

Investigation Report

Identification

Type of Occurrence:	Accident
Date:	19 February 2006
Location:	Close to Dakar / Senegal
Aircraft:	Transport aircraft
Manufacturer / Model:	Boeing Commercial Airplanes / Boeing MD-11/MD-11F
Injuries to Persons:	One crew member seriously injured One crew member and one passenger slightly injured
Damage:	None
Other Damage:	None
Information Source:	Investigation by BFU
State File Number:	BFU 2X004-06

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 - FIUUG*) 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

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Abbriviations

ACARS	Digitales Datenfunksystem für Flugzeuge	Aircraft Communications Addressing and Reporting System
AD	Bildschirm für Warnanzeigen	Alert Display
AOC	Luftverkehrsbetreiberzeugnis	Air Operator Certificate
APU	Hilfsturbine	Auxiliary Power Unit
ATC	Flugsicherung	Air Traffic Control
ATPL(A)	Lizenz für Verkehrspiloten	Airline Transport Pilot License
BFU	Bundesstelle für Flugunfalluntersuchung	German Federal Bureau of Aircraft Accident Investigation
CAT III	Betriebsstufe III	Category III
CAVOK	Wolken und Sicht in Ordnung	ceiling and visibility okay
CFDS	Zentraler Bildschirm für Fehlermeldungen	Central Fault Display Unit
CPC	Kabinendruckregler	Cabin Pressure Controller
CPCS	Kabinendruckregelsystem	Cabin Pressure Control System
CPL(A)	Lizenz für Berufspiloten (Flugzeuge)	Commercial Pilot Licence (Aeroplane)
CPS	Kabinendrucksensor	Cabin Pressure Sensor
CVR	Cockpit Tonaufzeichnungsgerät	Cockpit Voice Recorder
DFDR	Digitaler Flugdatenschreiber	Digital Flight Data Recorder
DMI	Liste zurückgestellter Beanstandungen	Deferred Maintenance Items
EAD	Bildschirm für Triebwerk- und Warnanzeigen	Engine and Alert Display
EASA	Europäische Agentur für Flugsicherheit	European Aviation Safety Agency
ECS	Klimasteuerungssystem	Environmental Control Systems
EU-OPS	Verordnung (EG) Nr. 859/2008 der Kommission	Commission Regulation (EC) No 859/2008
FCOM		Flight Crew Operating Manual
FIUUG	Flugunfalluntersuchungsgesetz	

FL	Flugfläche	Flight Level
FM	Flughandbuch	Flight Manual
FODA		Flight Operation Data Analysis
HIL	Liste offener Beanstandungen	Hold Item List
ICAO	Internationale Zivilluftfahrtorganisation	International Civil Aviation Organization
IU	Schnittstelleneinheit	Interface Unit
JAR 25	Vorschrift für die Zulassung von Verkehrsflugzeugen (CS 25)	Airworthiness Standards for Large Aircraft (CS25)
JAR-FCL 1	Vorschriften für die Lizenzierung von Piloten von Flugzeugen	Flight Crew Licencing Require- ments
JAR-FCL 3	Vorschriften für die Medizinische Tauglichkeit von Cockpitpersonal	Flight Crew Medical Requirements
JAR-OPS 1	Betriebsvorschriften für die gewerbsmäßige Beförderung in Flugzeugen (heute: EU-OPS)	Standards for the Operation of Commercial Transportation by Aeroplanes
NFF	keinen Fehler festgestellt	No Fault Found
NTSB	National Transportation Safety Board	National Transportation Safety Board
NVM	nichtflüchtiger Speicher	Non Volatile Memory
OFV	Kabinendruckregelventil	Outflow Valve
OM/A	Betriebshandbuch, Teil A	Operations Manual Part A
OM/B	Betriebshandbuch, Teil B	Operations Manual Part B
OM/C	Betriebshandbuch, Teil C	Operations Manual Part C
OM/D	Betriebshandbuch, Teil D	Operations Manual Part D
PF	Luftfahrzeugführer am Steuer	Pilot Flying
PIC	Verantwortlicher Luftfahrzeugführer	Pilot in Command
PNF		Pilot non Flying
RTS		Return to Service

slf		See Level Feet
slfpm		See Level Feet per minute
SSFDR	Flugdatenschreiber mit Halbleiterspeicher	Solid State Flight Data Recorder
TLB	Technisches Bordbuch	Technical Log Book

Synopsis

The German Federal Bureau of Aircraft Accident Investigation (BFU) was informed on 21 February 2006 by the operator of a Boeing MD11 of an incident with the cabin pressurisation system. The telephone message contained the information that on 19 February 2006 on a flight from Dakar (DKR) to Frankfurt (FRA) a pressure bump had occurred and the crew members had, for reasons of precaution, been treated by a physician. Three days after the initial notification the degree of the Pilot in Command's (PIC) injury became known to the BFU and an investigation into the serious incident was initiated. In the further course of the investigation, the incident was upgraded to an accident according to the definition of ICAO Annex 13 and the Law Relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft after a medical expert had attested that the PIC had suffered permanent damage of his right inner ear including hearing loss. The National Transportation Safety Board (NTSB), USA, participated in the investigation as State of Manufacturer of the aircraft.

On the cargo flight Dakar – Frankfurt, both pilots and a passenger experienced intense pain in their ears during climb out of Dakar at 1558 hrs in Flight Level (FL) 250 which was accompanied by a loud noise. The Alert Display (AD) of the Engine and Alert Displays (EAD) showed message Cabin Rate. The crew noticed an almost fully open outflow valve being indicated on the Cabin Pressure Control Panel. A cabin rate of more than 2,000 ft/min had been indicated. The crew reported the incident via Aircraft Communications Addressing and Reporting System (ACAS) to the maintenance organisation in Frankfurt and decided to continue their flight to Frankfurt at a reduced cruising altitude. There were no further problems with the pressurised cabin on the flight to Frankfurt. After the landing, the occupants of the aircraft sought medical help because of the pain in their ears. Injuries were diagnosed for the co-pilot and the passenger. The PIC suffered an injury of his right inner ear with permanent hearing loss. This diagnosis resulted in a permanent loss of his medical certificate.

Immediate Causes:

The accident was caused by an abrupt pressure bump within the pressurised cabin. What triggered the pressure bump could not be established with sufficient certainty. It is probable that the pressure bump was caused by a malfunction of one component or by exceedance of some fault tolerance of individual components of the Cabin Pressure Control System (CPCS).

Systemic Causes:

- The importance and possible effect of indicated malfunctions of the cabin pressure control system during previous flights was not analysed sufficiently.
- The standardised test procedure Return to Service was not sufficient enough to recognise the cause for the malfunction.
- The repeated display of level 3 alerts did not result in any particular maintenance action.
- The manufacturer of the cabin pressure control system has standardised and automated test procedures for the functional demonstration of components which did not detect single failures or failures related to the interaction of the different system components.
- The communication of fault descriptions and reports between the operator, the aircraft maintenance organisation, the components maintenance organisation and the manufacturer of components was insufficient.

1. Factual Information

1.1 History of the Flight

The freighter McDonnell Douglas MD-11/MD11-F was on a flight Frankfurt (FRA) – Dakar (DKR) – Sao Paulo (VCP) – Dakar (DKR) – Frankfurt (FRA). On 19 February 2006 at 1433 hrs coming from Sao Paulo the MD 11F landed at Dakar Airport.

During the flight preparation in the operator's station office in Dakar the crew inspected the technical documentation (BO2) of the airplane. There were several open items such as Auxiliary Power Unit (APU) inoperable, left door not usable, landing light defect and a partially inoperable engine fire warning. Based on the deferred item landing light with the added remark „Flight may not be conducted at night“ the PIC called the responsible maintenance organisation at the base airport in Frankfurt.

During transfer of the airplane from the incoming crew to the crew flying the leg from Dakar to Frankfurt PIC responsible for the outbound leg inspected the Tech Log. He noticed some irregularities with the cabin pressurisation which had occurred during the flight from Frankfurt to Dakar and from Dakar to Sao Paulo. These irregularities had been signed as fixed by the maintenance organisation. There were no open items regarding the cabin pressure system in the Technical Logbook (TLB), the Hold Item List (HIL) or the Deferred Maintenance Items List (DMI).

The pilots who had flown the airplane to Dakar confirmed to the PIC of the outbound leg that they had not experienced any problems with the pressurised cabin on this last leg.

After flight preparations had been completed the engines were started with the help of external air and electrical power equipment because the APU was inoperable.

At 1558 hrs the airplane took-off from runway 36 towards the north-east to Saint Louis (SLO). The flight path then took them across Algeria, the Mediterranean, past Genoa and Zurich to Frankfurt.

Still in climb, the crew was busy identifying possibly conflicting traffic and discussing avoidance thereof when both pilots and the passenger experienced an intense pain in their ears. According to the crew the airplane was above FL 220, probably in

FL 250. At this time, passing of FL 220 was reported to Dakar Air Traffic Control (ATC) because of known opposite traffic.

According to crew statements, the alert display of the EAD showed Cabin Rate and the cabin pressure control panel a fully open outflow valve; according to the pilot's report in the 1130 hrs - position. At the time of the observation, the indication for the outflow valve moved back towards the closed position. During the event, the crew also noticed an unusually high noise level in the cockpit.

The PIC reported that he had first thought of a broken window. When he enquired about the co-pilot's and the passenger's well-being verbal communication was almost impossible. He realised that both were responsive but complained of earache.

After a short period of time the occurrence repeated itself. Afterwards the cabin pressure control system became stable again.

According to statements of the PIC a change-over to system 2 on the cabin pressure control panel was not carried out because, at this time, the crew had no explanation for the pressure bump.

The crew decided to continue the flight to Frankfurt at a lower cruising altitude (FL 290) as previously intended. The incident was reported to the operator's maintenance organisation in Frankfurt via ACARS.

During the remainder of the flight no further problems with the pressure control system occurred. The PIC suffered from severe earache during the rest of the flight; especially in his right ear. This was accompanied by nausea, headache and severe tinnitus.

Close to Genoa an extended thunderstorm area had to be overflown. The increased flight level did not result in further problems with the pressurised cabin.

At 2120 hrs the airplane landed in Frankfurt.

