CIAIAC

COMISIÓN DE
INVESTIGACIÓN
DE ACCIDENTES
E INCIDENTES DE
AVIACIÓN CIVIL

Report A-008/2013

Accident involving a BOEING B-757-300, registration D-ABOC, operated by Condor, at the Gran Canaria Airport on 22 March 2013

GOBIERNO
DE ESPAÑA

MINISTERIO
DE FOMENTO

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Foreword

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) regarding the circumstances of the accident object of the investigation, and its probable causes and consequences.

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.5 of Regulation (UE) nº 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1.4 and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it's not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

Consequently, any use of this report for purposes other than that of preventing future accidents may lead to erroneous conclusions or interpretations.

This report was originally issued in Spanish. This English translation is provided for information purposes only.

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Abbreviations

° ' "	Sexagesimal degrees, minutes and seconds
°C	Degree(s) centigrade
A-NPA	Advanced – Notice of Proposed Amendment
AAIB	Air Accident Investigation Board
AAME	Association of Aviation Medical Examiners (United Kingdom)
AC	Air conditioning
APP	Approach
APU	Auxiliary power unit
AQM	Air quality monitor
ARP	Aerospace Recommended Practice
ASD-STAN	Aerospace and Defense Industries Association of Europe – Standardization
ATPL(A)	Airline transport pilot license (airplane)
AV	Atrioventricular
ATC	Air traffic control
BALPA	British Airline Pilots Association
BFU	German aviation accident investigation authority
BRE	Building Research Establishment (United Kingdom)
BUN	Blood urea nitrogen
Ca2+	Calcium ion
CAA	British Civil Aviation Authority
CAAS	Civil aviation authority of Singapore
CFR	Code of Federal Regulations (United States)
CNS	Central Nervous System
CO	Carbon monoxide
COT	Committee on Toxicity (United Kingdom)
CPL(A)	Commercial pilot license (airplane)
CRD	Comment response document
CSIM	Critical incident stress management
CVR	Cockpit voice recorded
Dept	Department
DoCP	Di-ortho cresyl phosphate
EASA	European Aviation Safety Agency
EC	Short duration
ECG	Electrocardiogram
EMG/ENG	Electromyography/electroneurography
EMGFS	Single fiber electromyography
ESAM	European Society of Aerospace Medicine
eV	Electron volt
FA	Flight Attendant
FAA	Federal Aviation Administration
FDR	Flight data recorder
FH	Flight hours
FL	Flight level
FMS	Flight management system
ft	Feet
GCAQE	Global cabin air quality executive
GCLP	Code ICAO for Las Palmas airport (Spain)
h	Hours
HAM	Hamburg Airport
HEPA	High efficiency Air
hft	Hectofeet
HIL	Hold-item list
hPa	Hectopascals
H-TWA	Hours-time weighted average
IATA	International Air Transport association

ICAO	International Civil Aviation Authority
IFE	In-flight entertainment
IgG	Immunoglobuline G
IgM	Immunoglobuline M
ILS	Instrument landing system
INSHT	Spain's National Institute for Occupational Health and Safety
IOM	Institute of Occupational Medicine (United Kingdom)
IPCS/WHO	International Program for Chemical Safety of the World Health Organization
IR(A)	Instrument rating (airplane)
Kg	Kilograms
Kt	Knots
LD	Limits of deviation
LPA	Gran Canaria Airport
m	Meters
METAR	Meteorological Aerodrome Report
Min	Minutes
MoCP	Mono-ortho cresyl phosphate
N2	Rotational speed of the intermediate pressure shaft (rpm)
N3	Rotational speed of the high pressure shaft (rpm)
N	North
NM	Nautical miles
NPIS	National Poisons Information Service (United Kingdom)
NTE	Neurotoxic esterase
NW	Northwest
O_2	Oxygen
OP	Organophosphate
OPIDN	Organophosphate-Induced Delayed Neuropathy
OSHA	Occupational Safety and Health Administration (United States)
PEL	Permissible exposure limit
PF	Pilot flying
PM	Pilot monitoring
P/N	Part number
ppb	Parts per billion
ppm	Parts per million
PR	Interval between the start of the P wave until the start of the Q wave or of the R wave (electrocardiogram)
QT	Time elapsed between ventricular depolarization and repolarization
S	South
s	Seconds
SAE	Society of Automotive Engineers
S/N	Serial number
SVOC	Semi-volatile organic compounds
TBP	Tributyl phosphate
TCE	Tri-chloro-ethyl phosphate
TCP	Tricresyl phosphate
TIC	Tentatively identified compounds. Compounds that can be detected using analytical methods but whose concentration requires additional testing to be determined.
TOCP	Tri-ortho-cresyl phosphate
TVOC	Total volatile organic compounds
TWR	Control tower
U.K	United Kingdom
UFO	"Unabhängige Flugbegleiter Organisation" – Independent organization of flight attendants in Germany
UTC	Coordinated universal time
VLA-EC©	Short duration exposure environmental limit value
VLA-ED®	Short duration exposure environmental limit value
VOC	Volatile organic compounds
W/O	Work order

Synopsis

Operator:	Condor Flugdienst Gmbh
Aircraft:	Boeing B-757-300
Date and time of accident:	22 March 2013, 16:10 UTC[1]
Site of accident:	Gran Canaria Airport (Spain)
Persons onboard:	8 crew (1 seriously injured, 2 minor injured, 5 not injured), 242 passengers, not injured
Type of flight:	Air transport – Scheduled – International - Passenger
Date of approval:	31 May 2016

Summary of the event

During the approach to the Gran Canaria airport, a strong odor was detected in the cockpit and in the passenger cabin. Coinciding with this smell, several crewmembers felt physical discomfort. The approach was completed and the aircraft landed with no further problems.

The crew decided to conduct a test of the air conditioning system before boarding the passengers for the next flight.

As soon as they started the test, they smelled a strong odor and seconds later the cabin crew reported that the two crewmembers in the 2L/R positions were having physical problems.

The crew immediately disconnected the air conditioning pack and the APU bleed and opened all of the aircraft's door to ventilate it. Oxygen was given to the two cabin crewmembers and the control tower was asked to send an ambulance, which evacuated both crewmembers to the airport's medical office, where they were initially treated before being sent to a hospital.

As of the writing of this report, the two crewmembers who were most seriously affected remain unfit for work.

[1] Unless otherwise specified, all times in this report are in UTC, which is the same as local time.

The investigation into this accident determined that there is circumstantial evidence indicating that several crewmembers were affected by contaminated cabin air that was being supplied by the aircraft's air conditioning system.

As of the writing of this report the investigation was unable to find any evidence as to the source of this potential contamination or as to the hypothetical toxic compound involved.

1. FACTUAL INFORMATION

1.1. History of the flight

The Boeing B-757-300, registration D-ABOC, took off at 10:44 on 22/03/2013 from the Hamburg airport (Germany) on flight DE 5944 to the Gran Canaria airport. The aircraft was deiced immediately before takeoff. Onboard were 8 crewmembers and 233 passengers.

The takeoff, climb and cruise phases of the flight were uneventful and the aircraft started its approach to the destination airport. As it was descending, at an altitude of about 6,000 ft, the crew noticed a strong smell that was apparently issuing from the air conditioning outlets. The purser communicated with her colleagues, who had also noticed the smell. She then called the cockpit to report a strong smell in the passenger cabin. It made her feel sick and she was worried about passing out.

Approximately 2 minutes later, the first officer informed the captain that he was physically unwell, as he was feeling slightly dizzy. The captain recommended that he don his oxygen mask. The first officer agreed and, after donning the mask, felt an immediate improvement. The crew completed the landing without further problems. The first officer removed the mask while taxiing.

The passengers were disembarked and the crew started preparing for the next flight, whose destination was Hamburg.

The crew held a meeting, during which the captain asked each crewmember to rate their physical condition on a scale from 1 to 5, with 5 being "very bad". The results were as follows:

— 1L: 3 or 4.

— 2L: 4.

— 2R: could not say.

— 4L: 2.

— 4R: 2.

— 5L: 3.

All of them reported headaches and nausea.

The crew contacted the airline's maintenance department, which instructed the maintenance technicians to check the engines for a possible bird strike, as well as oil and hydraulic fluid levels, water/wastewater lines and HEPA[2] filters. All of the checks were normal, and so the crew decided to run a test of the air conditioning system.

Three of the crewmembers expressed a desire to be off the aircraft during the test, though this was not possible due to the short amount of time left to prepare for the flight. Since the engine run-up test was supposed to be undertaken at an outside parking position, the crew was asked to remain on board and at their stations to give a feedback to the cockpit and be available for the fast boarding of the passengers afterwards.

The crew coordinated with the control tower, which cleared them to do the test at position R1, which is next to the 03L threshold. A tractor towed the aircraft to that position, during which the aircraft only had the APU running. Onboard were all the crew, a maintenance technician and an operator from the airline's Gran Canaria base. Each crewmember was in position so they could immediately report any anomaly. Once at R1, the APU bleed and the left air conditioning pack were connected. As soon as this was done, a strong smell became noticeable and seconds later, the cabin crew reported that the two crewmembers in the 2L/R positions were having physical problems.

The air conditioning pack and APU bleed were immediately secured and all of the aircraft doors were opened to ventilate the cabin. Oxygen was administered to the two cabin crew and the control tower was asked to send an ambulance, which evacuated the two crewmembers to the airport's medical office, where they were treated initially before being sent to a hospital. They remained at the hospital until early the next day.

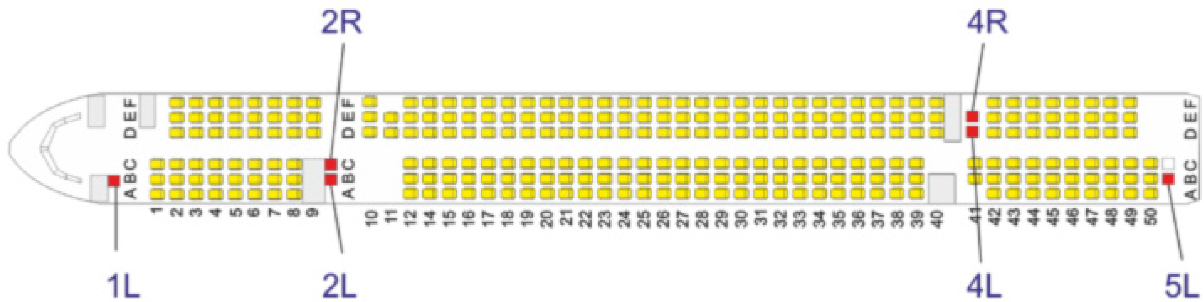

Figure 1. Seating map of the aircraft showing the positions of the cabin crew

The planned flight to Hamburg was canceled and a new flight was scheduled for the following day with a different aircraft that was flown in from Germany.

