (TTR) and Command Upgrade Course (CU). The training was also part of the Recurrent Simulator Training (RST) schedule with two training scenarios in the first and second year of the three-year cycle. This exceeded the regulatory requirement to undergo this training once in a three-year cycle (Regulation (EU) No. 1178/2011 FCL.740.A; Appendix 9 B 6. 3.4.1).

The Simulator Study Guide stated on page 43 Emergency Descent, among other things: *[…] Structural damage must be considered following a rapid or explosive* *decompression in which loss of pressurisation is instantaneous, an instant loss of pressure would normally be associated with an airframe/skin rupture or window blowout both of which may compromise the structural integrity of the airframe. […]*

Page 108 stated the most important items concerning Rapid Depressurisation as follows:

Anytime you hear the altitude warning horn the crews' first reaction must be to don oxygen masks and establish communications. The problem can then be investigated. […]

Objectives:

Prompt correct actioning of memory items

Immediate donning of oxygen masks at 100%

Cancelling of cabin altitude warning horn

Prompt decision making and effective communications

Timely action of emergency descent checklist

Further: *Causes of a rapid decompression include a door blow out. […]* and:

Physical Effects of a Rapid Decompression

Severe ear and sinus pain

Chest and joint pain caused by nitrogen bubbles in the blood expanding

Forced expulsion of air

You will feel very cold

[…] The rapid depressurisation and emergency descent procedure is a commonly failed exercise during simulator checks. The most regular error made by crews is to rush this procedure. […]

The Simulator Instructor Guide Chapter Rapid Depressurisation & Emergency Descent stated:

Simulator realism is limited to sound effects and instrument indications therefore it is important to remind students of other effects that would be experienced during a depressurisation. […]

The type of depressurization experienced should be recognized by the crew and this will determine if the aircraft can be descended at Vmo/Mmo or airspeed limited by the crew if structural integrity is in doubt.[…]

It is advisable to allow the crew to "touchdrill" any major handling/procedure exercise prior to performing it. For example, ask each student to review their actions out loud prior to inserting the "Rapid Depressurisation" malfunction. This gives them a greater chance of completing the exercise correctly on the first attempt, thus building confidence and creating a positive learning experience.

Objectives:

Prompt correct auctioning of memory items

Without delay, descent to lowest safe altitude or 10,000 ft, whichever is higher

[…]

Correct checklist called and actioned

[…]

This exercise may be considered complete once the crew has completed all required actions in the QRH, are in a stable level flight condition, have considered crew and passenger requirements, have given the number one to flight deck call and have evaluated and executed a next course of action.

The QRH Chapter MAN.2.19 Manoeuvres-Flight Patterns; Rapid Depressurization stated concerning the co-pilot as PM: *Pressurization mode selector – MAN; Outflow valve switch – CLOSE; If pressurization is restored, continue manual operation to maintain proper cabin altitude.*

1.17.2 Emergency Treatment on Ground

1.17.2.1 ICAO Requirements

As international organisation, ICAO published standards and recommendations for its member states. ICAO Doc 9137-AN/898 Part 7 Airport Service Manual; Part 7; Airport Emergency Planning has to be applied for emergencies at airports, among others.

Chapter 2.2 described possible emergency scenarios. Item 2.2.2 stated: *[…] a) Emergencies involving aircraft. These include: […] 3) incident – aircraft in flight […] ii) decompression […].*

ICAO differentiated under 2.2.3 between the emergency categories Aircraft Accident, Full Emergency and Local Standby. The difference of the last two scenarios depended on the risk of evolving into an accident and the probability of safe landing, respectively.

Chapter 2.2.4 stated: *[…] In a medical emergency the degree or type of illness or injury and the number of persons involved will determine the extent to which the airport emergency-plan is utilized. […] Important factors […] include sudden, serious illness or injury beyond the capability of the airport first-aid or medical clinic.*

1.17.2.2 Emergency-Plan Frankfurt-Hahn Airport

At the time of the occurrence, at Frankfurt-Hahn Airport the Emergency-Plan of 01.08.2017 was in force.