1.2 Injuries to Persons:

Injuries	Crew	Passengers	Total	Others
Fatal				
Serious	1			
Minor	1	1		
None				---
Total	2	1		

1.3 Damage to Aircraft

There was no damage on the aircraft due to the problems with the cabin pressure control system.

1.4 Other Damage

Not applicable.

1.5 Personnel Information

Pilot in Command (PIC)

The 38-year-old PIC held an Airline Transport Pilot's License (ATPL (A)) issued according to JAR-FCL, German. He was licensed as PIC and for instrument flight CAT III for the aircraft type McDonnell Douglas MD-11.

He had a medical class 1 certificate issued according to JAR-FCL 3, German. The last medical check was on 10 October 2005.

Total flight time:	About 9,000 hours
Total flight time as PIC:	3,672 hours
Total flight time on MD-11:	3,672 hours

Flight time during the last 90 days: 107 hours
Flight time during the last 30 days: 42 hours
Flight time during the last 24 hours: 15 minutes
Duty hours during the last 24 hours: 1.75 hours
Off duty prior to the flight: 40 hours

Co-pilot

The 59-year-old co-pilot held an Airline Transport Pilot's License (ATPL (A)) issued according to JAR-FCL, German. He was licensed as co-pilot and for instrument flight CAT III for the aircraft type McDonnell Douglas MD-11.

He had a medical class 1 certificate issued according to JAR-FCL 3, German. The last medical check was on 28 October 2005.

Total flight time: > 18,000 hours
Total flight time as PIC: About 6,700 hours
Total flight time on MD-11: About 725 hours
Flight time during the last 90 days: 135 hours
Flight time during the last 30 days: 30 hours
Flight time during the last 24 hours: 15 minutes
Duty hours during the last 24 hours: 1.75 hours
Off duty prior to the flight: 40 hours

The co-pilot worked as Captain on McDonnell Douglas DC 8 and Boeing B747-200 for the operator until 2004. On the aircraft type MD-11 he was co-pilot.

1.6 Aircraft Information

The aircraft MD-11 is registered with the Federal Republic of Germany since 5 January 2005.

Manufacturer:	Boeing Commercial Aircraft
Type:	Boeing Douglas MD-11/MD-11F
Year of manufacture:	1994
Manufacturer Serial Number (MSN):	48 581
Maximum mass:	285,990 kg
Engine manufacturer:	General Electric
Type of engine:	CF6-80C2D1F
Last technical inspection:	R-Checks: 13.02.06, 15.02.06, 17.02.06 C-Check: 07.02-12.02.06
Total operating hours:	49,269 hours

The aircraft was used as a passenger plane until 2004 and was then retrofitted as a freighter.

In September 2005 the aircraft diverted to Hong Kong after a cabin pressure incident on the flight Kanton - Taschkent.

On 17 February 2006 a hard landing in Sharjah occurred on a flight from Bangkok to Sharjah. The inspection of the aircraft after the hard landing was conducted in accordance with the Maintenance Manual in Frankfurt on 20 February 2006.

1.7 Meteorological Information

At the time of the occurrence CAVOK weather conditions prevailed in the vicinity of Dakar Airport. During cruise flight thunder storm areas had to be circumnavigated in South European Airspace.

1.8 Aids to Navigation

Aids to navigation were available. They did not have any influence on the course of events.

1.9 Communication

Radio communications were available.

After the event on 19 February 2006 a report was sent via ACARS to the maintenance organisation in Frankfurt.

Its content was:

DURING CLB SVRL PRESS BUMPS OF MORE THAN 2000 FPM OCCURED. THAT HURT.

A SUDDEN MOVEMENT OF THE OUTFLOW VLV WAS OBSERVED. C U

1.10 Aerodrome Information

Not applicable

1.11 Flight Recorders

The aircraft was equipped with a Cockpit Voice Recorder (CVR) and a Solid State Flight Data Recorder (SSFDR).

The time after the occurrence until the landing in Frankfurt exceeded the available recording time of the CVR. Therefore, no CVR recordings about the occurrence were available for the safety investigation.

The Allied Signal/Honeywell SSFDR, P-No. 80-4700-003, S-No. 9990 had a recording capacity of 25 hours and 354 parameters. Because of the delayed notification of the occurrence and the unclarity as to how to proceed, FDR data was no longer available for the safety investigation.

The recorded data was seized and analysed by the operator as Flight Operation Data Analysis (FODA).

With the exception of the cabin rate no parameter were recorded which could contribute to analyse the control and monitoring problem of the pressurised cabin. The parameter Cabin Rate was recorded once every 64 seconds. Because of the low sampling and recording rate the parameter was not used for the safety investigation.

1.12 Wreckage and Impact Information

1.12.1 Actions after the Incident

After the landing in Frankfurt on 19 February 2006, the aircraft was handed over to the maintenance organisation with the order to identify and fix a possible malfunction of the cabin pressure control system.

Basis for the fault analysis were the following entries in the technical logbook:

Leg Frankfurt – Dakar, 18 February 2006:

AFTER LEVEL OFF FL 310, LEVEL 1 ALERT CABIN RATE WITH FLUCTUATING CABIN RATE +/-5000 FPM, BUT CABIN ALT CONSTANT AT 4970, DP CONSTANT AT 8.1, OUTFLOW 1 AND 2 INDICATION! -> SWITCHED AIR SYSTEM MANUAL, STABILIZATION AFTER 2-3 MIN. AT FL 330 TRIED AIR SYSTEM AUTO AGAIN SAME RESULT AS BEFORE, ADDITIONAL LEVEL 3 ALERT „CABIN ALTITUDE“. INTERMITTED (FOR 1-2 SEC), BUT ALL OTHER INDICATIONS (CAB.ALT, DP) STABLE! -> AIR SYSTEM MANUAL AGAIN, DESCENT TO FL 310, INDICATIONS STABLE FOR REST OF FLIGHT.

Leg Dakar – Sao Paulo, 18 February 2006:

AFTER 4HRS FLIGHT TIME LEVEL 3 ALERT CABIN ALT ! (FL340) FOR A SHORT TIME. AVIONICS FAN OVRD RESETTED. HAPPENED APPROX. 6X DURING FLIGHT

Leg Frankfurt – Dakar, 19 February 2006:

DURING CLIMB OUT SEVERAL TIMES PRESSURE BUMPS OF MORE THAN 2000 FPM CABIN RATE OCCURRED. THIS WAS NOT ONLY INDICATED BUT FEELABLE ON THE EARDRUMS (PAINFUL) CHANGE OF CONTROLLER HAD NO POSITIVE EFFECT, ALSO SHARP SPIKES ON CABIN RATE.

The Central Fault Display System (CFDS) had recorded the indication FAULTY for the outflow valve.

The operator stated that the following components were removed from the airplane and sent to the components maintenance organisation and the manufacturer, respectively, with a specific investigation order.

- Cabin Pressure Controller CPC 1; P/N 2119702-3; S/N 61-204
- Cabin Pressure Controller CPC 2; P/N 2119702-3; S/N 43-A0147
- Outflow Valve Motor Assembly P/N 2740156-1; S/N 107-371
- Cabin Pressure Sensor; P/N 2119708-1; S/N 65-337
- Cabin Pressure Control Panel; P/N 2119704-1; S/N 32-280
- Pressurization System Automatic Disable Relay R 2-5744

Furthermore, the following system tests and checks were conducted:

- Cabin Pressure Decay Test according to AMM 21-33-01
- Inspection of the cable connection CPC - Control Panel and CPC – Outflow Valve
- Check of outflow valve mechanical linkages for free movement, lubrication of pushrods
- Pressurisation Test AMM 21-00-00

Maintenance documentation showed that during the cabin pressure test conducted prior to the removal of the components on 20 February 2006 pressure fluctuations of 2 psi occurred.

The following TLB entry was documented:

REP T 0017106; Ref.Complaint T 0017104. FAILED ACTIVE CABIN PRESS TEST on Air Synoptic Page is Delta P indic. Fluctuating of 2 psi.

1.12.2 Line-Maintenance Prior to the Occurrence

Leg Frankfurt – Dakar, 18 February 2006:

In order to determine the cause for several level 3 alerts (CABIN ALTITUDE) and one level 1 alert (CABIN RATE) during the flight to Dakar an automatic test of the CPC 1 was conducted. No error message was shown.

Another troubleshooting was conducted with the help of a maintenance procedure described in the Fault Isolation Manual (FIM) 21-31-07-00.

The aircraft was subsequently released to service.

Leg Dakar – Sao Paulo, 18 February 2006:

The item (T0031084) was signed as fixed on 19 February 2006 in Sao Paulo.

Checked ACC#1,#2,#3, ESC, CPC#1 and #2 for current faults and faults in the fault review. No current faults found. CPC#1 shows on the last 2 legs CPC#1. R-T-S of all systems performed and passed. Checked cabin low pressure warning switch. Found ok. FRA TS informed for further action.

Leg Dakar – Sao Paulo, 18 February 2006:

No report

Leg Frankfurt – Dakar, 19/20 February 2006:

Due to several “Pressure Bumps” which were indicated with more than 2,000 ft/min and during which the crews had experienced pain in their ears, trouble-shooting according to FIM 21-31-04-00 was performed.

Maintenance-Action Report:

T/S PERFORMED IAW. FIM 21-31-04-00, FOUND OUTFLOW VALVE MOTOR IN FAULT, REVIEW OF BOTH CPCS. OUTFLOW VALVE MOTOR REPLACED IAW AMM, ALL RETURN TO SERVICE TEST PASSED

The aircraft manufacturer was not informed about the faults and error indications in the cabin pressure control system and air conditioning prior to the accident and therefore not involved in the fault analysis.

1.12.3 Investigation at the Manufacturer and History of the Components

Before and after the accident, several components of the cabin pressure control system were repeatedly removed from and reinstalled to the aircraft and either examined and maintained at the aircraft maintenance organisation or at the manufacturer.

1.12.3.1 Cabin Pressure Controller P/N 2119702-3, S/N 61-204

After the accident on 20 February 2006, the operator sent the Cabin Pressure Controller (CPC) to the manufacturer for fault diagnostic. The manufacturer tested the CPC with the result: No Fault Found (NFF); (Appendix 1).