[2] High Efficiency Particulate Air.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal				
Serious	1			
Minor	2			N/A
None	5	242		N/A
TOTAL	8	242		

In April of 2013, the condition of the crewmember who had been in position 2R during the flight and engine test that took place on 22/03/2013 worsened, requiring her to be hospitalized. The symptoms presented were overall muscle fatigue, in particular of the lower limbs, difficulty walking, sensory disorder, trouble concentrating and general fatigue.

She was released from the hospital and continued treatment on an out-patient basis. The symptoms persisted and her health did not show improvement, even worsening at times to the point where she had to be hospitalized again.

Figure 2. Photograph of the aircraft at the Gran Canaria Airport

The crewmember in the 1L position initially felt only sick but did not suffer severe symptoms immediately after the event. This changed the next day, when she began to suffer symptoms of multiple paresthesia, cognitive disorders, rashes, chronic fatigue, lack of stamina, insomnia and night sweats.

As of the writing of this report, both crewmembers remain unfit for flight duty.

On the day after the event the operator tried to contact all the passengers of the flight and initially 30 of them were reached. Only one of those passengers reported a mild indisposition.

1.3. Damage to aircraft

The aircraft was not damaged in the event.

1.4. Other damage

There was no other damage.

1.5. Personnel information

1.5.1. Captain

- Age: 35
- Nationality: German
- License: ATPL(A), valid until 28/06/2015
- Ratings:
  - B757/B767, valid until 21/12/2013
  - IR, valid until 21/12/2013
- Class 1 medical certificate, valid until 21/02/2014
- Total flight hours: 7346
- Flight hours on the type: 544:6
- Duty hours in the previous 7 days: 26:59

1.5.2. First officer

- Age: 39
- Nationality: German
- License: CPL(A), valid until 20/09/2017
- Ratings:
  - B757, valid until 31/08/2013
  - IR, valid until 31/08/2013
- Class 1 medical certificate, valid until 5/05/2013
- Total flight hours: 597
- Flight hours on the type: 343:23
- Duty hours in the previous 7 days: 1:05

1.5.3. FA-1

- Age: 48
- Nationality: German
- License: B757/B767
- Total flight hours: 2013
- Position during the accident flight: 1L
- Duty hours in the previous 7 days: 25:44

1.5.4. FA-2

- Age: 19
- Nationality: German

- License: B757/B767
- Total flight hours: 709
- Position during the accident flight: 4R
- Duty hours in the previous 7 days: 00:00

1.5.5. FA-3

- Age: 35
- Nationality: German
- License: B757/B767/A320
- Total flight hours: 1574
- Position during the accident flight: 4L
- Duty hours in the previous 7 days: 23:18

1.5.6. FA-4

- Age: 44
- Nationality: German
- License: B757/B767
- Total flight hours: 2908
- Position during the accident flight: 5L
- Duty hours in the previous 7 days: 21:52

1.5.7. FA-5

- Age: 37
- Nationality: German

- License: B757/B767
- Total flight hours: 186
- Position during the accident flight: 2R
- Duty hours in the previous 7 days: 00:00

1.5.8. FA-6

- Age: 23
- Nationality: German
- License: B757/B767
- Total flight hours: 215
- Position during the accident flight: 2L
- Duty hours in the previous 7 days: 20:15

1.6. Aircraft information

1.6.1. General information

- Manufacturer: Boeing.
- Model: B-757-300
- Serial number: 29015
- Year of manufacture: 1998
- Certificate of airworthiness: valid until 19/10/2013
- Total flight hours: 43365
- Cycles: 15478
- Engines, number/manufacturer and model: two (2)/Rolls Royce RB211

Engine number	s/n	Total hours	Total cycles	Hours-cycles at last overhaul and date of overhaul
1	31718	28941	10676	23740 – 8977 July 2011
2	31553	41541	16335	32261 – 13331 February 2010

1.6.2. Maintenance information

The last maintenance inspection of the aircraft was the "Ramp check + 100 FH items", which was carried out on 22/03/2013, the day of the event, in Hamburg prior to the start of the flight from that airport to Gran Canaria.

At that time the aircraft had a total of 43360 flight hours.

1.6.2.1. Hold-item list (HIL)

Contained the following four entries:

- W/O 6309975. A notice to crews about vibrations in the cockpit. Explains that when the engine throttles are retarded to positions close to idle, the N3 vibrations can temporarily increase above 2.5 units and when the engine stabilizes, the vibrations fall below 2.5. This temporary increase in vibrations is considered normal and requires no action.

- W/O 6362172. Notifies crews that the carpet in the cabin, as well as the floor in the kitchens and bathrooms, had been replaced, which may result in a slight adhesive smell. This is normal.

- W/O 6360174. Notifies crews of new software installed on the IFE panel.

- 0675. Informs crews of an open item pertaining to wear or loss of placards in the cockpit.

1.6.3. Previous reports of odors in the cockpits of this aircraft

On 9 June 2012, this aircraft was making flight DE6412 from Dusseldorf (Germany) to Antalya (Turkey). With the aircraft established on FL 350, the crew smelled a strong burned plastic, accompanied by a heat surge in the cockpit, aft and forward galley. Emergency was declared and the pilots decided to divert to the Nuremberg Airport (Germany), which was some 45 NM southeast of their position, where they landed.

Emergency crews at the airport found no evidence or signs of fire or smoke, though they did confirm having smelled a strange odor in the cockpit.

1.6.4. Description of the cabin's environmental control system

During the cruise phase, transport aircraft fly at altitudes between 30,000 and 40,000 ft. At these altitudes, the outside air temperature is usually between -45° C and -55° C, while the barometric pressure is one-fourth that at sea level.

People would not be able to survive in these environmental conditions, so aircraft must have systems to condition the air inside the cabin to adapt it to human needs. This is typically done by pressurizing the cabin.

This system is tasked with maintaining the air pressure inside the cabin at no less than 750 hPa, equivalent to a pressure altitude of 2440 m, and the temperature at about 20° C. The relative humidity in the cabin is very low, between 5% and 20%. The air in the cabin is changed over about 15 times an hour.

The cabin environmental control system uses bleed air taken from the engine compressors or from the APU. It is usually at a temperature of 200° C and a pressure of 3100 hPa.

The environmental control system lowers the pressure and temperature of this bleed air before routing it into the cabin. It also maintains a suitable air pressure inside the airplane regardless of the altitude at which the aircraft is flying.

Transport aircraft and aircraft components are subject to certification specifications, which are to be followed by manufacturers. This also applies to the environmental control system, which needs to comply with specifications for cabin air purity. Cabin air has to be free of harmful or hazardous concentrations of vapours and gases.

These requirements (CS-25) have to be applied for the construction of the aircraft but not for the engine itself, although the bleed air comes out of the engine.

1.6.5. Inspection of the aircraft at the Gran Canaria Airport

The aircraft sent by the operator to replace the accident aircraft transported several airline technicians and their equipment so as to conduct a thorough inspection of the airplane.

These technicians, in the presence of two CIAIAC investigators, did an in-depth inspection of the aircraft without finding any problems. It was then decided to accurately reproduce the tests carried out by the crew to see if the odor could be made to reappear. During these tests an "Aerotracer" fume-detecting unit, brought by the airline's technicians, was employed. This unit is designed to detect volatile organic compounds found in aviation products, including specifically lubricating oils. An initial test was carried out with this unit connected only to the recirculation fan, during which traces of glycol and "Pattex", an adhesive, were detected.

Once at R-1, with the APU running, the APU bleed and the left air conditioning pack were connected. None of the people onboard noticed any unusual odors or experienced any physical symptoms. The fume sensor also failed to detect anything unusual, not even traces of the components detected the first time.

The air conditioning system was then checked with the remaining possible engine/APU bleed and air conditioning pack combinations at all engine power levels (from idle to take-off thrust). Nothing unusual was detected during the 50-minute long test.

The engines were checked again, along with the air conditioning ducts, hydraulic lines, APU, etc. The only finding of note was 5 liters of glycol that had pooled in the APU compartment. The glycol, possibly from a deicing treatment at the Hamburg Airport, was cleaned up.

1.6.6. Positioning flight to the Frankfurt Airport

On 26 March, four days after the event, a positioning flight was made by a full crew, different from the one involved in the event, to transport the airplane to Frankfurt, where the operator is based.

Onboard were also airline technicians who had traveled to inspect the aircraft, as well as all the equipment they had taken with them, which included Aerotracer and GrayWolf sensors, which were in use the entire flight.

When the crew boarded the aircraft to start the flight, they did not notice any unusual smells and none of the occupants felt any physical symptoms at that time.

During the taxi phase the smell returned, though it stopped some 3 minutes after the air conditioning packs were connected.

The Graywolf sensor recorded increases in TVOC coinciding approximately with those times when the strange odor was smelled by the occupants.

Around 1:40 h into the flight, they entered an area of slight turbulence, immediately after which an odor filled the entire cabin that was so intense that the pilots decided to don their oxygen masks.