It was divided in Part A (General) and Part B which described individual procedures.

The parts B 4 to B 7 described the process of treating and transporting injured and assisting uninjured persons.

Part B 4, Section 2 stated in regard to registration of persons involved: *[...] Registration of persons involved occurs using casualty cards, which are allocated to each individual person. [...] Even uninjured persons receive a casualty card*.

Section B 6 item 4.3 stated in regard to casualty cards: *At Frankfurt-Hahn Airport the casualty cards of the German Red Cross are used.*

Section 4.5 Registration and Situation Assessment: *Basis for the registration of persons involved is the identification number on the casualty card. The casualty cards remain visibly attached on the person until they reach hospital. [...] This is the basis so that this data can be compared with other available information (e.g. Passenger list).*

The procedure B 7 regulated the assistance of uninjured persons. Section 6.5 Registration of uninjured persons on site; Registration Building 314: *[...] The available casualty cards have to be used. Subsequently, based on their casualty cards the persons have to be listed in the registration sheets provided. The filling in of the registration sheets occurs in building 314. These data sheets have to be made available to the responsible authorities.*

The SLP-S of the administrative district stated that he knew about the EM-Plan but not its content.

During this occurrence, no casualty cards were used.

1.17.2.3 Operation Concept Air Accident Airport of the Administrative District Rhein-Hunsrück

The responsible representatives of the institutions involved described the procedures for rescue services and fire brigade in case of an air accident at Frankfurt-Hahn Airport in the Operation Concept Air Accident Airport of the administrative district Rhein-Hunsrück.

Procedures for scenarios such as Local Standby or Full Emergency according to ICAO Doc 9137-AN/898 Part 7 Airport Service Manual; Part 7; Airport Emergency Planning were not described. The distribution list in the Appendix Section 8.9 listed Frankfurt-Hahn Airport as recipient.

Chapter 2 Alert phase and Protection Targets definition of the alert phase 2; 11-50 injured or persons involved" of the version valid at the time of the occurrence stated: *An occurrence which can normally be processed with the rescue personnel provided at Kreisebene (district level) and which requires the functional process for hazard preventions described in this plan.*

The definition for alert phase 5; more than 150 injured or persons involved read: *For the performance of the tasks it is required to request more central personnel via the corresponding rescue coordination centers in addition to the already alerted forces.*

Appendix 8 indicated that at alert phase 2 four fire brigades, three emergency response teams (rescue), two emergency response teams (assistance) and one information and communications team would be alerted. At alert phase 5, all fire brigades of the administrative district would be alerted as well as all available emergency response teams and the Technisches Hilfswerk. Emergency response teams of several neighbouring administrative districts would also be alerted.

Part 6 of the operation concept described the conduct of the mission. Section 6.7 Registration of persons involved, injured/patients: *At the latest, documentation begins at the treatment location. The following goal is pursued:*

Overview over number of injured/involved at any time

Information as to the whereabouts of treated or cared for persons

[…]

Each person is registered using the casualty cards for the injured/ill [...]

Chapter 6 described two different treatment locations. In this context, the requirement to organise separate and structured classification areas was indicated.

1.18 Additional Information

As far as the BFU is aware, within the last 10 years three similar occurrences happened where it is highly likely that CPC failures caused by SEU on board of a Boeing 737 occurred. Two of the CPCs involved featured an older software version and the calculation parameters as critical were not identical to the one in the current case. Back then, the manufacturer provided software patches which implemented TMR procedures for the relevant parameters.

In 2019, the Spanish Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (CIAIAC), published the investigation report IN-008/2018 of an occurrence involving a B737-700 where at cruise flight CPC malfunction resulted in rapid decompression. The investigators came to the conclusion that the CPC malfunction may have been caused by SEU, among other things, because there were no other triggers. Their analysis also showed that the flight crew had not sufficiently monitored the indicated OFV position during the descent.