Based on the operator's indication regarding the fault history of the components further tests were agreed upon with the manufacturer. Thereby a conspicuous behaviour of the CPC was determined. The manufacturer of the CPC advised that the Non Volatile Memory (NVM) had not recorded any failures. In the scope of this test a modification with the description "mod change to eliminate pressure sensor drop outs" was conducted.

After the CPC had been sent back to the operator, the components maintenance organisation, which was also part of the operator's corporate group conducted a further, extended test in which more abnormalities were discovered. The components were given to the manufacturer once more who confirmed the found abnormalities. With the Extended Loop Testing faults on the central control unit of the CPC, S/N 61 – 204 were identified. From the fault description it could be determined that there was a fault in the interface unit for the incoming analogue and digital sensor signals of the cabin pressure control system. This interface unit also stored operating modes and fault messages of current and past flights (mode logic).

History of the Cabin Pressure Controller (CPC), P/N 2119702–3, S/N 61–204

According to maintenance records, the CPC had been installed in a different aircraft of the same operator in November 2005 after an overhaul. After eight cycles with a total of 44 operating hours, the CPC was removed again because cabin pressure problems had occurred.

The CPC was then sent to the manufacturer for inspection with the information on the cabin pressure failures. The manufacturer conducted a test with the result No Failure Found (NNF) and returned the CPC to the operator for re-installation.

Since re-installation into the aircraft which had the accident on 19 February 2006, six flights with a total of 36 hours flight time were conducted. With the exception of one leg, on all flights cabin pressure problems occurred. During the flight on 19 February 2006 a malfunction occurred which injured the crew.

A maintenance engineer described the situation in an email between the corporate group's components maintenance organisation and the manufacturer of the CPC from his point of view as follows:

"Nevertheless the CPC S/N 61 – 204 history is very suspicious."

"This CPC was installed on the aircraft (aircraft registration deleted) at 17.02.06 just 1 day before the event."

"Therefore we suspect the CPC S/N 61 – 204 as most probable cause for the pressurization problem."

1.12.3.2 Outflow Valve Motor Assembly P/N 2740156-1, S/N 107 -371

The outflow valve S/N 107-371 was removed from the aircraft on 20 February 2006 after the cabin pressure faults and together with other components sent to the component maintenance organisation and the manufacturer, respectively, for inspection.

Following the flight from Dakar it was determined that in the Fault Review the CPC and the outflow valve S/N 107-371 were marked as faulty. The maintenance personnel determined that the outflow valve S/N 107-371 was stiff and partially unmovable.

According to maintenance documentation and the statements of the operator, the outflow valve was installed in the aircraft in question on 17 February 2006. Until the incident, six cycles with a total of 36 operating hours were flown. As a result of reported irregularities with the cabin pressure control system a replacement took place on 17 February 2006.

The maintenance history showed, among other things, that the outflow valve S/N 107-371 was removed from another aircraft of the MD-11 fleet on 1 September 2005 after cabin pressure faults had occurred. Up until that time the component had worked without the need for maintenance for 6,182 cycles and 33,242 operating hours.

In November 2005, the outflow valve was re-installed as spare part. It was intended to replace another cabin pressure outflow valve which was suspected to cause cabin pressure irregularities. After three flights with 17 operating hours cabin pressure con-

trol problems occurred again. The maintenance organisation noticed an unusual noise from the gearbox of the AC-driven motor, the atypical closing and opening characteristics of the outflow valve and the abnormal indications on the cabin pressure control panel. Several indications connected with category 3 alerts (Level 3 – Emergency/Warning) occurred during this time.

The maintenance documentation shows that the component was once again removed from the aircraft on 15 November 2005. An inspection in the maintenance organisation did not reveal any faults. The component was sent to the spare parts stock as an airworthy component.

On 17 February 2006, the cabin pressure outflow valve was installed in the aircraft which later had the accident. The installation had become necessary because cabin pressure problems had previously occurred with this aircraft as well.

After the fault on 20 February 2006 the component was once again removed from the aircraft. It was noted that the Fault Review had documented fault entries for both cabin pressure controllers. The removed cabin pressure outflow valve was stiff and partially unmovable.

Therefore, this component was sent to the above-mentioned maintenance organisation. They made the following discoveries during a Configuration and Findings Evaluation on 23 March 2006:

Outflow Valve Actuator Unit, P/N 2740156–1, S/N 107–371

Test Results: FAILED

Reject Reason Detail: FAILED MECHANICAL STOPS AND MECHANICAL LIMIT SWITCH TESTS

Findings: FAILED STOPS AND SWITCH TEST

Summary of Actions taken: UNIT REPAIRED PER MANUAL CRITERIA DUE TO MECHANICAL STOPS AND SWITCHES OUT OF ADJUSTMENT. STOPS AND SWITCHES CLEANED AND READJUSTED TO RETURN UNIT TO SERVICE

Outflow Valve Actuator Assembly, P/N 2740156, S/N 18-374 was included in the examination because it could not be ruled out that this component had been installed in the aircraft at the time of the occurrence. The following findings were documented:

Test Results: FAILED

Reject Reason Detail: S6 TEST FAILED OPEN MECHANICAL SWITCH TEST

Findings: S6 SWITCH FAILED TEST

Summary of actions taken: UNIT REPAIRED PER MANUAL CRITERIA DUE TO S 6 SWITCH FAILED OPEN MECHANICAL SWITCH TEST. SWITCH WAS CLEANED AND READJUSTED TO RETURN UNIT TO SERVICE
Action Taken Code: REPAIRED

1.12.3.3 Cabin Pressure Sensor, P/N 2119708–1, S/N 65–337

The Cabin Pressure Sensor (CPS) S/N 65– 337 was removed from the aircraft after the return from Dakar and sent to the components maintenance organisation and the manufacturer, respectively, for inspection.

The manufacturer documented the following findings:

Indication INOP

Reason for Return Code: REPAIR

Failure Description: SENSOR WAS OUT OF CALIBRATION

Findings: CALIBRATED SENSOR WITH R 3

Action Taken Code: REPAIRED

1.13 Medical and Pathological Information

Pilot in Command (PIC)

During the occurrence the PIC had experienced severe pain in his ear. Immediately afterwards he felt nausea and dizziness and experienced severe tinnitus in his right ear. After arrival in Frankfurt the pain in the right ear was continuing accompanied by a sense of some hearing loss and severe tinnitus.

An otorhinolaryngologist at the operator's Aeromedical Centre diagnosed the PIC with an acute right inner ear disorder including tinnitus after Barotrauma and prescribed infusions.

On the same day, a rheologic infusion therapy with 20 infusions was begun. Because the infusion therapy did not show the intended results, it was followed up by a hyperbaric oxygen therapy with 20 sessions in a pressure chamber centre at a German university.

Even after the therapy, vertigo, severe tinnitus and a progressive hearing loss in the right ear accompanied by sleep disorder remained.

In September 2006 the University Department of Otolaryngology, Head and Neck Surgery, Tübingen, prepared an extensive expert opinion. The expert opinion determined a severe sound sensation amblyacousia including tinnitus in the right ear connected with vestibular symptomatology (vertigo).

The link in a chain of evidence of the accident and the resulting damage to the right inner ear was confirmed as had the operator's Aeromedical Centre done right after the occurrence.

The expert opinion also describes Barotrauma as cause for the damage to the right inner ear.

In March 2007, the PIC's medical certificate was revoked because of the hearing loss in the right ear and the vestibular symptomatology (vertigo).

In October 2008, the head of the Aeromedical Centre attested the permanent loss of the medical certificate after an extensive examination of the PIC due to hearing loss in the right ear and the vestibular symptomatology (vertigo).

Neither the presented expert opinion nor the PIC indicated or knew of an illness prior to the occurrence which would have resulted in a pre-damage of the acoustic organ.

Co-pilot

The co-pilot stated during an interview conducted by the BFU that he had experienced severe pain in his ears during the occurrence. He responded with restriction when the BFU enquired about his health.

Passenger

The passenger present in the cockpit during the occurrence had experienced severe pain in his ears. In the further course of the flight the pain in his ears continued connected with a loud whistling sound and indisposition.

The following days the pain and tinnitus in his ears continued. The passenger was treated by an Otorhinolaryngologist.

The passenger subsequently stated that the pain in his ears continued for two days after the occurrence and the tinnitus had become permanent but with interruptions.

1.14 Fire

Not applicable.

1.15 Survival Aspects

Not applicable.

1.16 Tests and Research

Not applicable.

1.17 Organisations and their Procedures

The Luftfahrt-Bundesamt (LBA) approved the operator according to German and European regulations. The company was founded in 1994 and at the time of the accident operated a fleet of 19 MD-11F aircraft under its own Air Operator Certificate (AOC).

The operator was organised according to JAR-OPS 1 (now EU-OPS) and the Operations Manual Part A (OM/A) determined and described the responsibilities.

The Operations Manuals Part A, Part B and Part C, (OM/A, OM/B, OM/C) were in force as procedure documentation for all departments and crew members.

The head of the maintenance department was responsible for the maintenance system. His responsibilities included the determination of necessary processes for the maintenance procedures of the entire aircraft fleet. This included the control and supervision of maintenance executed by his department but also those of suppliers within the corporate group and those which had been outsourced.

The head of the flight safety and quality management department was responsible for the quality management within the operator. He had to report directly to the operations manager. The quality manager was responsible for supervision of the compliance with and the suitability of the procedures necessary to guarantee safe operational practices and airworthy aircraft.

A contract between the operator, the aircraft maintenance organisation and the components maintenance organisation regulated the management of maintenance tasks. The same was true for any outside company which performed line maintenance in foreign countries.

1.18 Additional Information

1.18.1 System Description Cabin Pressure Control System MD-11

A control system controls the cabin pressure of the cockpit, the cargo compartment and the avionic compartment. Pressure build-up and pressure control occur through opening and closing of the cabin pressure outflow valve.

In addition to the cabin pressure control system, pressure relief valves limit the cabin differential pressure to 9.1 psi. The warning message CABIN PRES RELIEF is indicated in the cockpit whenever there is a pressure difference of 8.9 psi or more.