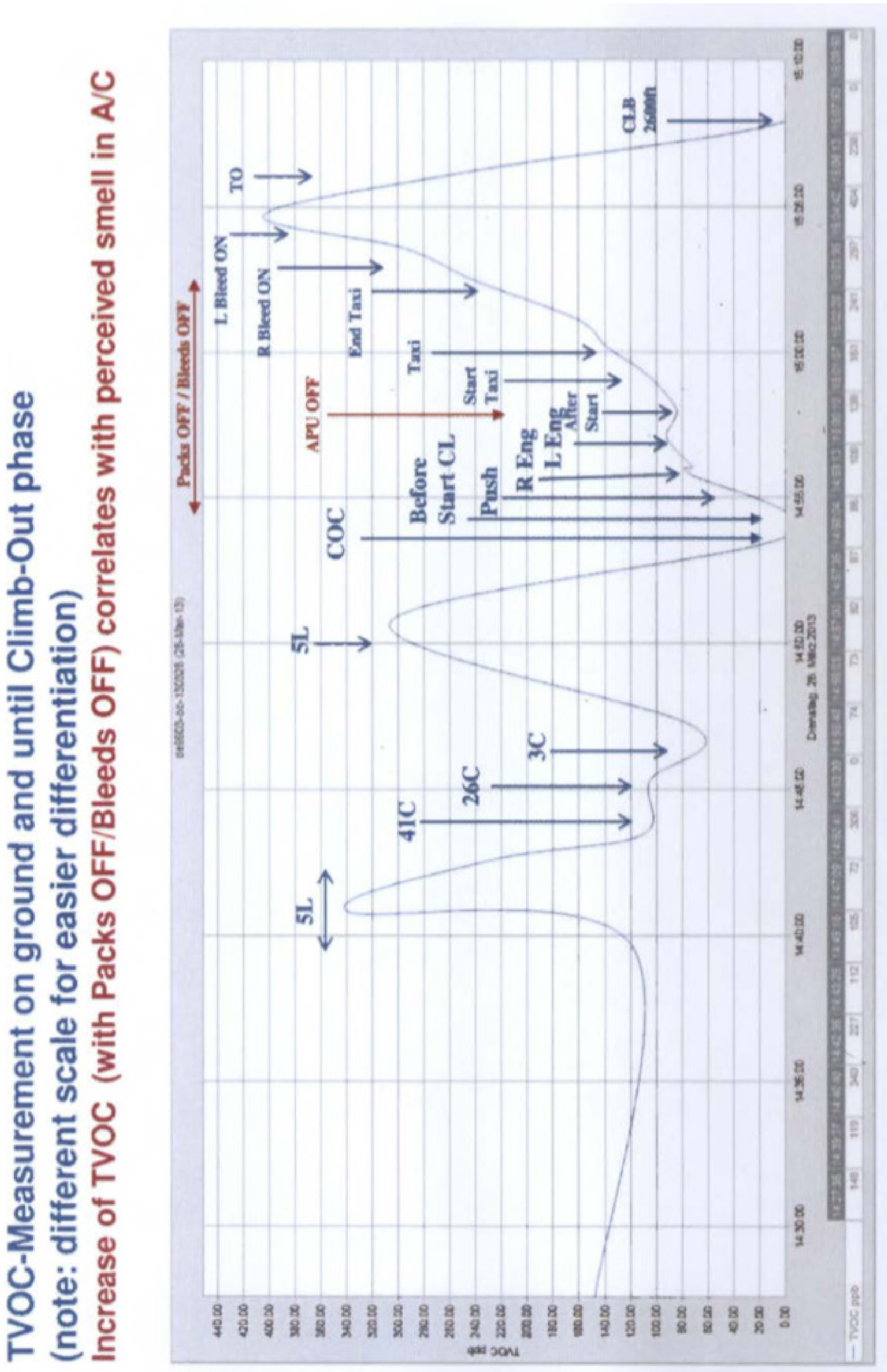

Figure 3. Graph with the TVOC readings of the Graywolf sensor from the time the crew boarded the aircraft until the initial climb phase

Even so the first officer felt his tongue going numb and irritation in his throat. These same symptoms were also reported by the purser.

The turbulence stopped after about 10 minutes, with the odor disappearing immediately afterwards. The pilots removed their oxygen masks. The symptoms affecting the tongue and throat of the first officer and purser likewise disappeared.

While descending into the Frankfurt Airport the odor returned, and both pilots once more donned their oxygen masks. The purser felt her fingers go numb. The odor cleared up by the time they reached 6000 ft and the landing was completed without further incident.

No one else onboard felt any physical symptoms during the two fume events that occurred during the flight.

After landing the operator proposed that all of the occupants who had been onboard undergo a medical exam. This proposal was rejected since by then, all of the symptoms had disappeared in the individuals who had experienced them.

Neither the GrayWolf nor the Aerotracer sensor indicated the presence of TVOCs and/or compounds from aviation products during the final two fume events (second and third) that occurred during the flight.

The reason why the Graywolf did not give any indications during these phases could be because the odor was caused by compounds that are not ionized in the unit's probe (those with an ionization energy higher than 10.6 eV). Examples of such compounds include the following:

- Chlorodifluoromethane
- Chloroform
- Dichlorodifluoromethane
- Formaldehyde
- Methane
- Methanol
- Nitroethanol
- Nitromethane
- Nitropropane, 2-
- Propane
- Tetrafluoromethane

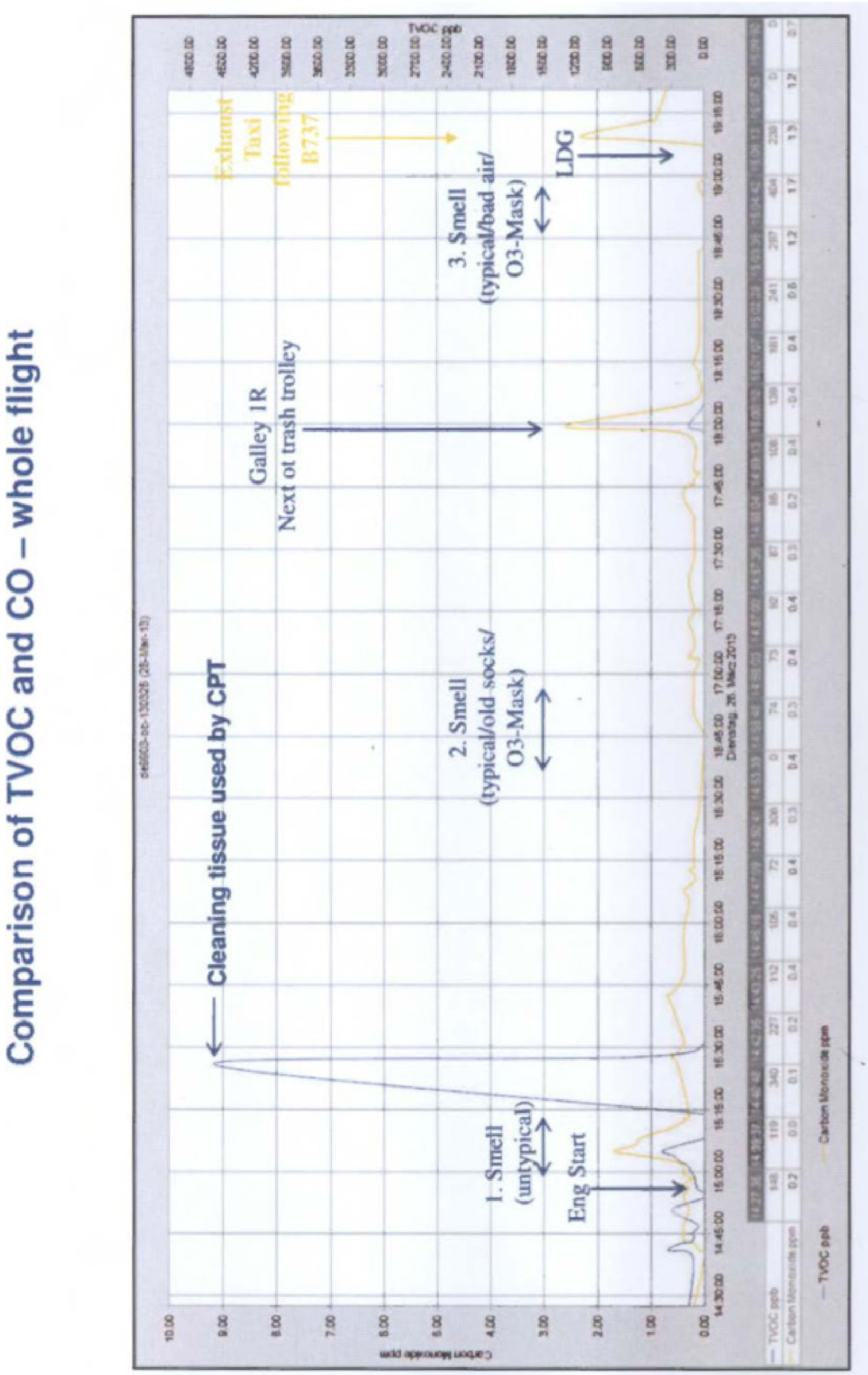

Figure 4. Comparison of TVOC and CO readings throughout the flight

1.6.7. *Inspection at the Frankfurt Airport*

The aircraft landed at the Frankfurt Airport the afternoon of 26/03/2013.

The following morning, Condor asked the airport's firefighting service to test the air in the aircraft's cabin. The airline informed the service that during the flight to Frankfurt, the crew had noticed an undefinable sweet-acrid smell, with some of them reporting headaches and numbness of the finger tips.

That same day the firefighting service personnel went to the aircraft, which had been parked on the apron overnight. When the firemen arrived, the aircraft's doors were open. The temperature inside the cabin was 9° C. The findings from their inspection were as follows:

- No specific odor was detected inside the aircraft.
- The portable gas detection equipment did not detect anything unusual.
- Several air samples were taken and sent to a laboratory. The analyses detected only traces of tetrachloroethylene, a compound normally used in adhesives or cleaning products. It has a sweet smell that could account for the odor described by the crew.

However, given the time that had elapsed since the event, the reliability of the results was low.

After returning to the Frankfurt Airport, three more test flights were conducted, with no problems detected.

It was decided to do another test flight, but with a deicing treatment prior to the flight to more closely mirror the conditions of the accident flight, which included a deicing treatment. During the deicing application, the APU was running. A large amount of de-icing fluid was intentionally sprayed into the APU inlet.

This time a large amount of smoke entered the cabin, both on the ground with the APU supplying the air conditioning packs, and in flight, with the air supplied by the engines. The Gray Wolf displayed a rise in TVOC values.

Only one occupant onboard the aircraft showed any physical symptoms during the event, namely, a headache. This person donned an oxygen mask, which immediately alleviated the symptom. No one else onboard felt any symptoms or resorted to using oxygen.

In light of the results of this test, the operator decided to prohibit deicing treatments with the APU running.