An ECCAIRS database enquiry showed that since 1998 a total of 35 cabin pressure losses with subsequent emergency descent were documented by the BFU. In 19 cases rapid decompression had occurred; in 12, pressure loss was gradual. Only in one case was it possible to restore cabin pressure during the emergency descent. Physical damage of the pressurized cabin was in none of the cases the cause for the pressure loss. In fact, the causes were temporary or permanent malfunctions of individual ECS components or operating errors of the flight crew.

1.19. Useful or Effective Investigation Techniques

NA

2. Analysis

2.1 General

In cruise flight, at FL370, an incorrect calculation by the CPC 2 resulted in an incorrect calculation of the reference value of the OFV position which caused the opening of the OFV and subsequent rapid decompression. The flight crew was forced to use their oxygen masks. They closed the OFV manually and the cabin pressure began to increase again. Subsequently, an emergency descent with still manually closed OFV was conducted. For several minutes, the cabin was pressurised with the maximum allowable differential pressure. After levelling off from the emergency descent, the flight crew opened the OFV completely and a second rapid decompression occurred. The injuries the passengers suffered were most likely caused by the re-pressurisation phase between the two decompressions.

2.2 Environmental Control System

2.2.1 Cabin Pressure Controller

The incorrect calculation of the CPC 2 was most likely caused by a Soft Error, a so-called Single Event Upset (SEU). The CPC manufacturer came to this conclusion by exclusion because the CPC neither showed any functional irregularities nor any hardware damage. According to the manufacturer, the probability of a SEU event with such consequences was at most $3.5x10^{-8}$ events per flight hour. It, therefore, corresponded with the certification requirements of CS-25 Large Aeroplanes concerning the failure probability of the entire system.

2.2.2 System Redundancy

According to the certification requirements, the failure probability considered the redundancy of individual components of the entire system and included that flight crews as last resort reacted correctly to system failures in each situation. In this case, the redundancy was not sufficient to restore the cabin pressure altitude to normal levels in time.

After the CPC 2 failure, the cabin pressure altitude continued to increase. Due to swift OFV control switches between the remaining CPC and the pressure switch, OFV oscillation lasting for several seconds occurred. This unwanted type of control occurred because cabin pressure altitude did not exceed 15,000 ft and the limitation of the maximum cabin rate of descent, implemented in the CPC logic for reasons of convenience, resulted in repeated triggering of the pressure switch.

Rapid decompression caused by a large irreversible leakage would promptly result in a cabin pressure altitude of more than 15,000 ft, hence such an oscillating type of control would not be expected. This would have subsided after a few cycles due to damped oscillation. Based on the latency until stable system function is re-established, the BFU is of the opinion that such system behaviour does not seem suitable. On the one hand, cabin pressure altitude continued to increase in this phase by another 1,500 ft even though several alarm limits had already been passed. On the other hand, the system malfunction progressed long enough that finally the flight crew as last resort had to intervene by controlling the OFV manually.

According to the NNC “Cabin Altitude Warning or Rapid Depressurization”, they switched the OFV to manual operating mode and therefore had control over the OFV position. However, they were neither able to correctly determine the triggering system constellation nor to correctly implement the counteractions or effectively monitor the system behaviour of the ECS during the subsequent emergency descent.

The ECCAIRS data enquiry the BFU conducted showed that since 1998 a total of 35 cases with pressure loss on board of transport aircraft had occurred. All of them resulted in emergency descents. It was possible in one case only to re-establish cabin pressure. It has to be assumed that in the other 34 cases the ECS system redundancy had not been sufficient to prevent rapid decompression. Structural damage of the pressurized cabin was not the cause in any of the cases.

2.2.3 Digital Selector Panel

Mounting location and design of the Digital Selector Panel of the Digital Cabin Pressure Control Systems in the cockpit made it more difficult for the flight crew to correctly recognise the conditions of the cabin pressure altitude and monitor it.