The Cabin Pressure Control System provides the following functions:

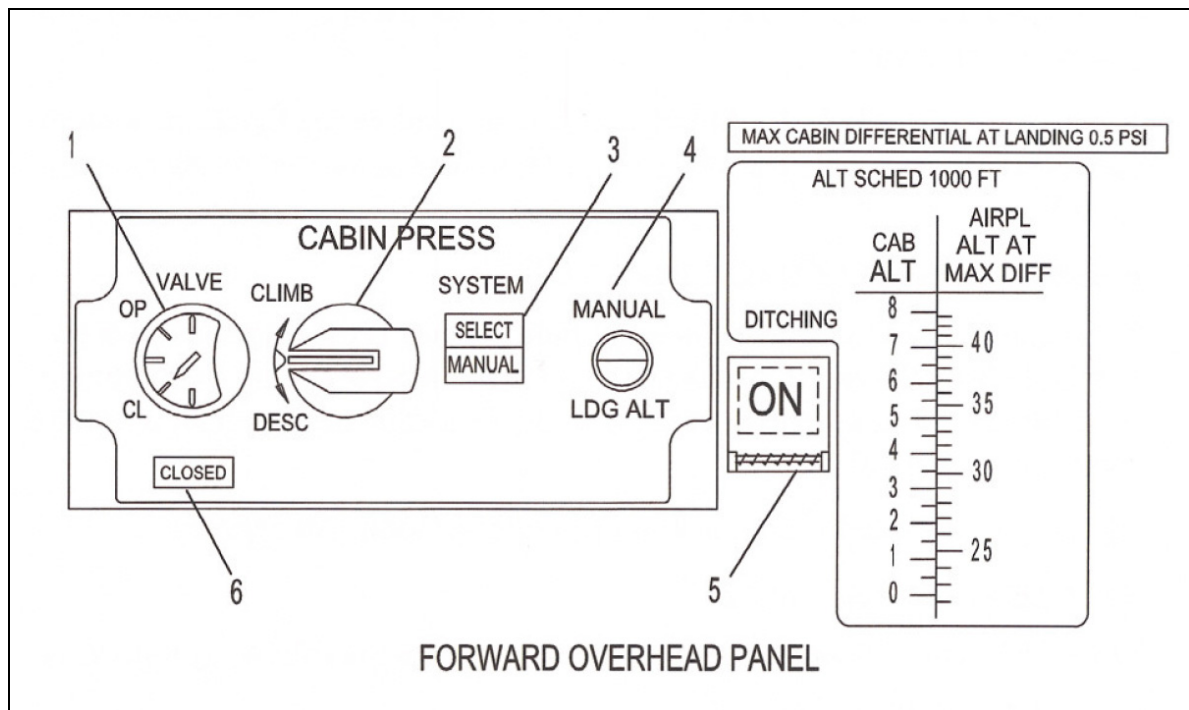
- Pressurisation control in all flight phases
- Fuselage over-pressurisation protection
- Monitoring pressure levels and cabin change rate

Pressurisation is normally controlled automatically. In case of failure change over to manual control occurs.

The cabin pressure control system allows a flight altitude of up to 43,200 ft. Cabin pressure is thereby equivalent to an altitude of less than 8,000 ft. Maximum cabin climb rate is 750 fpm and maximum cabin descent rate is 350 fpm.

The cabin pressure control system controls the cabin pressure outflow valve so that the crews and passengers experience the cabin pressure as comfortable. The system consists of two digital Cabin Pressure Controllers (CPC), a cabin pressure control panel, an outflow valve, and three relief valves.

The values for the cabin altitude, the cabin altitude rate change, the cabin differential pressure, and the outflow valve position generated by the cabin pressure control system and system status information are displayed in the cockpit on the air synoptic page. The cabin pressure control panel displays the outflow valve position visually.



Drawing Cabin Pressure Control Panel

Quelle: Boeing Manual

1. Outflow Valve Indicator
Displays position of outflow valve during manual and automatic operation of cabin pressure control system.
2. Cabin Press Manual Rate Selector
Adjusts the position of the outflow valve when the system is in manual.
3. Cabin Press System Select Switch
This is an alternate action switch that allows selection between manual and auto modes.
4. Cabin Press Manual LDG ALT Knob
The knob is used to enter the landing field altitude.
5. Ditching Switch

Among other things, it closes the outflow valve for emergency landings on water.

6. Closed Light

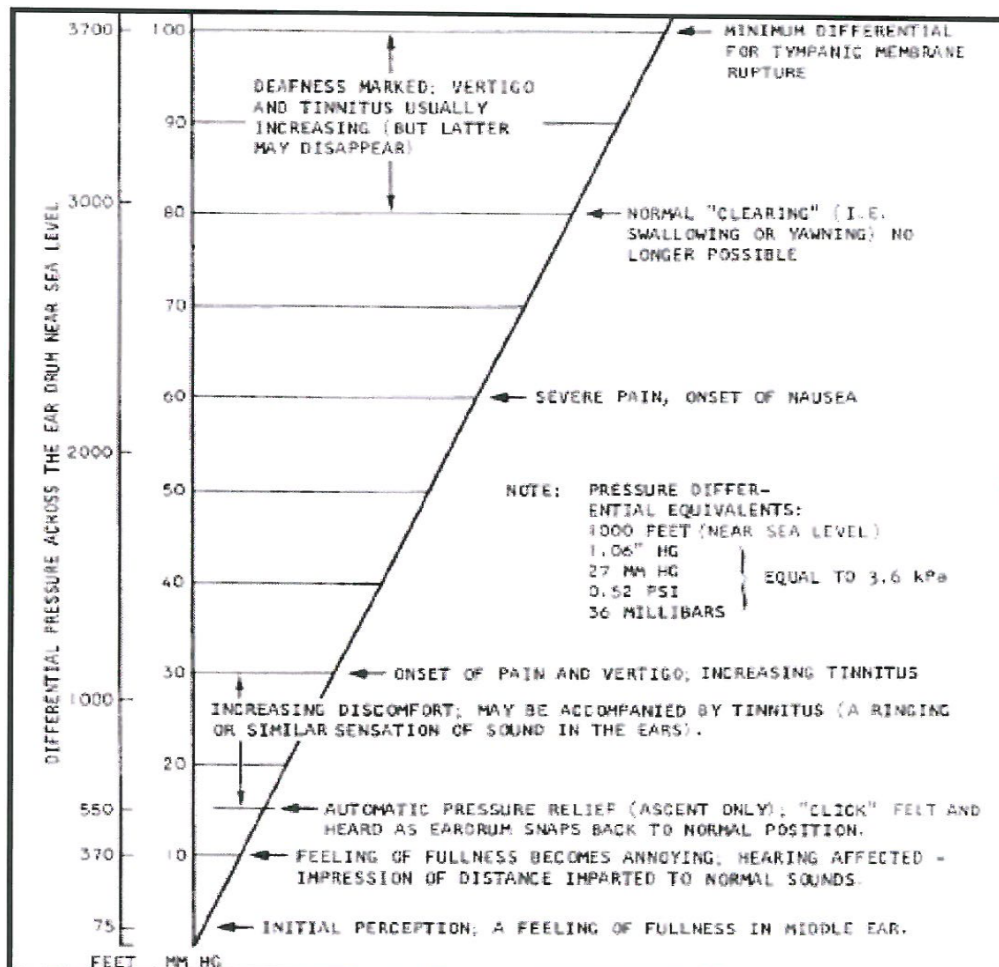
Illuminates when the outflow valve is fully closed.

The cabin pressure control system is part of the Environmental Control Systems (ECS). All indications including alerts and the exchange of internal data for cabin pressure and temperature occur in the central system (Appendix 4).

1.19 Useful or Effective Investigation Techniques

The manufacturer of the cabin pressure control system has designed and realised a dynamic simulation model on the basis of the programming language Matlab/Simulink in order to simulate the reaction of the cabin pressure control system during pressure sensor failure – dropout.

The results of the simulation were compared with the possible physiological effects of cabin altitude changes on the ears of aircraft occupants described in the Aerospace Recommended Practice 1270, Rev. A of the Society of Automotive Engineers.



Physiological effects of cabin altitude changes.

Honeywell

On 8 February 2007 the manufacturer provided the BFU with the results and explained them.

They stated that the simulation model was based on the following assumptions:

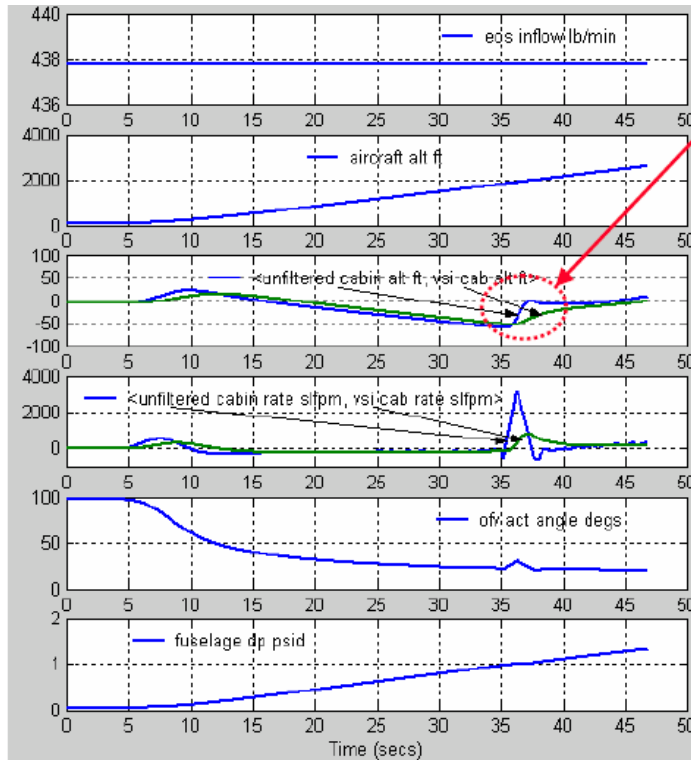
- Volume of the pressurised cabin: 29,500 – 35,500 cu-ft
- The cargo compartment was fully loaded.
- At the time of the occurrence, the pressurised cabin had a volume of about 20,000 cu-ft.
- Air inflow at sea level: 438 lb/min
- Air inflow at 40,000 ft: 337 lb/min

- Rate of climb after take-off in Dakar: 4,000 ft/min

Further assumptions were that the cabin pressure sensor failed or delivered erroneous data for 100 milliseconds in 20,000 ft and at a rate of climb of 2,000 ft/min in the first simulation and in the second simulation for two seconds.