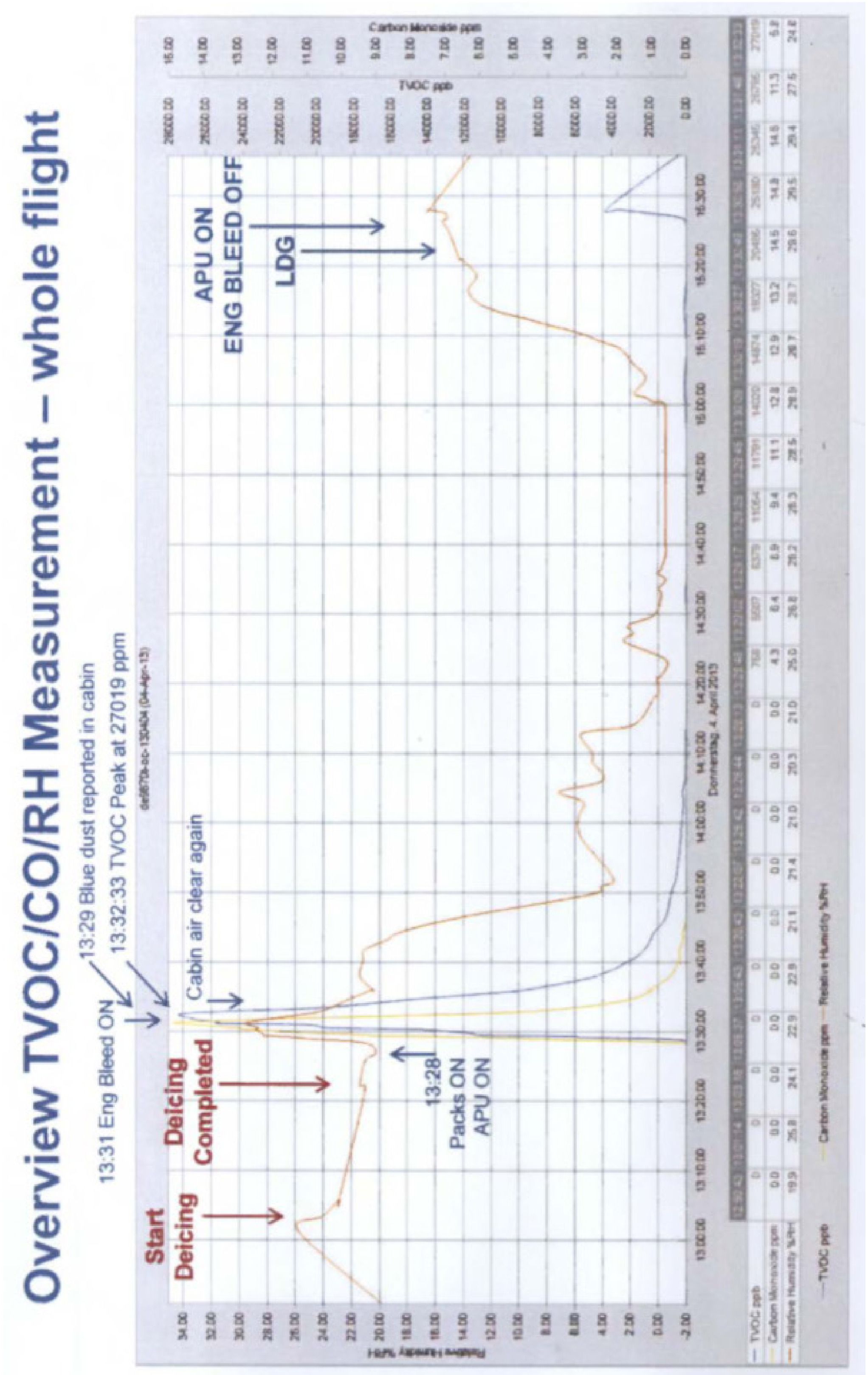

Figure 5. TVOC, CO and relative humidity readings during the flight of 04/04/13, which had undergone a deicing treatment

The operator then requested assistance from the aircraft manufacturer, Boeing, which deployed a team of specialists to the operator's base at the Frankfurt Airport.

Several air samples were taken inside the cockpit and cabin, both with the aircraft on the ground and in the air[3].

This team inspected the aircraft and verified the presence of a unique odor inside the cabin. Although the source of the odor could not be determined, a precautionary decision was made to replace the main components of the air conditioning system and the APU, as well as to clean the cabin.

These elements were later inspected, although anything remarkable was found.

Several test flights were then conducted without any unusual odors being smelled in the cabin and with none of the occupants feeling any symptoms.

The aircraft was returned to service. According to the data provided by German authorities, for the remaining part of 2013 there have been five other smell/fume/smoke reports filed by the crews flying this particular aircraft.

1.7. Meteorological information

The weather situation on the island of Gran Canaria the day of the event was as follows: cloudy periods; probability of light showers, mainly in the north; moderate wind from the northwest, strong at times, affecting the north and northeast (including the capital) from the coast to the summits; while variable, weak winds would predominate on the rest of the island, with breezes along the coasts. In the evening, the wind would be moderate from the north, becoming strong at times in the east and west and remaining weak in the south, and decreasing in the north.

In the rest of the archipelago, the most significant weather conditions were as follows: average wind speeds on the surface in excess of 30 knots (kt) northwest of the Teide, moderate turbulence between 60 and 110 hectofeet (hft) north of 27°30′ N, large areas of clouds with bases at between 30 and 35 hft and tops at 70-80 hft NW of La Palma, N of El Hierro, La Gomera and Tenerife.

The METARs issued for the Gran Canaria Airport between 15:30 and 19:30 on the day of the event were as follows:

GCLP 221530Z 03019KT 9999 FEW025 BKN035 20/12 Q1015 NOSIG

[3] With the exception of the analyses during the ground inspection at Gran Canaria airport, the measurements and taking of air samples took place without the supervision of a safety investigation authority.

GCLP 221600Z 01016KT 9999 FEW025 BKN045 20/11 Q1015 NOSIG

GCLP 221630Z 02016KT 350V050 9999 FEW025 BKN045 21/11 Q1015 NOSIG

GCLP 221700Z 02018KT 9999 FEW025 BKN042 20/10 Q1015 NOSIG

GCLP 221730Z 36015KT 320V020 9999 FEW025 BKN045 20/10 Q1015 NOSIG

GCLP 221800Z 36015KT 9999 FEW025 BKN042 20/10 Q1015 NOSIG

GCLP 221830Z 36014KT 9999 FEW025 BKN042 20/10 Q1016 NOSIG

GCLP 221900Z 36013KT 320V020 9999 FEW025 BKN042 19/10 Q1016 NOSIG

GCLP 221930Z 35013KT 9999 FEW025 BKN042 19/10 Q1016 NOSIG

1.8. Aids to navigation

Not applicable.

1.9. Communications

The initial contact with approach control was at 15:49:19, with the aircraft at that moment descending through FL195 to FL130.

The remaining communications between the aircraft and ATC stations (approach and the control tower) were completely normal and provided no information of any relevance to the investigation of the event.

The last communication took place at 16:06:53, when the controller instructed the pilot to follow the marshaller to stand T04.

At 17:51:39 the crew called the control tower reporting technical problems and requesting to do a wide range of engine tests.

This was followed by several communications between various stations at the airport and the crew to coordinate the tests.

The most relevant communications that took place afterward are outlined below:

At 18:12:33 the controller cleared the aircraft for pushback.

At 18:35:17 the crew called the tower to request permission to start the tests, which the tower granted immediately.

At 18:36:08 the crew informed the controller that they were having additional problems and could not proceed with the engine start-up.

At 18:41:12 they called the tower requesting an ambulance.

After the evacuation of the three affected crewmembers, the tests were resumed on the aircraft.

At 19:34:11 the crew called the tower to report the completion of the tests.

Finally, at 19:49:24 the marshaller called the TWR to report that the aircraft had finished taxiing to stand T14, where it would be parked.

1.10. Aerodrome information

Not applicable.

1.11. Flight recorders

1.11.1. Flight data recorder

The aircraft was equipped with an Allied Signal solid-state flight data recorder, P/N 980-4700-042 and S/N 5613, which records a little over 1000 flight parameters. The FDR was downloaded at the CIAIAC laboratory.

It was verified to contain valid data on the flight in question.

The information contained in the recorder did not indicate the presence of any abnormalities.

Figure 6 shows a graph of the values for several outside air parameters (pressure altitude, outside temperature, total pressure, static pressure), as well as for aircraft systems (N2 for both engines, position of the engine bleed valves, automatic cabin pressure fault indications, and agreement between the positions of the APU bleed valves and bleed isolation valves). The graph spans from the time the aircraft was on approach at an altitude of 10,000 ft until seconds after landing.

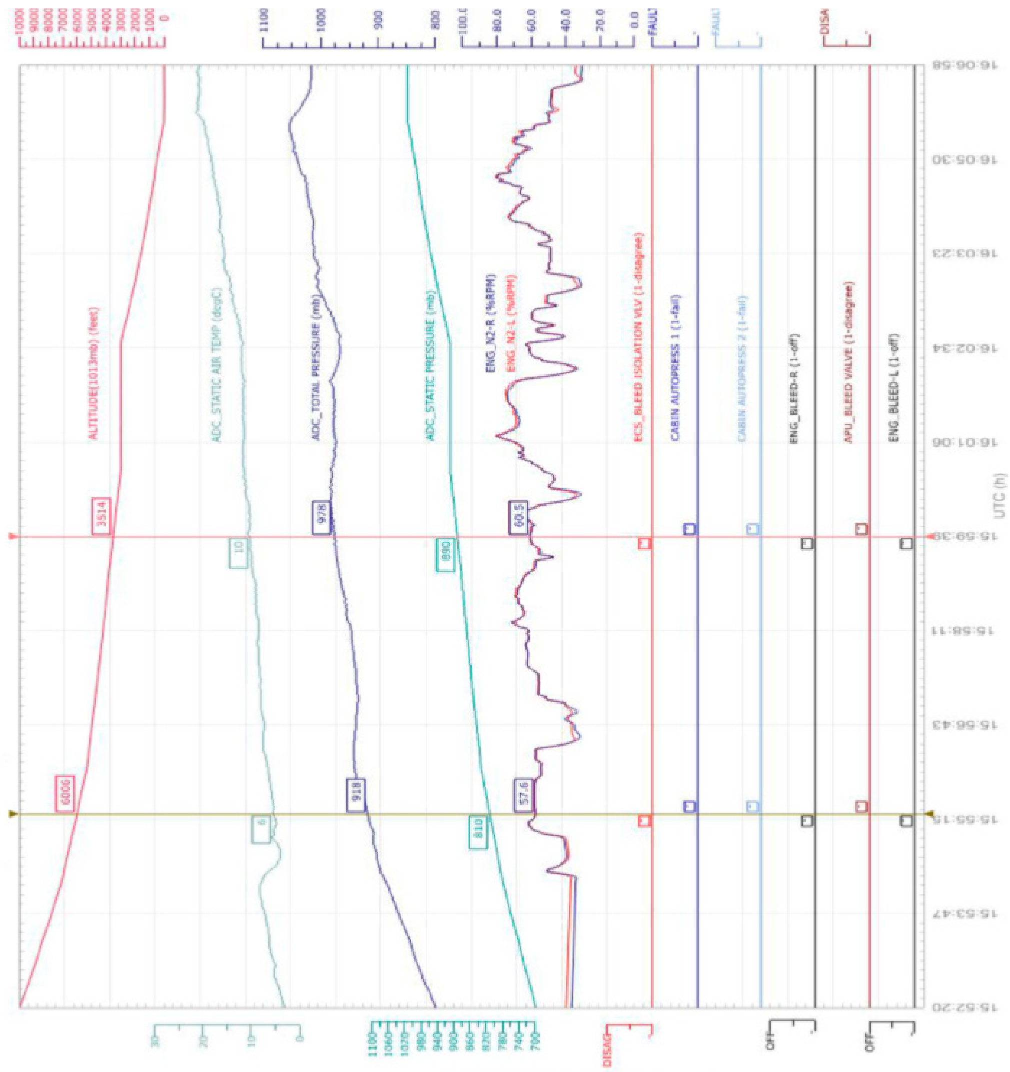

Figure 6. Graph showing several parameters during the approach

1.11.2. *Cockpit voice recorder*

The aircraft had an Allied Signal four-channel, solid-state cockpit voice recorder (CVR), P/N 980-6022-001 and S/N 105. Channels 1, 2 and 3, lasting 30 minutes each, recorded the signals from the crewmembers' communications microphones and the passenger address system in high quality. Channel 4, with a 2-hour duration, recorded the sounds from the area microphone in medium quality.