The location at the right overhead panel made it necessary for both pilots to actively focus their attention upward in order to monitor the relevant instruments. The BFU is of the opinion that in the situation caused by the rapid decompression it is highly likely that instruments which were not in the direct line of sight of the pilots received less attention than the ones directly on the panel ahead of them. Partial condensation on the oxygen masks caused by the rapid decompression, made visual verification of the cabin pressure altitude more challenging.

It has to be assumed that the panel design with several combinations of analogue instruments did not contribute positively to the situational awareness of the pilots. It has to be assessed as critical that the design of the cabin pressure altitude indication allows the needle to migrate into the scale from high altitudes. Aircraft are commonly not operated with cabin pressure altitudes below MSL, but the cabin pressure altitude indication should not allow any misinterpretation.

Besides the described analogue combined instruments there are no acoustic or optical warning devices which could have alerted the crew to the following abnormal configurations of the pressurized cabin:

- Fully open OFV during cruise flight
- Cabin pressure altitude passing MSL during descent
- Maximum positive cabin differential pressure

The correct recognition of these parameters presumed an active attention of the pilots.

2.3 Flight Crew

The crew had flown the same route together the day before and could therefore expect a certain routine. However, at the time of the occurrence they had not been at their physiological performance high due to the time of day. During cruise flight, work load was low, so, a startle effect can be assumed for the initial few seconds of the occurrence.

The pilots were trained in accordance with the requirements of the aircraft manufacturer and the operator. During the periodically recurring training program the scenario of rapid decompression in the cabin with subsequent emergency descent was regularly trained. The completion of this training twice in a three-year cycle exceeded the regulatory requirements. Due to the limitations of accurately representing a loss of cabin pressure in a simulator and because of the absence of any of the associated physiological effects, the instructors were asked to play the scenario as unambiguously as possible by selecting only one of the rapid decompression simulator scenarios, which ensures, that the trainee clearly understands, that a loss of cabin pressure had occurred.

In addition, the documentation used by the pilots for preparation indicated that with such pressure loss it is highly likely that the airplane was structurally damaged and therefore pressure could not be restored. Accordingly, the simulator scenarios were exclusively trained in a way that emergency descent to a safe altitude was absolutely always necessary because permanent pressure loss had to be assumed.

Even though the training documentation indicated that most mistakes were made because the necessary actions were taken too fast, this kind of drill-like and unambiguous training generated a certain expectation in terms of Confirmation Bias[3] in the pilots concerning the trigger and further development of the situation. Only this can explain that certain parameters and indications contradicting the actual working theory such as the indication of the fully open OFV, the active fail and alternate lights or the rapidly decreasing cabin pressure altitude at increasing differential pressure after the OFV was closed during the descent, were not noticed.

In addition, initially the OFV was not closed completely or not adequately checked after closing it manually. Had the OFV been closed completely, the cabin pressure would have increased even more clearly which in turn would have had the potential to influence the crew's decision to initiate an emergency descent.

Even though the item Cabin Altitude Controllable was included in the QRH checklists for Rapid Depressurization and for Emergency Descent and had been read by the crew accordingly, the development of the cabin pressure altitude was not monitored and they continued - contrary to the actual state - to assume a depressurised cabin.

The BFU is of the opinion that the flight crew prioritised the timely completion of the procedure because 28 seconds after the pressure loss was noticed, the OFV was switched to manual control and after another 15 seconds the emergency descent initiated; verbal briefing in terms of coordinated decision making concerning the subsequent procedures did not occur.