The simulation showed the following results:

Predicted CPCS response to 100 msec pressure sensor failure

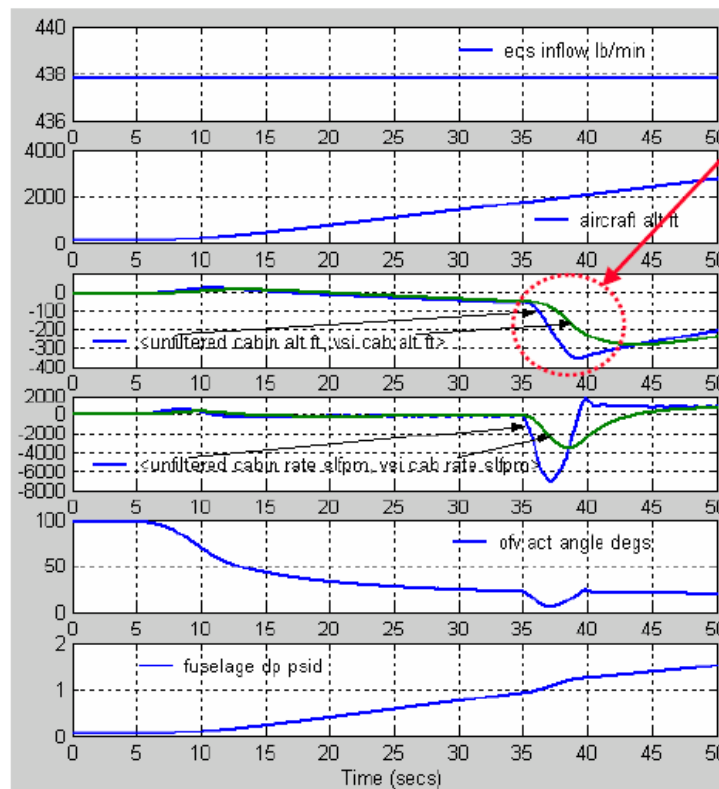


Pressure sensor failure for 100 msec results in an unfiltered cabin altitude bump of ~60 sif

Results during 100 ms downtime of CPCS

Honeywell

Predicted CPCS response to 2 sec pressure sensor failure

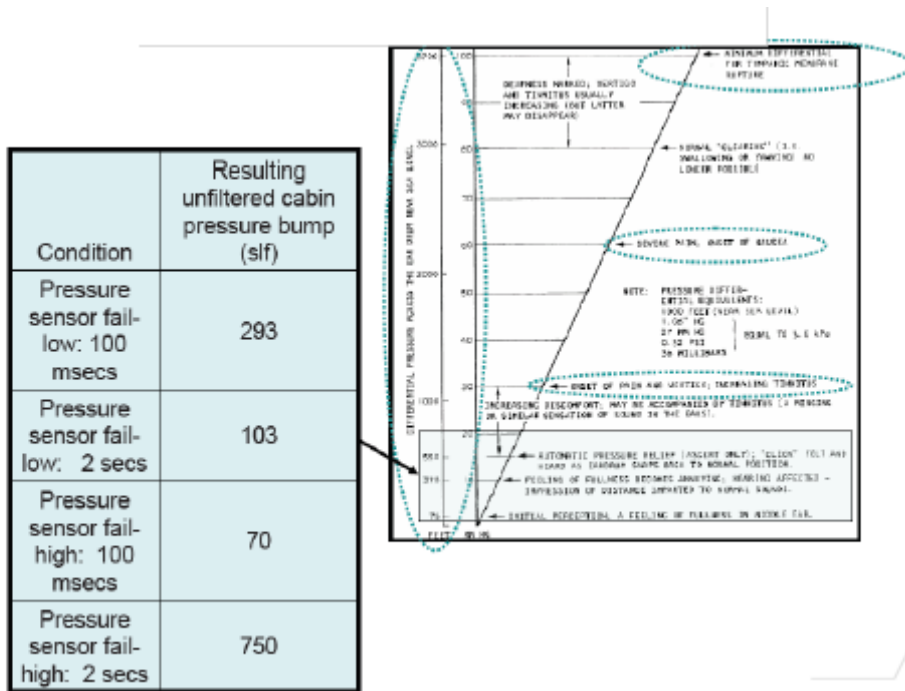


Pressure sensor failure for 2 secs results in an unfiltered cabin altitude bump of ~300 sif

Results during 2 s downtime of CPCS

Honeywell

The manufacturer deduced the possible physiological effects on the ears of aircraft occupants during the simulation of cabin altitude changes from the *Aerospace Recommended Practice 1270*.



Physiological effects of cabin altitude changes on the ears

Honeywell

2. Analysis

The cabin pressure control fault on 19 February 2006 on the flight from Dakar to Frankfurt was at first neither by the operator nor by the BFU considered as a serious incident or an accident according to the Law Relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft or ICAO Annex 13. Only a telephone call on the fourth day after the occurrence giving the BFU the information that one crew member was medically treated or in hospital provided the BFU with a basis for the decision making process to classify the occurrence either as serious incident or accident. At this time the BFU did not have any direct access to the components of the Cabin Pressure Control System because they had already been removed from the aircraft by operator and maintenance organisation and had been sent to the responsible components maintenance organisation and the manufacturer, respectively.

Given these circumstances, the BFU could only gather facts, beyond the statements of the persons on board, regarding this occurrence and the removed components through the documentation of the operator and the findings evaluation report of the manufacturer. Extent and profundity of the BFU investigation was determined by the analysis of the written documentation of operator and maintenance organisation and by the statements of manufacturer and crew.

To analyse the causality of the injuries the people on board suffered and a possible malfunction of the cabin pressure control system, medical expert opinions were consulted. The severe injury the PIC suffered resulted in the classification as accident according to ICAO Annex 13.

The BFU analysed the occurrence on the basis of the determinations in the medical expert opinion, the results of the examination of the components and the documented cabin pressure control system faults in the maintenance records prior to the accident.

2.1. Time and Causal Correlation

The report of the operator's Aeromedical Centre which had conducted the initial treatment of the PIC after arrival in Frankfurt showed that there was a correlation between the occurrence after the take-off of the MD-11 in Dakar and the determined in-

jury. The BFU identified the further examinations and treatments as a confirmation that the injury had indeed occurred on the flight from Dakar to Frankfurt.

The BFU was not provided with any detailed medical examination results of the co-pilot and passenger. Nevertheless, the statements of the co-pilot and the passenger confirmed the correlation. Both witnesses stated that they had experienced the occurrence after take-off in Dakar and suffered considerable pain and would also relate the PIC's injuries to the occurrence.

Therefore, the BFU has no doubts that the injuries the crew and the passenger had suffered are related to the malfunction of the cabin pressure control system.

Regarding the verification of a causal connection the BFU refers to the medical expert opinion of the University Department of Otolaryngology, Head and Neck Surgery, Tübingen. The expert opinion describes Barotrauma as cause for the inner ear damage in the right ear and deduces a connection between the accident and the injury. For the BFU this is sufficiently plausible.

In summary, the BFU is of the opinion that if there had not been a cabin pressure control system deficiency neither the PIC nor the co-pilot or the passenger would have suffered any injuries.

2.2. Specific Conditions

2.2.1 Crew and Operational Aspects

The PIC was properly licensed and qualified to conduct the flight. With a total flight time of 3,672 hours as PIC which he had acquired exclusively on the MD-11, he was very familiar not only with the aircraft type but also with flight operations and the flight route.

The co-pilot was also adequately licensed and qualified. He had a total flight time of more than 18,000 hours and 6,700 hours as PIC on other aircraft types and therefore was very experienced. After 725 hours of flight time on the MD-11 he was familiar with the aircraft type but also with his role as co-pilot.

The BFU has no knowledge of any irregularities of the team work in the cockpit, caused by decision makings or other actions after the event.

The crew has made themselves familiar with the deferred open items before their flight from Dakar to Frankfurt. Based on the information that in the Technical Logbook, the Hold Item List and the Deferred Maintenance Items list nothing was noted

which would have had to be fixed before the next flight, the crew acted correctly and routinely. A sense of responsibility for the safe conduct of flight can be detected in the fact that the PIC contacted the responsible maintenance organisation at the home base in Frankfurt regarding a defective landing light. The BFU is of the opinion that there were no formal or objective reasons for the crew to not undertake the flight.

The crew was made aware of the entries in the Technical Logbook concerning the problems with the cabin pressure control system. Since all entries had been marked as fixed, the flight could be conducted without any reasonable doubt.

Except for the fact that because of a defective APU the engines had to be started with an external air starter, flight preparation and all flight operations were routine tasks for the crew.

Both crew members were surprised by the sudden event during the climb. Because of the noise level, the pain in their ears and the temporary abnormal indications on the cabin pressure control panel, they could not identify the problem right away. The BFU is of the opinion that a broken window could indeed have been the cause. Therefore, there was no reason for a change over to system 2 of the cabin pressure control system.

Because of the short duration of the re-occurrence only moments later, the crew was not in a position to identify the problem or work through a respective checklist.

The BFU is of the opinion that it was a consequent decision to report the occurrence via ACARS to the maintenance organisation in Frankfurt immediately after it occurred.

Neither the crew nor the decision makers on the ground considered to abort the flight and return to the airport of departure. The health impairment of the occupants was not realised.

The further course of the flight in a reduced altitude was uneventful.

2.2.2 Technical Aspects

The BFU has no doubt that after the take-off in Dakar and before reaching cruising level, a problem with the cabin pressure control system occurred. Even though the integrity of the aircraft and its flight performance was not impaired by the occurrence, the PIC was severely injured which resulted in the permanent loss of his medical cer-

tificate. After the occurrence was classified as accident, a safety investigation according to the Law Relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft was logically consistent.

Because the BFU did not have immediate access to the components of the cabin pressure control system after the occurrence or the landing in Frankfurt, the components could not, or only to a limited extent, be examined by the BFU. All facts and assessments relate to findings of the operator, the maintenance organisation and statements and descriptions of the manufacturer.