The recorder was verified to contain recordings of the flight in question, though they started after the event had occurred. This is because after the accident, the CVR continued recording for longer than the available duration, resulting in the previous information being overwritten.

Most of the conversations were in German. Only the communications with ATC and some conversations with maintenance personnel were in English.

The recordings were reviewed by an investigator with the German Federal Bureau of Aircraft Accident Investigation (BFU), who concluded that they contained no information of use to the investigation.

1.12. Wreckage and impact information

Not applicable.

1.13. Medical and pathological information

The two flight attendants and the first officer who were affected immediately during the fume event were initially taken to the medical office at the Gran Canaria Airport, from where they were taken by handling company personnel to a hospital in the city of Las Palmas, where they met the first officer. Due to the late hour, the laboratory at this hospital was already closed and no tests were done. As a result, they were taken to the Clínica del Perpetuo Socorro, where they were treated in the emergency room. All three of them left the hospital after midnight and went to meet the other crew members for an operational debriefing in the hotel.

1.13.1. Captain

The captain did not experience any symptoms during the event thus he did not ask for medical treatment in Las Palmas. After arriving in Hamburg on the next day he went to a hospital with the two other crew members as a precaution. He was not seen by a physician that night but the blood and urine analyses carried out were evaluated as normal.

He continued to fly.

About one week later he experienced light neurologic symptoms in hands and knees, which disappeared after a few days and six weeks respectively. Since then he is free of symptoms (see 1.18.1).

1.13.2. First officer

He did not exhibit symptoms.

Neither the physical exam nor any of the diagnostic tests carried out revealed anything out of the ordinary.

- Physical exam: normal.
- Hemogram: normal.
- Serum cholinesterase: normal.
- Urine: normal.
- Venous blood gas: normal.

He also was not seen by a physician that night in the hospital, but a urine and blood analysis was carried out. The results from both analyses were evaluated as normal.

He remained free of symptoms and continued to fly.

1.13.3. FA-1

The flight attendant did not ask for medical treatment in Las Palmas. After arriving in Hamburg on the next day she went to a hospital together with three other crew members.

She was not seen by a physician that night but results of the blood and urine analyses carried out were evaluated as normal.

The next day (Sunday) she experienced several neurological and cognitive symptoms. On Monday she went to see her family physician, where she was given a sick note "unfit to fly".

She never recovered and finally became "permanently unfit to work."

1.13.4. FA-2

The flight attendant did not ask for medical treatment in Las Palmas. After arriving in Hamburg on the next day she went to a hospital and was given a sick note "unfit to fly until 26 March 2013".

She recovered completely and remained free of symptoms.

1.13.5. FA-3

The flight attendant did not ask for medical treatment in Las Palmas. After arriving in Hamburg on the next day, she went to a hospital with FA-2.

She felt a little twitchy and used her following scheduled off-days to relax.

After those days, she went flying again and remained free of symptoms.

1.13.6. FA-4

The flight attendant did not ask for medical treatment in Las Palmas. After arriving in Hamburg on the next day she went to a hospital with three of her crew members.

She was not seen by a physician that night but the blood and urine analyses carried out revealed nothing out of the ordinary.

The next day she went to see an accident insurance consultant (mandatory in Germany) and subsequently her family physician, where she was given a sick note "unfit to fly until 2 April 2013."

She recovered completely and remained free of symptoms.

1.13.7. FA-5 (2R)

She received initial medical treatment in a hospital in Las Palmas. The physical exam was normal, with O_2 saturation at 98%.

The examination of the extremities was normal.

Neurological exam. Unstable walk with a wide gait, bending of the knees, discrete left lateralization with eyes closed which the patient corrects.

- Hemogram: normal
- Serum cholinesterase: normal
- Urine: normal
- Venous blood gas: normal
- Carboxyhemoglobin: 3%

The doctor diagnosed the patient with gait and balance problems.

After arriving in Hamburg on the next day she went to a hospital with her crew members.The neurological exam administered to her revealed proximal muscle weakness and paresthesia in the lower limbs, as well as an unsteady gait and fatigue. Her diagnosis was "polyneuropathy due to other toxic agents". Although the hospital wanted to take her stationary she insisted on being brought home to Berlin. She was put in a taxi and driven to Berlin, where she arrived around 4 o'clock in the morning. After a short sleep she went to the Charité Hospital in the morning, where she became admitted until 28 March 2013.

She also underwent a conventional electromyography/electroneurography (EMG/ENG), which was normal, as well as a single fiber EMG (EMGFS) pathological.

On 15 April she was again admitted to this hospital.

Physical and neurological exams normal (including mobility and coordination), except walking and standing: slow, lurching gait, unsteady, unable to stand on one foot, unable to walk a straight line. Unterberger[4] test failed Pallhypesthesia[5] 5/8 in lower limb.

The chemical laboratory analyses were normal (they did not include cholinesterase).

A magnetic resonance scan of the brain showed nonspecific minimal gliosis in the front left white matter, irrelevant. A new EMGFS was also performed that showed a slight dysfunction in neuromuscular transmission. Altogether, 31 single fiber measurements were performed. As a whole, a pathological Jitter was verified twice (one of 65 µs, and the other of 73.8 µs), as well as two blocks. The medium Jitter was found in the first EMG single fiber analysis at 33 µs, and the second one at 28.8 µs.

This hospital's diagnosis was:

"In our general assessment, considering the existing bibliography, after checking the patient's anamnesis and symptoms, everything points to poisoning by tricresyl phosphate. Proof of this is also found in the abnormalities found in the single fiber EMG, since the toxic metabolite of tricresyl phosphate is an irreversible acetylcholinesterase inhibitor, which can lead to a dysfunction in neuromuscular transmission caused by tricresyl phosphate."

The diagnosis report, however, acknowledges that tricresyl phosphate poisoning is hard to prove using currently available techniques".

A blood sample from this flight attendant was sent to Dr. Abou-Donia in the United States, who specializes in neurotoxin poisoning, and specifically in determining methods

4 The Unterberger test has the patient close their eyes and walk in place. It is used to assess balance.

5 Pallypesthesia refers to a pathologic reduction in sensitivity.

for identifying the damage to the nervous system that these substances can cause.

Dr Abou-Donia reported that he had analyzed the presence in the patient, in comparison to healthy control subjects[6], of various antibodies against specific nervous system proteins related to neurogenesis, myelogenesis and gliogenesis. The report states that these antibody concentrations were relatively elevated versus the healthy control subjects[7]. In the table of results, the highest percentages versus the control group were for antibodies against myelogenesis proteins, followed by gliogenesis proteins.

These results do not serve to diagnose any specific disease; however,according to Dr Abou-Donia, if there is a history of exposure to chemical compounds and neurological symptoms, they can be used to support a diagnosis of chemically induced brain damage, and that the increased concentration of these antibodies in the blood is compatible with neuronal injury.

She never recovered and finally became "permanently unfit to work".

1.13.8. FA-6 (2L)

She received initial medical treatment in a hospital in Las Palmas. The general exam was normal. O_2 saturation was 98%.

The exam of the extremities was normal.

Neurological exam. Unstable walk with a wide gait, discrete left lateralization with eyes closed which the patient corrects.

- Hemogram: normal
- Serum cholinesterase: normal
- Urine: normal
- Venous blood gas: normal

After arriving in Hamburg on the next day she went to a hospital where she stayed overnight. Her diagnosis was "polyneuropathy due to other toxic agents". She left the hospital the next day with a sick note "unfit to work" until 2 April 2013.

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[6] The size of the control group is unknown. Whether the antibodies are of the IgG or IgM (acute phase) type is also not specified.
[7] Between 428% and 3,231 %

Due to continuous health problems she went to see her physician, who diagnosed a severe reduction of functional lung parameters.

She began working soon again. During one of her flights on a company's B757 she suffered a severe lung relapse. She went through lung treatment and changed to fly another aircraft type. While continuing to fly her state of health declined and she often had to call in sick. By the end of the year she had to terminate her work contract.

She made one more attempt with another airline, where she intended to fly long-distance flights only. Since her fear of another medical recidivism increased, she finally gave up working as a flight attendant for good and is now working at her parents' business.

1.14. Fire

There was no fire.

1.15. Survival aspects

Not applicable.

1.16. Tests and research

1.16.1. Analysis of cabin air samples

Several air samples from the aircraft's cockpit and cabin were analysed by electrochemical gas sensors (Aerotracer, GreyWolf) and gas chromatography (see sec. 1.6.6 and 1.6.7).

1.16.1.1. Analyses from the initial events's air

No cabin air monitoring data are available covering the first fume event during the approach into Gran Canaria airport on 22 March 2013. The same holds true for the subsequent tests of the engines and APU with different power and air conditioning switch settings by the flight crew and a mechanic on the ground at Gran Canaria, once the cabin crew had left the aircraft. These tests were stopped by order of the BFU and the aircraft was secured.

1.16.1.2. Analyses from the ground inspection air at LPA

After that, the aircraft underwent a close inspection in presence of CIAIAC investigators (see 1.6.5). Cabin air monitoring was performed using an Aerotracer fume detecting device at different power and switch settings for engines, APU, and the air conditioning system. At the initial test traces of glycol and an adhesive were detected. During the subsequent tests no traces of any air contamination were indicated.

During a subsequent inspection of the APU approximately five litres of de-icing fluid (mainly propylene glycol) were removed from the APU compartment.

1.16.1.3. Analyses from the positioning flight air samples

On 26 March 2013 the positioning flight to Frankfurt/Main (Germany) took place. During this flight, three fume events were observed.

The first strange odour occurred during taxiing but disappeared some three minutes after the air conditioning packs were connected during the initial climb phase. Total Volatile Organic Compounds (TVOC) had been recorded by the use of a GreyWolf sensor (see fig. 2). No other symptoms were documented for the crew and passengers. There are no data available from the Aerotracer device.

The second fume event occurred during the cruise phase while flying through slight turbulences. During the next ten minutes the flight crew donned their oxygen masks due to the onset of perceived symptoms (see sec. 1.6.6).

The third and final fume event occurred during the descent into Frankfurt/Main airport. Again, the pilots donned their oxygen masks until the odor disappeared when passing 6000 feet.

During the last two fume events neither of the two measuring devices indicated the presence of TVOCs.