These actions were taken as coaction of both pilots and not verbalised. The BFU is of the opinion that it would be sensible to split the procedure in two parts: one speedy and drill-like up until the point where all occupants are safely supplied with oxygen and another primarily not time-critical one which is initiated by a FORDEC-like[4] briefing,

[3] Confirmation Bias: Describes the tendency to process information by looking for, or interpreting, information that is consistent with one's existing beliefs. „Human Factors - Psychologie sicheren Handelns in Risikobranchen"; Badke-Schaub, Hofinger, Lauche; Springer Verlag 2008)

[4] FORDEC: Decision making model in aviation: Facts, Options, Risks, Decision, Execution, Control

where the flight crew evaluates the current situation and derives the subsequent strategy on this basis. This process would positively support the creation of situational awareness.

The pilots focused on getting the aircraft to a safe altitude which humans could survive without cabin pressure. This resulted in an attention distribution to the disadvantage of the further development of the cabin pressure altitude, whereby the excessive pressure during the descent, which almost certainly resulted in the injuries of the passengers, was not recognised. It was also not noticed, that the cabin pressure altitude indicator passed MSL. After the descent, this required the flight crew to a big transfer of knowledge in order to recognise the situation correctly and initiate the right counter measures.

The pilots did not sufficiently take into consideration the maximum cabin differential pressure with fully closed OFV indicated on the DSP and the altitude of about 9,000 ft indicated by three systems. The sum of these parameters has to be viewed as sufficient to put the pilots in a position to identify the wrongly as high indicated cabin pressure altitude after levelling off. Had this been the case, it would have been highly likely that the manual opening of the OFV had occurred more controlled. The second rapid decompression could have been prevented.

The corresponding indication in the operator's Simulator Study Guide and the conclusions in the investigation report of the Spanish CIAIAC published due to a similar occurrence indicate that hasty completion of relevant procedures and insufficient monitoring of cabin pressure parameters are frequent error sources of flight crews after rapid decompression.

The BFU analysis also shows that in only one of the 35 cases, involving cabin pressure loss and subsequent emergency descent, reported by several operators over the last 22 years, cabin pressure was restored and the emergency descent terminated. Even though a data set does not show if and/or how often it was attempted to unsuccessfully restore cabin pressure, it has to be assumed that flight crews with similar training react similarly in identical situations.

In addition, the survey of the 35 cases showed that none of the aircraft had suffered structural damage. The pressure loss had been caused by failure of individual ECS components. It has to be assumed that the structural damage propagated during training of rapid decompression scenarios does not correspond with statistical reality and is able to create false expectations in flight crews (Confirmation Bias), as the current investigation shows.

The BFU deems it sensible that the training scenario of rapid decompression is modified so that flight crews are made more aware that only the part up until every occupant is safely supplied with oxygen is time critical. In the subsequent part it should be more important to complete the checklists correctly and to accurately identify and monitor the underlying malfunction.

Seven seconds after they had realised the pressure loss, the flight crew had donned their oxygen masks. This means they were no longer subject to oxygen deficiency symptoms. Oxygen supply of cabin crew and passengers is ensured for about 15 minutes after activation.

In addition, the operator should consider implementing different training scenarios in regard to rapid decompression including restoration of the cabin pressure in order to sensibilise flight crews for the importance of monitoring the cabin pressure parameters during emergency descent and to minimise the probability of Confirmation Bias.

2.4 Survival Aspects

2.4.1 Pathomechanism of the Injuries

According to final information, 33 persons on board the aircraft were injured. The ENT medical specialist of the Zentrums für Luft- und Raumfahrtmedizin der Luftwaffe at Fürstenfeldbruck stated that it is highly likely the disorder and injuries of the middle ear were caused by the excessive pressure in the cabin lasting several minutes.

The nosebleed several patients suffered from is subject to a similar mechanism. The expert opinion is, however, that it can be caused by rapid decompression or by excessive pressure, whereas the latter is more probable.

The excessive pressure was caused by the re-pressurisation of the cabin during the descent while the OFV had been closed manually. This was not noticed and not adequately monitored. Therefore, the crew did not initiate suitable countermeasures.