2.2.2.1 Assessment of the Simulation Model Results

The results from the dynamic simulations model the manufacturer of the CPCS had designed and realised for the MD-11, were for the BFU an important basis to understand the possible effects a CPCS component failure could produce.

The simulation showed that a 100-millisecond loss of pressure sensor signal caused the outflow valve to open by about 10°. With the simulation it was reproducible that at a differential cabin pressure as it could have existed at the time of the occurrence, a pressure bump of 6,000 ft/min (unfiltered cabin rate in slfpm) was possible.

Essential for the consideration of the cabin pressure control system's function is the fact that the rate of air movement from the cabin depends on the outflow valve's opening angle and the differential cabin pressure. The cabin altitude rate change therefore depended on the duration of a possible loss of pressure sensor signal.

The simulation by the manufacturer where initially the pressure sensor failed for 100 ms and then for 2 s resulted in perceptible physiological effects on the ears as was described in the graph *Aerospace Recommended Practice 1270*. According to which permanent, organic injuries are not caused with these failure times.

The BFU considers it as highly likely that during the occurrence the failure time of the estimated 100 ms or 2 s were exceeded.

The statement of the crew during an interview by the BFU supports the longer duration of loss of pressure sensor signal; they had described the opening of the outflow valve at the 11:30 o'clock position in the overhead panel. Based on the simulation (Frame 6, Graph 100 ms) the BFU estimates an angular rate of 10°/sec as commanded rate for the outflow valve. The 11:30 o'clock position in the overhead panel would correspond with an opening angle of the outflow valve of 90°. An opening an-

gle of the outflow valve of 90° would only be possible with an angular rate of about 8°/sec.

An opening of the outflow valve to 90° would, by a differential cabin pressure of 8 psi, lead to a significantly increased cabin rate and a very high outflow of air from the cabin. Based on the opening time of the outflow valve of about 8 sec and a further 8 sec the motor needed to close it again the outflow of air from the cabin could be in the damage range for a sensory organ given the indications of the *Aerospace Recommended Practice 1270*.

Neither with the simulations nor model calculations done by the manufacturer nor the scenario described by the BFU could the real course of events be proven with sufficient certainty. The reason was no data from the flight data recorder or any other recorded data was available.

2.2.2.2. Technical Findings

The BFU does not understand why the manufacturer could not read out any data or failure codes from the non-volatile memory of the cabin pressure controller when they conducted an inspection of the component after the accident. The conclusion the memory was empty is not in line with the system failure scenario. A pressure sensor drop out should have resulted in a failure message.

The investigation had to content with a further disadvantage. Flight data recorders of older generation aircraft, to which the MD-11 belongs, do not record data regarding the behaviour of the cabin pressure control system or the sample rate is too low to catch short events. The recording of the parameter Cabin Rate every 60 seconds on the FDR and FODA did not ensure that a cabin pressure control system failure lasting less than 60 seconds could be recorded at all.

For the BFU it is highly likely that a second cabin pressure control system failure occurred, as the manufacturer had also described. According to the system design a change over to the back-up system after a cabin pressure control system failure of 100 milliseconds would occur. BFU and the manufacturer of the cabin pressure control system estimate that the cabin pressure controller failed for more than 100 milliseconds and therefore a change over should have taken place. The real reason for the failure and the non-transfer to CPC 2 could not be established by the manufacturer or the BFU did not receive any information about it.

2.2.3.1 Assessment of the Determinations on the CPCS Components

After the occurrence on 19 February 2006, several CPCS components were removed by the operator and sent to the aircraft maintenance organisation, the components maintenance organisation and to the manufacturer of the system components for trouble-shooting and analysis. This course of action corresponded with normal maintenance procedures but not with the procedures required by investigation authorities for serious incidents or accidents. For this reason and because of the delayed initiation of the investigation, the BFU had to rely on the findings and conclusions of the manufacturer and maintenance organisation.

Cabin Pressure Controller

Based on the technical records and the exchange of e-mails it could be established that the CPC P/N 2119702-3, S/N 61-204 was installed in the aircraft at the time of the accident. The determinations and findings made after 19 February 2006 by the maintenance organisations were partially obscure and insufficiently plausible to the BFU. Only at the end of the investigation did it become understandable that the maintenance organisations had confused the serial numbers.

According to the system design and given the previous history and the failure history of the CPC the non-volatile memory should have recorded failures or malfunctions. It could not be excluded that entries have been inadvertently deleted during the automated test procedures, which were conducted at the components maintenance organisation and the manufacturer.

The BFU specifically noted the modification described as "mod change to eliminate pressure sensor drop outs" which was carried out during the inspection.

The fact that the components maintenance organisation found a failure after the CPC had been returned to them and they had conducted their own extended test, indicates an insufficient test procedure of the manufacturer. This was confirmed by the second test run at the manufacturer's which then confirmed the failure.

The explanation that there was a fault in the interface unit for the incoming analogue and digital cabin pressure control system sensor values could be a plausible reason for the "empty" non-volatile memory for failure codes.

Outflow Valve Motor Assembly

The technical records showed that the CPC S/N 107-371 was installed in the aircraft at the time of the accident. According to the maintenance organisation's Technical Investigation Report and several e-mails, the outflow valve came from the spare parts stock on 20 February 2006. According to the data in the e-mails, the CPC S/N 18-374 could also have been installed. After another enquiry on 15 July 2007, it was stated that the component S/N107-371 was indeed installed. The BFU regarded the documented history of the components as contradictory.

Both, the repeated findings in the history of the outflow valve S/N 107-371 and the failure description after the last inspection – Test Results: Failed – cause the BFU to come to the conclusion that the component was defective and could have contributed to the malfunction of the cabin pressure control system. However, it cannot be concluded with absolute certainty that this component was indeed installed in the aircraft at the time of the accident.

Very similar failure descriptions and test results were also documented for the outflow valve S/N 18-374 and therefore a sound operation seems questionable.

In the course of the investigation it was confirmed that at the time of the accident the outflow valve S/N 107-371 was installed in the aircraft. According to the maintenance organisation's Technical Investigation Report and several e-mails, the outflow valve came from the spare parts stock on 20 February 2006. According to the data in the e-mails, the CPC S/N 18-374 could also have been installed. Until the final clarification on 15 June 2007 the BFU regarded the documented history of the components as contradictory. Based on this background the BFU asked for an examination of both components.

Both, frequent faults in the history of the outflow valve S/N 107-371 and the failure description after the last inspection with the remark: "Test Results: FAILED" allow the conclusion that the component was faulty and could have contributed to a malfunction of the cabin pressure control system. Very similar failure descriptions and test results were also documented for the outflow valve S/N 18-374 and therefore a sound operation seemed questionable.

From the documentation provided and the interview, the BFU has gained the impression that especially the cabin pressure controller had been changed several times prior to the accident and the verification management was not always plausible.

Cabin Pressure Sensor, P/N 2119708–1, S/N 65–337

According to the statements of the operator, the cabin pressure sensor S/N 65–337 was installed in the aircraft at the time of the accident. The BFU is of the opinion the verification management was not clear enough.

The failure descriptions and findings of the maintenance organisation and the manufacturer with the indications “INOP” and “SENSOR WAS OUT OF CALIBRATION” allow the conclusion of possible malfunctions and operational inaccuracies of the component.

Summary

Even though the documentation of failure descriptions and findings prepared by the maintenance organisation and the manufacturer did not supply a clear and unambiguous explanation for a concrete and verifiable system malfunction, there were numerous indications of inaccuracies and possible temporary failure which could have had an impact on the system environment of the cabin pressure control system.

These indications corresponded with the complaints from the line maintenance and the entries in the TLB.

The BFU is of the opinion that a temporary malfunction of the CPC in connection with a malfunction or inaccuracy of the pressure sensor is highly likely. This failure combination could, however, not be proven.

2.3 Defences

Defences are measures to protect a system from the consequences of technical or human failure. Humans do not act alone in this system; they are one element in a complex socio-technical system.

The analysis of the accident involving the MD-11 examined and assessed both, the line maintenance and the maintenance of components. The key points were the cabin pressure control system and its components as well as communication and management of failure messages.

2.3.1 Line Maintenance

The maintenance program of the aircraft manufacturer, certified by the responsible civil aviation authority, predetermines certain maintenance actions. The crews enter their complaints during regular flight operations into the Technical Logbook (TLB) or the Hold Item List (HIL). These items or complaints are assessed and fixed through qualified maintenance staff during the next landing or at the next scheduled maintenance.

The retracing of the TLB and HIL entries by the BFU showed that there had been several entries concerning the cabin pressure control system over a longer period of time. These were either signed as fixed or marked and postponed as items for a scheduled maintenance action. Several months after the accident it became clear that the recurring malfunctions in the cabin pressure control system were due to two different causes. However, up until that time one had to act on the assumption that the cause was unknown.

The investigation showed that crews had identified cabin pressure control system problems properly and entered them into the TLB accordingly.

The BFU took special note for instance of the level 3 alerts (CABIN ALTITUDE) and level 1 alert (CABIN RATE) which occurred on the flights Frankfurt – Dakar and Dakar - Sao Paulo on 18 February 2006. The TLB entry that the complaints had been fixed made clear that all complaints including the level 3 alerts had been checked by the intra-system function “Return to Service”. The TLB showed that this entry had been transmitted to the maintenance centre in Frankfurt. Although cabin pressure control system failures had occurred on earlier flights which had been indicated as level 3 alerts, an in-depth trouble-shooting did not take place. Alternative measures to determine the cause of the indicated failures, like a Cabin Pressure Test, the exchange of the CPC1 or shutting down the CPC1 according to the MEL procedure, did not occur and the maintenance organisation in Frankfurt did not order to do so.

Even taking into account that the aircraft manufacturer did not require any special maintenance actions and a Return to Service test was common practice after level 3 alerts, the BFU has come to the conclusion that, in this case, the procedure was insufficient. The investigation has shown that the CPC internal Return to Service test did not comprehensively detect failure situations caused by external sensors and other components. From the technical viewpoint it would be sensible to expand the

test. Given the cost effectiveness of the phase-out aircraft type MD-11 it is hardly justifiable.