1.16.1.4. Analyses from the ground and inflight air samples

After the return of the aircraft to Frankfurt/Main additional tests were undertaken (see 1.6.7). Prior to one of the test flights de-icing fluids were applied. In this flight fume entered the cabin, one person experienced symptoms (headache), which immediately alleviated after the patient donned an oxygen mask. According to figure 5 the TVOC peak reached a height of 27.019 ppm on this flight.

The air samples taken in the aircraft's cabin were analyzed using gas chromatography, which identified the following gases at the maximum concentrations shown:

Compound	Maximum concentration (ppb)
Acetone	429
Benzene	2.49
Benzene. 1-ethyl-3-methyl	7.2
Benzyl Chloride	0.42
Bromomethane	2.8
Butanone. 2-; MEK	289
Butoxy ethyl acetate. 2-; 1-methyl-4-(1-methylethyl)-benzene)	16.6
Chlorobenzene	11.2
Decane	15.2
Dodecane	22.7
Ethyl Acetate	48.7
Ethylbenzene	2.54
Heptane	3.57
Hexadecenal. 7-	13.5
Hexane	40.3
Methyl isobutyl ketone	6.31
Methylene Chloride	7.8
Nonanal	1.7
Styrene	14.3
Tetrachloroethylene	150
Tetrahydrofuran	11.9
Toluene	98.3
Trimethyl benzene. 1.2. 3	28.2
Trimethyl benzene. 1.2.4	3
Trimethyl benzene. 1.3.5	28.2
Undecanal	2.8
Undecane	29.8
Vinyl Acetate	42.4
Xylene. o-	17.9

1.16.2. *Analysis of samples of liquids used to deice aircraft*

Four samples of different liquids used to deice aircraft were sent to a laboratory, where they were analyzed using gas chromatography/mass spectrometry, in an effort to determine what volatile organic compounds (VOC) were given off when heated to 200º C.

No compounds other than glycol, which is the main component in deicing liquids and whose toxicity is described in section 1.18.9.2, were detected when heated to 200ºC.

1.16.3. *Inspection of the APU*

The APU was sent to the facilities that the manufacturer, Honeywell Aerospace, has in Phoenix (United States) for evaluation.

The APU was analyzed using various methods to determine if the engines were generating any toxic gases.

The tests involved monitoring the air at the intake of the APU and the engine bleed air simultaneously in an effort to detect the presence of compounds that could have been generated by the engine. Samples were also taken at these two points. These tests and samples were carried out during three different stages of APU operation: minimum environmental controls, maximum environmental controls and main engine start.

The samples were analyzed using four different techniques: air quality monitoring (AQM), high-efficiency liquid chromatography, gas chromatography and mass spectrometry.

Additionally, part of the air at the intake and at the bleed was routed to a nearby room for olfactory evaluation by a group of eight people.

The results were as follows:

- The AQM identified several CO_2 concentration peaks in the bleed air in excess of the concentration at the motor intake. These were detected during the "main engine start" mode. Two were in the 3-15 ppm range, another was 5 ppm and the fourth was 25 ppm.

In the manufacturer's experience, CO_2 peaks below 10 ppm rarely lead to odor complaints.

- Formaldehyde and acetaldehyde were detected in every sample except for those taken during the "main engine start" operation. The average values of these compounds were between 4.1-6.3 ppb[8] and 1.8-2.5 ppb, respectively. These values are well below

[8] Parts per billion (American), equivalent to a thousand million.

the odor detection threshold, which is 830 ppb for formaldehyde and 50 ppb for acetaldehyde. These values are also below 1/10 of the 8-hour total weighted average permissible exposure limit (PEL) set by the U.S. Occupational Safety and Health Administration (OSHA).

- Tricresyl phosphate isomers were detected only during the "main engine start" operation, in the 0.0090-0.255 ppb range, which is well below the OSHA-PEL, which is 6.6 ppb.

- Traces of multiple compounds and TICs9 were detected, with the highest levels being for isopropyl alcohol (2-propanol), acetone, butanone, toluene and carbon disulfide, all of which were below the odor perception threshold.

- The only smell reported by any of the participants was a "dirty" smell, with no reference being made to an "oily" smell.

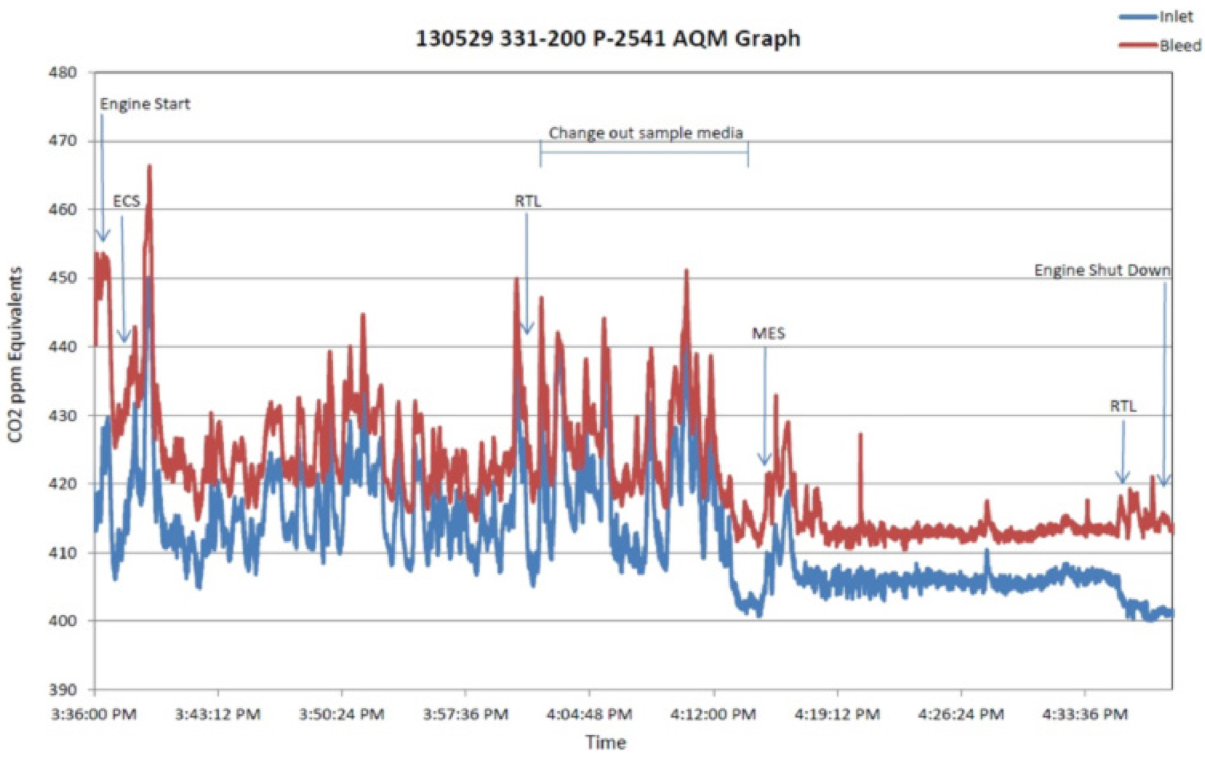

Figure 7. Results of the AQM

1.17. Organizational and management information

Not applicable.

[9] Tentatively identified compounds. These are compounds that can be detected using analytical methods but whose concentration can only be determined using additional tests.

1.18. Additional information

1.18.1. Captain's statement

The flight's callsign was DE5944 and it took off from Hamburg (HAM) to Las Palmas (LPA) at 10:44 UTC, nine minutes after its scheduled departure time and being de-iced.

The aircraft took off with two entries in the HIL (see 1.6.2.1). The captain had requested a technician to come on board because there had been a humming sound at door 1R. The aircraft had 8 crewmembers and 242 passengers onboard.

They had taken on 24.5 tons of fuel. This included 706 kg of extra fuel. The captain was acting as the pilot flying (PF) while the first officer was the pilot monitoring (PM).

The flight was uneventful until the approach phase. They were cleared by ATC to perform standard terminal arrival SAMAR4C, which they planned by inserting the data into the FMS, along with the ILS Z approach to runway 03L. They did the approach briefing and carried out the appropriate items in the descent checklists.

Canaries APP cleared them to descend to 4000 ft following radar vectors. They were instructed to hold heading 165 east of the island.

After descending through 6000 ft, they suddenly noticed a strong smell from the air conditioning outlets just as they were passing through a thin cloud layer.

He was the first to notice it and informed the first officer, who confirmed smelling the odor a few seconds later. Immediately afterward the purser called the cockpit to report smelling the same odor in the passenger cabin.

About two minutes later the first officer reported feeling unsure about his physical condition, and mentioned that he was feeling a little dizzy.

The pilot recommended that he don his oxygen mask as a preventive measure, which the first officer did, feeling immediately better. Neither pilot was incapacitated at any time during the flight.

The captain did not feel any symptoms and landed the airplane safely following a stabilized ILS approach to runway 03L. The airplane touched down at 17:04 UTC.

The first officer removed the oxygen mask while they were taxiing. They recorded an actual in-block time at stand 4 of 17:10 with 5 tons of fuel remaining. The passengers disembarked normally via the jetway into the terminal building.

He had not noticed any unusual engine readings during the event.

They decided not to declare an emergency due to crewmember incapacitation since the first officer did not feel unable to carry out his duties at any time, and they were not aware at that time of the odor having had an effect on any of the flight attendants.

After the passengers were disembarked, the crew prepared for the next flight (walkaround, refueling, cleaning, etc.), but ground personnel were informed that they were not ready to board the passengers yet.

The entire crew was gathered and each gave their own impression about the unidentified smell and whether it had caused them any physical discomfort.

The captain coordinated any potential actions to isolate the problem with the station in Frankfurt. They checked for a possible bird impact, verified the oil levels in the engines/APU to see if the tank had been overfilled, checked the drinking and wastewater lines and inspected the condition of the HEPA filters in the forward compartment. None of these checks revealed any problems.

The next test proposed was a check of the air conditioning with the packs connected to the engines in different configurations. They would also check the configuration with the packs connected to the APU.

After coordinating with the airport, the aircraft was towed to position R1, next to runway 03L. Once there, all of the crewmembers sat in their respective positions so they could report if the smell reappeared during the test and where it was coming from.

He stated that they evaluated the potential risk to the crewmembers before connecting anything and that they agreed to secure all air bleeds and the AC packs immediately if the smell was detected again.

When they connected the APU bleed to the left pack, the intense smell reappeared and seconds later they received a call from the passenger cabin, reporting not only the detection of the smell but also health problems involving the two flight attendants seated in the 2L/R positions. All of the bleeds and packs were disconnected and he requested that the doors be opened to ventilate the aircraft.

When he left the cockpit to check on the condition of the two affected crewmembers, they were already using portable oxygen bottles at a high flow rate. Both remained conscious.