The manual full opening of the OFV after levelling off following the emergency descent resulted in a second rapid decompression until the cabin pressure altitude had adjusted to the actual altitude of the aircraft. It could not be determined how many of the injuries had been caused by this manoeuvre. The second rapid decompression could have been prevented by opening the OFV slowly and gradually. This would have required the flight crew to correctly interpret the situation.

2.4.2 Medical Care on the Ground

The treatment of injured passengers and their transport was affected by delays and organisational insufficiencies which were caused by different factors.

While the aircraft was on approach to Frankfurt-Hahn Airport, the responsible air navigation service provider informed the airport fire brigade. The forces at the site reacted in accordance with the expected “medical emergency” and provided the required rescue resources at the parking position of the aircraft. At the time, they did not know type and extent of the incident.

The information the air navigation service provider had passed on was based on the descriptions of the flight crew. The pilot had told the controller that they had experienced rapid decompression. This information was not passed on to the local fire brigade. The interview with the purser determined that at that time the flight crew acted on the assumption that only one passenger had been injured.

Alerting additional rescue personnel occurred after fire fighters and the Airport Ground Operations Manager on duty had entered the aircraft at the parking position and assessed the situation. It was no longer possible to alert additional personnel beforehand and therefore shorten the time required to treat and transport the passengers.

Directly after the airport fire brigade had received the information about the actual situation in the aircraft, they alerted the rescue coordination centre Bad Kreuznach and asked for the activation of the dispatch keyword MANV (large number of casualties) in order to activate the required resources to handle the situation. The rescue coordination centre Bad Kreuznach neglected to do so. At 2331 hrs, they alerted one emergency medical physician and one emergency ambulance with the dispatch keyword “acute hearing loss” to further assess the situation at the airport.

Only after these forces had arrived and confirmed the situation, at 2357 hrs, the necessary rescue resources were alerted with the dispatch keyword “MANV”. Many of the alerted rescue personnel were volunteers of disaster control or extended rescue services, who were alerted at home and on demand. This means another approximately 30 minutes passed before sufficient rescue personnel was on site to process the situation in a structured manner and begin the medical classification of the injured passengers.

Many of the injured passengers required ENT medical expertise for the final assessment of their disorders. Since it was not possible to do so on-site and in the direct vicinity of the airport, there were no hospitals with the required ENT department, it became necessary to transport the passengers to hospitals which were up to 100 km away.

In addition to the language barrier, the situation became more difficult, because some passengers experienced their injuries as minor and questioned the transport to a faraway hospital. The BFU is of the opinion that this difficulty would not arise to such an extent with severely or life-threateningly injured passengers. The fact that the transport to hospitals separated injured family members from uninjured and that it was unclear as to if and when the patients would return to the airport after their examinations resulted in further delays.

The organisation of these necessary measures for the passengers originated with the operator. The operator stated that up until the next morning when the local representative arrived, they had had no information that the night before passengers had been taken to hospital for medical treatment. The responsible Airport Ground Operations Manager was tasked with informing the operator's OCC by telephone.

The BFU is of the opinion that the Airport Ground Operations Manager had passed on incomplete information. The simultaneous exercise of several different operational functions at the airport by one person resulted in insufficient communication of the actual situation to the OCC.

The operator would have been able and required to mobilise further resources which would have contributed to a more optimised development of the situation. The BFU is of the opinion that the operator's OCC could not react adequately because during the night the information was transmitted to the OCC more and more infrequently. That is why so many necessary actions could only be arranged the next morning.

Frankfurt-Hahn Airport and the administrative district Rhein-Hunsrück provided emergency plans for the standardised completion of such scenarios. However, these did not include a scenario such as this and were therefore not applied. Departing from the "Einsatzkonzept Flughafen", the senior lead paramedic supervisor alerted the rescue personnel as he saw fit because it was exclusively a medical emergency and no technical rescue personnel or additional fire fighters were required.