The aircraft manufacturer describes in the MD-11 Flight Crew Operating Manual (FCOM) level 3 alerts as (red) failure indications which require immediate crew attention. An immediate action to remedy the failure situation is required. Therefore, this kind of failure message indicates highest priority for crews as well as maintenance staff.

Even if the aircraft manufacturer requires a Return to Service test after level 3 alerts as trouble-shooting measure and confirmation of functionality, a procedure for an extended failure analysis should be employed whenever there is repeated failure occurrence in flight in connection with other failure descriptions.

2.3.2 Test Procedure at the Manufacturer

Based on the unclear failure situation and failure descriptions and the conspicuous findings determined through their own component tests and the somewhat longer maintenance history, the maintenance organisation asked the manufacturer to inspect and test several cabin pressure control system components. These included two cabin pressure controllers, one outflow valve and one cabin pressure sensor.

The manufacturer compiled a Configuration and Findings Evaluation Report (CAFE). Specially trained personnel inspected the components visually and conducted tests with automated test equipment according to requirements and procedures established by the manufacturer.

After the test, the components were sent back to the customer together with a test report and an airworthiness certificate. Therefore, operator and maintenance organisation could assume that the inspected components were fully functional and ready for installation into an aircraft.

The fact that the maintenance organisation conducted an additional test based on the manufacturer's test report and their earlier experience with the CPC S/N 61-04 and determined a malfunction, points to the limitations of the routine components test executed by the manufacturer or to insufficient communications between principal and contractor. The BFU is of the opinion that a component test at the manufacturer should be so comprehensive and penetrative that even "hidden" failures can be de-

tected. This is especially true whenever the customer indicates any special problem with the component.

2.4 Communication of Failure Information

Continuous airworthiness in everyday flight operations is based on predetermined maintenance procedures. Recognition and communication of failure information plays an important part.

The investigation showed that the on-board supervision of the cabin pressure control system in the MD-11 was sufficient and fully functional. Both, level 3 and level 1 alerts were indicated appropriately on all previous flights.

The crews entered the failure messages into the TLB as required by the Operating Manual Part A (OM/A).

These entries in the TLB were then signed by the responsible personnel. Formal requirements were therefore complied with. The BFU has considerable doubt concerning the professional processing. Conversations with people involved, the comparison of the entries in the TLB over a longer period of time and several e-mail provided to the BFU have made clear that complaints have occurred time and again despite the previous sign off. The BFU is of the opinion that the reasons were on one hand an unclear communication and on the other that the causes for the complaints were not clearly identified.

The malfunctions in the cabin pressure control system were not always reproducible and the interaction of the system components involved was very complex. Precise failure descriptions and procedures for trouble-shooting would have been necessary.

The exchange of failure descriptions and realisations from the trouble-shooting and debugging demanded clear and unambiguous communications structures in all companies involved such as the aircraft maintenance organisation, the components maintenance organisation, the aircraft manufacturer and the cabin pressure control system components manufacturer. The BFU is of the opinion that these were not always present. The BFU was informed that the component manufacturer was involved in the trouble-shooting process before the accident occurred. On enquire by the BFU the manufacturer stated that the problem with this particular CPC and aircraft was not known to them. Even after the accident the insufficient communication between the companies involved was evident. On the occasion of a phone conference in Febru-

ary 2007, it became known that the component manufacturer had not been informed about essential data regarding the accident.

The BFU concurs with the aircraft manufacturer's comments that they should have been informed about the failures and failure indications in the cabin pressure control system and the air conditioning prior to the accident. An exchange of the findings and assessments between the operator, the maintenance organisations and the aircraft manufacturer would have been appropriate.

The BFU developed doubts about the reliability and validity of the technical documentation. With three out of four components the BFU has received differing answers regarding which S/N was actually installed in the aircraft at the time of the accident. This fact points out the shortcomings concerning the verification management on installed components. The BFU is of the opinion that all data entered into the maintenance history should correspond with the components installed in the aircraft.

2.4.1 Organisational Aspects

The investigation showed that both, the head of maintenance and the head of flight safety and quality management were informed about the on-going problem with the cabin pressure control system. Maintenance records showed that individual components were replaced several times in order to isolate the system malfunction. As far as the BFU could determine, every maintenance action was completed with a Return to Service test.

Based on the complex distribution of responsibilities with different sub-contractors it was not possible for the head of maintenance or the head of quality management to determine in detail which measures would have been appropriate given the individual failure descriptions.

The complexity of the failures in the cabin pressure control system and the air conditioning would have made a closely-structured procedure during the trouble shooting process and a clear communication which involved the responsible managers essential. Only then would the postholder maintenance been able to control and manage the maintenance actions.

3. Conclusions

3.1 Findings

- The aircraft had a valid certificate of registration.
- The crew was properly licensed and qualified to conduct the flight.
- The class 1 medical certificates of the crew were valid.
- During climb out of Dakar in FL 250, an abrupt pressure bump occurred in the cockpit which resulted in pain in the ears, which was felt by both crew members and the passenger, and a very loud noise level.
- The operator's Aeromedical Centre diagnosed the PIC with an acute, right inner ear trauma including tinnitus after Barotrauma.
- In the course of his treatment an expert opinion determined that the PIC had suffered a severe sound sensation amblyacousia in the right ear including tinnits connected with vestibular symptomatology (vertigo).
- In October 2008, the PIC's medical certificate was revoked.
- Co-pilot and passenger were treated after the occurrence by an Otorhinolaryngologist because of the pain in their ears.
- Based on witness statements and the expert opinion of the University Department of Otolaryngology, Head and Neck Surgery, Tübingen, a time dependent and causal relationship between the injuries of the occupants and the malfunction of the cabin pressure control system has to be assumed.
- The simulation and model calculation prepared by the manufacturer is plausible. The values estimated as input parameters, however, do not correlate with the values determined by the BFU.
- The opening angle of 90° of the outflow valve observed by the crew resulted in an air outflow from the cabin which could lead to the damage of a sensory organ as described in the *Aerospace Recommended Practice*.
- There were no status and error message recordings in the non-volatile memory of the CPC.
- Failure of the components could only to a limited extend be determined by inspections carried out by the maintenance organisation and the manufacturer.

Evidence suggests a temporary error in the CPC in connection with the failure of the pressure sensor or the exceedance of some tolerance threshold.

- On flights prior to the accident flight, several failures including level 3 alerts were indicated and entered into the TLB.
- Indicated failures including the level 3 alerts were checked with Return to Service tests (RTS) by the maintenance stations. Repeated failure messages did not result in special maintenance actions.
- Test procedures for the CPC at the manufacturer did not reveal a malfunction which the operator's maintenance organisation had identified.
- Failure information and realisations from conducted maintenance actions were not sufficiently clear and only delayed communicated between the operator and the maintenance organisations involved.

3.2 Causes

Immediate Causes:

The accident was caused by an abrupt pressure bump within the pressurised cabin. What triggered the pressure bump could not be established with sufficient certainty. It is probable that the pressure bump was caused by a malfunction of one component or by exceedance of some fault tolerance of individual components of the Cabin Pressure Control System (CPCS).

Systemic Causes:

- The importance and possible effect of indicated malfunctions of the cabin pressure control system during previous flights was not analysed sufficiently.
- The standardised test procedure Return to Service was not sufficient enough to recognise the cause for the malfunction.
- The repeated display of level 3 alerts did not result in any particular maintenance action.

- The manufacturer of the cabin pressure control system has standardised and automated test procedures for the functional demonstration of components which did not detect single failures or failures related to the interaction of the different system components.
- The communication of fault descriptions and reports between the operator, the aircraft maintenance organisation, the components maintenance organisation and the manufacturer of components was insufficient.

4. Safety Recommendation

The BFU intends to address the following safety recommendations to the operator:

Safety Recommendation 08/12

For continuous airworthiness of the aircraft fleet the operator should ensure that whenever safety related failure messages and failures occur these are recognized and assessed as to their risk potential. If applicable, actions to recognize failures and remedy them should be initiated which go beyond the standard trouble-shooting routine and the so called Return to Service Test.

Safety Recommendation 09/12

The operator should ensure a clear cut communication whenever trouble-shooting involves different departments and external organisations.

Failure descriptions should be unambiguously worded. The communications partners should be clearly named and the intended communications channels adhered to. This is specifically of importance with failure descriptions and for determinations during the testing of aircraft systems and components whenever not only the maintenance organisation which is part of the operator is involved but also the aircraft maintenance organisation bound by contract, the components maintenance organisation, the aircraft manufacturer and the components manufacturer.

The BFU intends to address the following safety recommendations to EASA:

Safety Recommendation 10/12

EASA should amend the aeronautical regulations for commercial air transport regarding continuous airworthiness.

So that operators ensure that safety related failure messages or malfunctions which recur despite routine maintenance actions are recognized and assessed in regard to their risk potential. If applicable, actions to recognize failures and remedy them should be initiated which go beyond the standard trouble-shooting routine and the so called Return to Service Test.

Investigator in charge: Johann Reuss

5. Appendices

Appendix 1 Findings Report of the Cabin Pressure Controller (CPC), P/N 2119702–3, S/N 61–204

Appendix 2 Findings Report of the Outflow Valve Motor Assembly P/N 2740156-1, S/N 07 0 - 371

Appendix 3 Findings Report of the Cabin Pressure Sensor, P/N 2119708–1, S/N 65–337

Appendix 4 Environmental Control Interface Diagram

Page 1 Of 2

Honeywell
Configuration and Findings Evaluation Report (CAFE)

Date: 02/04/2006

Notification: 000300165687 Sales Order: 0000214804 Service Order: 5000262315
Repair Station: HZ3R571L

Cust: Cust Code: PLANT1000 Com/Military: C
Rating:

Responsible C.A.: NELL DONAHO Item Receipt Date: 11/29/2005 Ship Date:
Cust PO / Clir: 250214483 / Honeywell Contract / Line: 0440005991 / 000050

Customer Reject Number: Warranty Requested (Y/N): Warranty Approved (Y, N, Pending):

-----AS-RECEIVED CONFIGURATION AND HISTORY-----

Material Number: 2119702-3 Serial Number: 61-204 Series: 3
Change: NSN: Model#:

Material Description: Cabin pressure controller
Quantity: 1.000 Reusable Container: No Installed Date: Removed Date:
TSN: 185 TSO: 0 TSR: 0 CSN: 8 CSO: 0 CSR: 0 Last F.T.:

-----AS-SHIPPED CONFIGURATION-----

Material Number: 2119702-3 Serial Number: 61-204 Series: 3
Change: NSN: Model#:
Material Description: Cabin pressure controller Cust Matl:

Authorizing Documents:
CMM 21-32-14 REV 3

-----CUSTOMER REASON FOR REMOVAL-----

Cabin press problems.