The first officer called the tower to request an ambulance and stairs so they could leave the airplane in that remote position. The medical service arrived some 15 minutes later, taking the two affected crewmembers, accompanied by a third crewmember, to the airport's medical station.

The remaining crewmembers were taken by bus to the terminal while technical and maintenance personnel remained onboard to conduct the engine test and locate the source of the odor. They ran the test with the engines running and using different bleed and air pack configurations, but the odor appeared and then faded without providing any clues that could help them isolate the problem.

During this test they received a phone call from Frankfurt with instructions from the BFU to stop all maintenance actions, take the airplane to a parking stand and close it up until the investigation team arrived.

All of the crewmembers who had not been affected met at the terminal and were taken to the hotel after a short briefing.

The flight crew went to a hospital where the first officer could undergo a medical examination and so they could check on the two injured flight attendants. Once there the FA who was accompanying the other two was sent to the hotel. The affected FAs, after a long night undergoing medical tests, arrived at the hotel at 03:30.

The CSIM (Critical Incident Stress Management) team was informed so that it could meet with the crewmembers upon their return to Hamburg, scheduled for the following afternoon.

When they were picked up for the ferry flight to Hamburg, all of the crewmembers were showing symptoms of inadequate rest, nausea, tingling and the two most affected crewmembers reported numbness in their legs and feet and needed assistance to walk.

After reaching Hamburg, they were briefed by the CISM team and taken to different hospitals, accompanied by members of the team.

All of the crewmembers were examined and then driven to their homes in different vehicles.

During the month of July the captain was asked if he had noticed any changes in his condition. He replied that a week after the event he felt an unusual pain in the joints in his hands and fingers at night. His knees returned to normal after 2-3 days but he continued having slight numbness and tingling in his hands and lower part of his arms for six weeks. He described it feeling as if they were constantly falling asleep several times a day. He did not lose strength and his motor skills remained intact. At no time was he declared unfit to work or fly.

According to his doctors, the cause of these afflictions may not have been physical.

Neither the blood tests immediately after the event or those done later revealed anything out of the ordinary.

The symptoms stopped after mid-May.

1.18.2. First officer's statement

The key points of his statement matched those of the captain's.

As for his health, the first officer reported not feeling any change in his physical state after the event and that he had felt well throughout.

1.18.3. Statements by the flight attendants

Five of the six flight attendants were interviewed by the official BFU representative to the investigation in the month after the event.

The sixth FA could not be interviewed at that time due to her physical condition, though she was interviewed in July.

All of the FAs made the same key observations, which have been combined into a single account.

They stated that 20 minutes before landing, they noticed an acrid, "chemical" smell. The purser, who was in the forward galley, began to feel ill and even feared that she might lose consciousness.

The two FAs in the aft galley described the smell as strong and acrid, similar to that of "old socks".

The two FAs who were in position 2, opposite row 12, noticed the smell 10 minutes before landing. They added that there were a lot of children onboard and that the flight had been a little "agitated", so they initially thought the source of the smell could be diapers. Already during the approach they felt sick and dizzy, which continued after landing and while taxiing to parking.

Both flight attendants felt unusually unwell, had to sit down and kept silent during the remainder of the flight while facing the passengers. Only after touch down they exchanged words about their current feelings.

During the disembarkment of the passengers both attendants offered chocolate at the door. Usually passengers accept this little farewell present very willingly, but this time the chocolate was hardly taken. However, nobody complained about the smell or anything related to it.

After all passengers had left the aircraft, one of these flight attendants had to vomit.

1.18.4. Chemical exposure limits

Directive 98/24/EC on the protection of the health and safety of workers from the risks related to chemical agents at work lays out the minimum stipulations for protecting workers against hazards to their health and safety due to or associated with the effects of chemical agents present in the workplace or with any activity involving chemical agents.

Article 3, Section 2 of said Directive specifies that the Commission, after checking with the Advisory Committee on Safety, Hygiene and Health protection at Work, shall propose European objectives in the form of indicative occupational exposure limit values for the protection of workers from chemical risks, to be set at the Community level.

Section 3 of the same Article 3 states that Member States shall establish a national occupational exposure limit value for any chemical agent for which an indicative occupational exposure limit value is established at the Community level, taking into account the Community limit value, determining its nature in accordance with national legislation and practice.

The indicative occupational exposure limits were published in three directives: 2000/39/EC, 2006/15/EC and 2009/61/EC.

Spain has been complying with Section 3 of Directive 98/24/EC by having its National Institute for Occupational Health and Safety (INHST), an agency of the Ministry of Labor and Social Security, periodically publish the national limits.

Thus, the document "Workplace exposure limits for chemical agents in Spain. 2013" contained the limit values adopted by the INHST for the year 2013.

This document also specifies the following two categories for environmental limit values (VLA in Spanish):

- Environmental Limit Value – Daily Exposure (VLA-ED ®). Reference value for daily exposure (ED in Spanish). The VLA-ED® represent conditions to which, based on our current knowledge, most workers can be exposed 8 hours a day, 40 hours a week, throughout their professional lives without suffering any adverse health effects.

- Environmental Limit Value – Short Duration Exposure (VLA-EC ®). Reference value for the Short Duration Exposure (EC in Spanish). The VLA-EC® must not be exceeded for any short duration in the course of a workday. For those chemical agents with known acute effects but whose main toxic effects are chronic in nature, the VLA-EC® serves to complement the VLA-ED®, and thus exposure to these agents must be evaluated in terms of both limits. In contrast, chemical agents with mainly acute effects, such as irritant gases, are only considered based on their VLA-EC®.

In addition to this, the regulation specifies "Deviation Limits (LD)". For many chemical agents with an assigned VLA-ED®, there is no VLA-EC®; however, any deviations above the VLA-ED® must be tracked, even when this value is within the recommended limits. In these cases the deviation limits are applied. These deviation limits (LD) are defined using considerations of a statistical nature by studying the variability observed in a large number of measurements to determine the short-duration exposures in actual industrial processes. Any deviation in exposure levels for workers may exceed the value 3xVLA-ED® for no longer than 30 minutes in one workday, and it may not surpass the value 5xVLA-ED® under any circumstances.

In the United States limits for air pollutants are contained in CFR29 (Code of Federal Regulations), Part 1910, subpart Z.

The table below lists the limit values, as per Spanish and American laws, for the compounds found in the air samples taken from the aircraft's cabin. The symbol "-" indicates that the compound in question is not included in the list.

Compound	Spain		United States
	VLA-ED® (ppm)	VLA-EC® (ppm)	8H-TWA[9] (ppm)
Acetone	500	-	1000
Benzene	1	-	1
Benzene. 1-ethyl-3-methyl	-	-	-
Benzyl Chloride	1	-	1
Bromomethane	1	-	-
Butanone	200	300	200
Ethylbenzene	100	200	100
Chlorobenzene	5	15	75
Decane	-	-	-
Dodecane	-	-	-
Ethyl acetate	400	-	400
Heptane	500	-	500

[10] 8 Hour time-weighted average.

Compound	Spain		United States
	VLA-ED® (ppm)	VLA-EC® (ppm)	8H-TWA[9] (ppm)
Hexadecenal, 7-	-	-	-
Hexane	500	1000	500
Methyl isobutyl ketone	20	50	100
Methylene Chloride	50	-	25
Nonanal	-	-	-
Styrene	20	40	100
Tetrachloroethylene	25	100	100
Tetrahydrofuran	50	100	200
Toluene	50	100	200
1,2,3- Trimethyl benzene	20	-	-
1,2,4- Trimethyl benzene	20	-	-
1,3,5- Trimethyl benzene	20	-	-
Undecanal	-	-	-
Undecane	-	-	-
Vinyl acetate	5	-	10
Xylene. O-	50	100	100

According to German and international law aircraft cabins are subject to indoor pollution monitoring[11]. As a consequence in German legislation occupational limit values designed for hazardous materials working places do not apply[12].

Guideline values for indoor pollution monitoring were issued by the Umweltbundesamt (German Environmental Protection Agency) in 1999[13]. According to this document TVOC concentrations of 200 – 3,000 µg/m3 can cause irritation and discomfort, concentrations of 3,000 – 25,000 µg/m3 evoke neurotoxic reactions, e.g. headache, and concentrations of > 25,000 cause inflammation reactions and incapacities of the lung function in human beings.

The German guideline is supported by international researchers who define 3,000 µg/m3 as an upper TVOC threshold value for human exposure[14].

[11] DIN EN ISO 16000-1 2006. Innenraumluftverunreinigungen – Teil 1: Allgemeine Aspekte der Probeentnahmestrategie. Beuth, Berlin

[12] Bekanntmachung des Bundesumweltamtes 2014. Ermittlung und Beurteilung chemischer Verunreinigungen der Luft von Innenraumarbeitsplätzen (ohne Tätigkeit mit Gefahrstoffen). Bundesgesetzblatt 57: 1002-1018.

[13] Seifert, B. (1999) Richtwerte für die Innenraumluft – Die Beurteilung der Innenraumluftqualität mit Hilfe der Summe der flüchtigenorganischen Verbindungen (TVOC-Wert). Bundesgesundheitsbl. – Gesundheitsforsch. – Gesundheitsschutz 42:270-278

[14] Mølhave, L., Grønkjaer Jenden, J., and Larsen, S. (1991) Subjective reactions to volatile organic compounds as air pollutants. Atmospheric Environment 25A: 1283-1293

1.18.5. Similar events

In recent years there have been many incidents involving odors in the cabin that have resulted in safety recommendations being issued.

The sections below summarize the reports on those events considered to be significant and that involve aircraft of the same type as the one in this report. Also included is a general report written by the BFU on this topic.

1.18.5.1. Report 1/2004. Report on the incident to BAe-146, G-JEAK

During the approach of a BAe-146-200 aircraft to the Birmingham Airport on 5/11/2000, a strong smell of oil was noticed in the passenger cabin.

The first officer exited the cockpit to check on the situation and, shortly afterward, began feeling nauseous. The first officer's symptoms and physical problems worsened. The captain recommended that he don his oxygen mask, which he did. Despite this, the first officer was unable to carry out his duties for the remainder of the flight.

The captain also started feeling symptoms, though milder than the first officer's, and was able to complete the flight.

The investigation into this event revealed the presence of an oil leak from the APU caused by a faulty seal that allowed part of the spilled oil to be ingested by the APU. This resulted in oil fumes entering the cabin through the environmental control system (bleed).

The report also states that during the investigation, similar events were reported in other aircraft types, which resulted in the report being expanded, to a certain extent, to these other events involving the following aircraft types:

- 9 cases on BAe 146.

- 10 cases on Boeing B757.

- 1 case on a Boeing B737.

- 3 cases in Fokker 100.

Issued with this report were five safety recommendations.