The emergency plan ICAO had required and the airport compiled was also not applied, because there was no occurrence scenario with large quantities of injured persons without the simultaneous aircraft accident on airport operating areas. The escalation levels of the emergency plan based on the ICAO probability of a landing accident were not applicable in this case. The non-applicability of the scenarios of both emergency plans resulted in a significantly increased organisational and coordination effort for the rescue personnel. On the one hand, the handling of the scenario slowed down further and on the other hand, the actions provided for similar scenarios were not carried out which had a negative effect.

After the passengers had been taken to one building, classification was carried out in an insufficient manner. Several teams classified the passengers and documented their results on the provided form in different ways. At the beginning of the classification, passenger lists, with which they could have compared their documentation, were not available. The classified passengers were not marked accordingly. In combination with the language barrier between the local rescue personnel and the non-German-speaking passengers, this increased the risk of multiple classifications significantly.

Both emergency plans included indications as to the structure of a classification area and for the use of casualty cards and bracelets. The necessary resources were provided locally but not used. Because classified persons were neither strictly separated from non-classified ones, nor marked according to their classification category, the groups mixed and the complexity of the situation increased. In total, the facts mentioned above are the reasons that at the time of the publication of this investigation report, it was not possible to name a definite number of injured persons due to diverging information of the organisations involved.

The BFU is of the opinion that it has to be taken into consideration that the total number of 33 injured persons of 196 aircraft occupants is comparatively low for such an occurrence and they did not require a substantial on-site emergency medical treatment and were ambulant patients, due to their injury patterns which were limited to ENT. The focal points of the emergency medical service were the classification of persons and the transport logistics. A conventional air accident of an aircraft of this category where high forces occur and result in complex injury patterns for passengers lead to a significantly higher workload for all rescue personnel involved as was the case here. The process delays did not result in an aggravation of the sustained injuries.

The investigation of the BFU revealed that the transport documentation of the passengers who were transported to hospitals was partially inconsistent. Enquiries with the hospitals involved showed that partially significant discrepancies existed between the intended (according to the documentation) and the effectively treated passengers. Six passengers were not transported to the hospital intended and documented. They were treated in other hospitals. The BFU could not unambiguously clarify the reasons. The necessary individual tracking of injured persons in the scope of accident investigation was made more complicated even though the number of casualties was comparably low for such an event.

The rescue personnel of airport and administrative district had only limited detailed knowledge about the different emergency plans and the underlying rational of their respective counterparts.

3. Conclusions

3.1 Findings

The flight crew was licensed for the flight in accordance with existing legal requirements. Both members of the flight crew had completed the required training. Their flight experience on type was high.

The aircraft had been registered and maintained compliant to rules. Up until the occurrence, the Environmental Control System showed no irregularities.

The meteorological conditions were not a factor. During the occurrence it was night with visual meteorological conditions.

The Cabin Pressure Controller 2 commanded the complete opening of the OFV during the cruise flight.

This control command was based on an incorrect calculation of the OFV reference position. It is highly likely that this was caused by a Single Event Upset in the CPC 2.

After CPC 2 was automatically deactivated, the OFV began to oscillate which caused the cabin pressure to increase further. The oscillation was caused by the rapid change of control between the pressure switch of the OFV and CPC 1.

According to the memory items for rapid decompression, the flight crew donned their oxygen masks and activated the oxygen masks for the cabin.

The flight crew switched the OFV to manual control, initially closed it to a 9.3°open position and then closed it fully.

At the time the emergency descent was initiated, cabin pressure altitude had decreased by about 2,000 ft. The flight crew did not notice it.

During descent with closed OFV, cabin pressure increased up to the maximum differential pressure of 8.72 psi and both pressure relief valves were activated. The crew did not notice this. Positioning and design of the cabin pressure control system indication made the correct identification of the situation more difficult.