-----GENERAL CONDITION AS RECEIVED-----

Last FT date 4/21/05. Dirty, scratched/scuffed, chipped paint, labels peeling,
connector caps missing.

-----WORK ACCOMPLISHED-----

FINDINGS: INCOMING FAULTS PRINTED OUT NFF AT FINDINGS TEST TESTED PER AT2119702-3 REV
B FINAL: TEST ONLY TESTED PER AT2119702-3 REV B

FRB FF905 10102 00 21153 T

349 053678

Findings Report Cabin Pressure Controller P/N 2119702-3, S/N 61-204

Source: Honeywell

Appendix 2

Honeywell		Repair Station: ZX4R716M	Date: 03/23/2006
Configuration And Findings Evaluation			
Repair Order: 2006-1366283-001	Customer: 496		
Customer P/O: 250231690	Orig Customer:		
Part Number: 2740156-1	Part Desc: ACTUATOR	Serial No: 107-371	
Series: 6	Mods:	Ship Date:	
Quantity: 1		Received Date: 02/28/2006	
Aircraft Tail #:	Aircraft S/N #:	Date on:	Date off:
Model #: N/A	Engine S/N:		
TIMES / CYCLES			
Time Since New:	33295	Cycles Since New:	6191
Time Since Overhaul:	33295	Cycles Since Overhaul:	6191
Time Since Repair:	000000	Cycles Since Repair:	000000
Time Since Last Shop Visit (Enter UNK if	unk		
CUSTOMER REASON FOR RETURN			
ESTIMATE FUNCTIONAL TEST,SEE UNSV TAG ATTACHED,SELECT CABIN PRESSURE MANUAL,ALERT DURING TAXI,WHEN LINK IS NEAR CLOSED POSITON,SPECIAL INVESTIGATION BY OEM,SEND FINDINGS REPORT TO MR. PETER HUCK,REF TO PO FOR FURTHER INST, AH			
GENERAL CONDITION AS RECEIVED (HIDDEN DAMAGE)			
Condition Received Text: dirty	Shipping Container: Reusable: NO		
Reason for Return Code: Investigation	Removal Type: Unscheduled		
TEST EVALUATION			
Test Results Type: Incoming	Test Results: Failed		
Test Date (dd/MMM/yyyy): 02-Mar-2006	Reject Reason Detail: Failed mechanical stops and mechanical limit switch tests		
DETAIL DISASSEMBLY / EVALUATION FINDINGS			
Failure Description:	Findings: Failed stops and switch tests		
Related Area:	Non-conformance:	Recurrent Failure:	
Failed Part #:	Part Name:	Condition:	Primary Failure
SERVICE BULLETINS / AUTHORIZING DOCUMENTS			
Manual #: 21-32-22 Rev: 5 Date: 12/23/2005			
WORK PERFORMED / COMMENTS TO CUSTOMER			
Workscope Performed / Summary of Actions Taken:	Unit repaired per manual criteria due to mechanical stops and switches out of adjustment. Stops and switches cleaned and readjusted to return unit to service.		
Action Taken Code:	Repaired		
Customer Confirmed Removal Reason:	Yes		
Evaluation Type:	Evaluated - Minor Fault Found		
		 303 702076	
FINAL CONFIGURATION		Part No: 2740156-1	S/N: 107-371
Series: 6		Mods:	DATE: 03/23/2006
MECHANIC/ANALYST: Eric Stewart			
1 of 1			

Findings Report Outflow Valve Motor Assembly P/N 2740156-1, S/N 107 -371

Source: Honeywell

2568354109 09:57:44 03-10-2006 2/2

Honeywell

Repair Station: ZX4R716M Date: 03/10/2006

Configuration And Findings Evaluation

Repair Order: 2006-1366614-001	Customer: 496	
Customer P/O: 250231794	Orig Customer:	
Part Number: 2119708-1	Part Desc: SENSOR	Serial No: 65-337
Series:	Mods:	Ship Date:
Quantity: 1		Received Date: 03/06/2006
Aircraft Tail #:	Aircraft S/N #:	Date on: 02/22/2006
	Engine S/N #:	

TIMES / CYCLES

Time Since New:		Cycles Since New:	
Time Since Overhaul:		Cycles Since Overhaul:	
Time Since Repair:	000000	Cycles Since Repair:	000060
Time Since Last Shop Visit (Enter UNK if unknown):	UNK		

CUSTOMER REASON FOR RETURN

ESTIMATE REPAIR IAW DCC, SEE UNSV TAG ATTACHED, INDICATION INOP, FOR SPECIAL INVESTIGATION, SEND REPORT TO PETER HUCK, AH

GENERAL CONDITION AS RECEIVED (HIDDEN DAMAGE)

Condition Received Text	NORMAL	Shipping Container: Reusable	NO
Reason for Return Code	Repair	Removal Type	Unscheduled

DETAIL DISASSEMBLY / EVALUATION FINDINGS

Failure Description:	SENSOR WAS OUT OF CALIBRATION WITH PRESSURE AT 50.000 IN HGA. SNSOR WAS READING 8.016. SHOULD BE 7.992 - 8.008.	Findings:	CALIBRATED SENSOR WITH R3.
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Related Area: Non-conformance: Recurrent Failure:

Failed Part #:	Part Name:	Condition:	Primary Failure
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SERVICE BULLETINS / AUTHORIZING DOCUMENTS

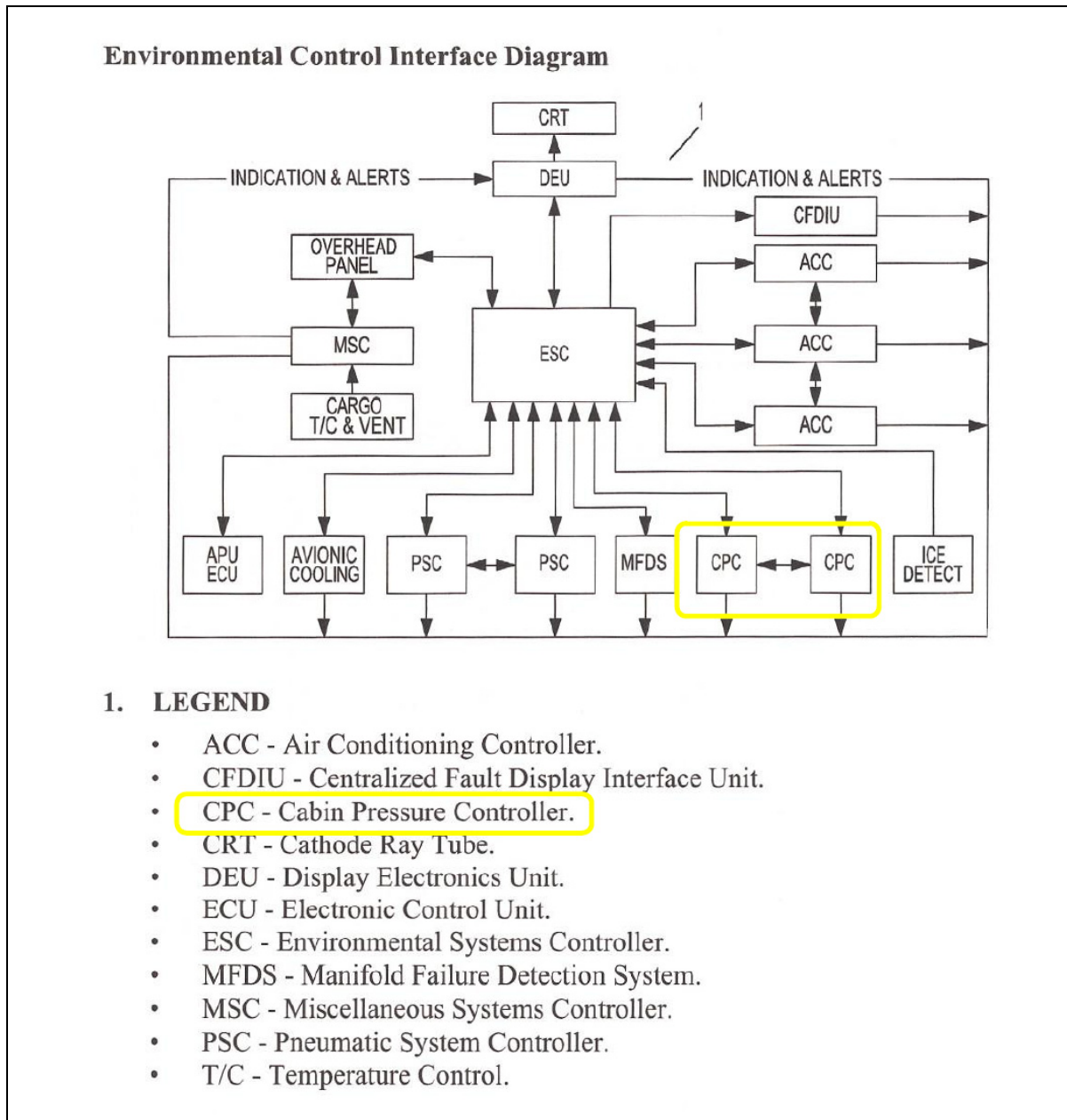
Manual #: 21-32-16 Rev: 3 Date: 07/25/2004

WORK PERFORMED / COMMENTS TO CUSTOMER

Workscope Performed / Summary of Actions Taken	CALIBRATED SENSOR WITH R3.
Action Taken Code	Repaired
Customer Confirmed Removal Reason	No
Evaluation Type	Evaluated - Minor Fault Found

Findings Report Cabin Pressure Sensor, P/N 2119708-1, S/N 65-337

Source: Honeywell



Environmental Control Interface Diagram

Source: Boeing Manual