The cabin pressure altitude passed MSL at a time as the aircraft passed FL190 and ended for about 4 minutes 20 seconds at a pressure which corresponds with 7,000 ft below MSL. Despite the fact, that in this case it cannot be proven that this overpressure or the two rapid depressurizations caused the injuries, from a medical perspective, overpressure scenarios pose a higher risk of injury to humans.
The standardised simulator training of rapid decompression always resulted in emergency descent with unrecoverable cabin pressure. This may have influenced the expectations of the flight crew.

The BFU statistical analysis of occurrences involving rapid decompression and subsequent emergency descent showed that only in one of 35 cases the ECS function was recovered and the emergency descent terminated. It cannot be retraced whether the flight crews had even made the attempt to recover cabin pressure or if the attempt was in vain. In each case, ECS malfunction was the cause of the rapid decompression and not structural damage of the aircraft.

After levelling off after the emergency descent, the flight crew could not correctly identify the status of the cabin pressure control system because they had not sufficiently monitored the ECS function in the manual operating mode and their mental image did not correspond with the real situation.

After levelling off after the emergency descent, correct realisation of the situation taking into consideration all of the available parameters would have been possible. However, the crew would have had to reverse their working hypothesis and apply learned knowledge.

The complete manual opening of the OFV resulted in a second rapid decompression which adjusted the cabin pressure altitude with the altitude of the aircraft.

Deficits in the communication of relevant information between the parties involved on the ground resulted in multiple delays in processing the situation after the landing.

There were two emergency plans compiled by the airport and the administrative district. They were compiled in accordance with two different requirements and were therefore not identical. Both emergency plans did not include a scenario which corresponded with the occurrence. The responsible personnel of the administrative district had no knowledge of the emergency plan of the airport and vice versa. During the mission this resulted in increased organisational and communicational time and effort for the personnel involved.

The support of the operator was not made use off to the full extent, because the flow of information between the Handling Agent at the site to the OCC of the operator was insufficient. Accordingly, at the end of the occurrence the situational assessment of the OCC did not correspond with the situation at the site. The simultaneous exercise of several different organisational functions by the Handling Agent has to be viewed as the causal factor.

The classification of the injured and the corresponding documentation was not performed in accordance with the requirements of the emergency plans. This caused inconsistencies which negatively influenced the organisation of the situation and the traceability of the whereabouts of individual injured passengers.

The process delays had no negative effect on the severity of passenger injuries.

Due to the ENT focus of the injuries and the rural surroundings of the airport, the long transport distances to the nearest hospitals with ENT-departments became necessary.

The documented number of passengers intended for certain hospitals did not correspond with the numbers these hospitals actually examined. Six passengers were not transported to the hospital they were supposed to go to, according to the documentation.

3.2 Causes

The occurrence was caused by a fully opened OFV commanded by the ECS during cruise flight at FL 370.

The malfunction was caused by a Single Event Upset in one of the Cabin Pressure Controllers.

In this case, the system redundancy of the cabin pressure control system was not sufficient to prevent rapid decompression.

4. Safety Recommendations

4.1. Safety Actions

In 2019, the operator involved modified the recurring simulator training for pilots so that use and interpretation of the indications of the ECS Digital Selector Panels are covered more closely. In addition, a training scenario was implemented in the recurring training documentation where the pressurized cabin re-pressurises during emergency descent and the flight crew has to react accordingly.

The airport forces involved as well as the Landkreis Rhein-Hunsrück personnel have re-enacted the scenario during an ICAO emergency training in May 2019. Focal points were, among other things, patient classification, mission documentation and patient transport. Measures were implemented to optimise the organisational process should a similar occurrence happen again.

Accordingly, the BFU does not see the need to publish safety recommendations concerning the training of flight crews or the coordination of the rescue services actions on the ground.

4.2 Safety Recommendations

None

Investigator in chief:	Harendza
Field investigation:	Kostrzewa, Jäkel
Assistance:	Rokohl, Blau, Lampert, Hempelmann

Braunschweig 17 June 2022

5. Appendices

None