Recommendation 2001-5 was directed at the FAA, as the certification authority for the Boeing 757 type so that, in concert with Boeing, actions be taken to require operators of this aircraft type to ensure that the maintenance and modification standards for the aircraft's air conditioning, engine and APU systems be such that air supply contamination by oil from the engines and/or APU, or by any other potentially hazardous substance, is avoided.

Boeing indicated that all airplane models occasionally experience some odors or fumes from a variety of sources, but a review of available data indicated that the 757-200 model with Rolls Royce RB211-535C engines appears to have a higher incident rate than expected, and that most of the 757-200 airplanes with this engine type are operated by British Airways.

A working team was formed by Boeing, Rolls Royce (the engine manufacturer), Honeywell (the APU manufacturer) and GE-Wales (company responsible for overhauling the 535C engines for British Airways) to look into the problem. They concluded that the odors were caused by oil leakage in the engine. Though the APU seemed to have contributed to some of the events, they determined that its contribution to those events involving the B-757-200 with RB211-535C engines had been negligible.

These findings resulted in improved engine overhaul and oil servicing procedures, as well as in re-emphasizing crew oxygen procedures at British Airways.

The FAA regarded the measures adopted as addressing the requirements of the safety recommendation and closed it out.

1.18.5.2. Study on events reported involving cabin air quality. BFU

As a result of the increased number of reports involving "odors" in the cabin, the German accident investigation bureau conducted a study based on 845 accidents, serious incidents and incidents reported from 2006 to 2013.

In 663 of the cases a relationship with the cabin air was established. In the remaining180 cases health impairments were described, which were not connected with cabin air quality (e.g. broken toe, burned hand).

In the study, the events were divided into four categories:

- Fume events involving flight safety.
- Fume events possibly affecting the occupational safety of the flight crews.
- Fume events affecting the comfort of the occupants.
- Fume events involving possible long-term effects in the occupants.

The data in the study revealed that on several occasions, the criteria for rating an event as a serious incident were met since the crew decided to make use of oxygen masks or one member of the flight crew was partially incapacitated.

In only a few cases was the safety margin reduced to the point that the likelihood of an accident occurring was high, legally speaking.

There were clear indications of physical harm, in terms of workplace health, affecting flight crews and flight attendants. Only a few reports mentioned effects to passengers.

In 10 of the events reported to the BFU, the affected individual stated suffering from long-term symptoms. All of these cases involved fumes in which an oily or "dirty sock" smell was reported.

In this study, the BFU noted that with the current resources and accident investigation methods, it is not possible to investigate past incidents of this type. The BFU recommended using the principles of clinical toxicology to ascertain the possible long-term effects of these events.

Finally, it concluded that the data considered in the study revealed no significant reduction in flight safety. It also added that while the fume events had taken place and could have had adverse health effects, the long-term effects of the emission events could not be evaluated.

As a result of its study, the BFU issued four safety recommendations on the following aspects:

- Improved identification and actions to avoid possible health risks due to contaminated cabin air.
- Standardized reporting protocols.
- Improved methods for verifying compliance with cabin air requirements during the certification process for transport airplanes.
- Evaluation by a qualified institution of the possible relationship between long-term health effects and fume events.

1.18.6. Investigations conducted in the U.K

The British Airline Pilots Association (BALPA) has been studying and evaluating the scientific aspects involved in cabin air for over 10 years.

This association has invested significant funds to research the possible interrelationships between potential air cabin contamination events and illnesses in flight crews. Despite this, BALPA acknowledges not finding any consistent and credible evidence that meet the scientific criteria of said relationship.

In light of the growing concern in this area, the Transport Department in the United Kingdom decided to commission Cranfield University's Institute for Environment, Health, Risk and Futures to conduct a study.

As part of this study, cabin air quality measurements were taken over the course of 100 flights. No fume events occurred in any of these flights, nor were the conditions needed to activate the incident reporting criteria met. The most significant findings were:

- Most of the VOC/SVOC detected were limonene and toluene.
- Most of the average concentrations of TVOC measured were below 2 ppm. There was evidence of an increase in TVOC coinciding with some reports involving the air quality.
- A total of 30 air samples were collected during events in which odors were detected, and also when changes in the monitor readings occurred. The concentrations of the compounds measured were no different from those samples taken routinely during different phases of flight. There was evidence of correlation between some peaks in TVOC and certain events, but most of the peaks recorded were not associated with any event.
- The levels of carbon monoxide and toluene did not exceed the safety, health or comfort limits described in the European standard, "Aircraft internal air quality standards, criteria and determination methods".[15]
- The concentrations of other contaminants, such as TCE, TBP, TOCP, xylene, limonene, toluene, CO, etc., were below the occupational exposure limits.
- The concentrations of toluene, limonene, xylene, undecane and TCE measured in aircraft cabin air were similar in magnitude to those present in developed countries houses. CO concentrations are often higher than those measured in aircraft cabins. As for TCP and TBP, the report stated that there were insufficient data to establish comparisons.
- The samples taken during air quality events did not contain elevated concentrations of any of the contaminants measured.

[15] Reference document BS-EN-4618 of the British Standards Institution.

- There was no evidence that the concentration of any of the contaminants monitored exceeded the health and safety standards specified in the available guidelines.

The Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) is an independent scientific committee that advises the Food Standards Agency, the Department of Health and other government departments and agencies in the United Kingdom on matters related to the toxicity of chemical products.

In 2007, this committed was commissioned to advise the Department for Transport on cabin air quality, a task it continues to carry out to this day.

At this committee's last meeting, held in late 2013, four research projects on this subject were reviewed: Cranfield University 2008, 2009; Institute of Environment and Health 2011 a/b; Institute of Occupational Medicine 2012. The committee also considered papers published in the scientific literature since 2007.

Based both on the information previously considered and on the new projects, the COT drew a total of thirteen conclusions:

- Contamination of cabin air by components and/or combustion products of engine oils, including triaryl phosphates, does occur, and peaks of higher exposure have been recorded during episodes that lasted for seconds

- Episodes of acute illness, sometimes severely incapacitating, have occurred in temporal relation to perceived episodes of such contamination.

- There are a number of air crew with long-term disabling illnesses, which they attribute to contamination of cabin air by engine oils or their combustion products.

- The acute illness which has occurred in relation to perceived episodes of contamination might reflect a toxic effect of one or more chemicals, but it could also have occurred through nocebo effects[16].

- While there is strong scientific evidence that nocebo effects can lead to (sometimes severely disabling) illness from environmental exposures that are perceived as hazardous, there is no simple and reliable way of establishing that nocebo responses are responsible for individual cases of illness.

- The patterns of illness that have been reported following fume events do not conform with that which would be expected from exposure to triaryl phosphates such as o-TCP.

[16] A worsening of a disease's symptoms or signs resulting from the expectation, conscious or not, of the negative effects of a therapeutic treatment.

- The COT considers that a toxic mechanism for the illness that has been reported in temporal relation to fume incidents is unlikely.

- Decisions to undertake further research will need to balance the likelihood that it will usefully inform further management of the problem against the costs of undertaking the work.

- One possibility would be to collect better information. This would require airlines to record and retain a limited set of information on all flights that they operate

- As an extension to the above study, a case-control approach could also be used to investigate associations of fume incidents with operational parameters.

- Another possible extension to a systematic study of fume incidents would be to collect and store samples of urine, and possibly blood, from crew members within 48 hours (the earlier the better) after such events. These could then be analyzed for biomarkers of potential toxic pollutants, as in the studies by Schindler at al. (2013) and Liyasova et al. (2011).

- Since 2007, there have been significant advances in the technology that is available for air-monitoring, and in theory it should now be possible to develop a compact system in which a particle counter would run continuously, and trigger other sampling instruments if and when a fume incident occurred. The samples collected could then be used to identify any chemicals that occurred at exceptionally high concentrations.

1.18.7. Positions on cabin air quality

Aircraft fume events and their potential impact on health have received significant attention for at least the past decade. There are currently two main trains of thought on the existence of systematic contaminations of cabin air, with practically opposing positions.

One posits that the presence of systematic air cabin contamination by oil and/or other engine fluids is having adverse effects on the health of crews and passengers, a condition known as "aerotoxic syndrome".

There is a counter current that upholds the lack of evidence of any such general effects on health, and that acknowledges only the presence of isolated poisoning cases, and does not accept the use of the term "aerotoxic syndrome". To support its position, this group relies in large part of the National Research Council's recommendation not to designate "aerotoxic syndrome" as a viable term due to the lack of substantiating data. This group further maintains that the effects of such cases are transient irritation, with no long-term or serious health consequences.

There is an additional third stance that posits that our current knowledge of this subject is insufficient to confirm or disprove its existence, and that therefore more research is needed.

1.18.7.1. Positions in favor of the existence of air cabin quality contamination

The Global Cabin Air Quality Executive (GCAQE) is an organization whose members include pilot and flight attendant associations, unions, and other groups from Europe, the United States and Australia, and whose primary goal is to improve the quality of cabin air.

This organization maintains that the air used to pressurize all aircraft cabins, except for the Boeing 787, is taken directly from the engines (from bleed air). It notes that this air is contaminated with engine oil and/or hydraulic fluid, which contains toxic chemical substances, and is then delivered into the cabin without being filtered.

This contamination does not occur solely due to occasional leaks; on the contrary, because the seals are not completely watertight, these fluids are always flowing and mixing with the air inside the compressor. This air is heated by the compression effect, and the resulting high temperatures it reaches can lead to the pyrolysis of the oil and the production of other chemicals. The air that is channeled into the cabin to pressurize it is obtained from the engine bleed.

The organization argues that exposure to complex mixtures of chemicals can have synergistic effects whose toxicity has never been evaluated. It also maintains that the standards for exposure to chemicals are not applicable at altitude and they are only for exposure to one agent, not for complex mixtures.

It states that exposure to contaminated air will have greater or lesser effects on an average individual, both in the short and long term, that depend on other factors such as: levels and types of chemicals present during the exposure, history of different exposures to contaminated air, genetic factors, age, medical conditions, medications, etc.

The GCAQE also states that short- and long-term health effects have been reported by both crews and passengers after exposure to contaminated air.

The solution proposed by this organization is a change to the design of air conditioning systems for aircraft such that they do not use bleed air from the engines or the APU.

The Aerotoxic Association was founded in 2007 in the United Kingdom by a group of crewmembers whose careers were supposedly affected by contaminated cabin air. This association also believes in the existence of said contamination and in the existence of adverse health effects attributable to this contamination, which they call "aerotoxic syndrome".

This term was first used in the study "Aerotoxic Syndrome: Adverse health effects following exposure to jet oil mist during commercial flights", written by Dr. Harry Hoffman, Professor Chris Winder and Jean Christophe Balouet, Ph.D.

This association proposes adopting solutions similar to those put forth by the GCAQE.

1.18.7.2. Positions against the existence of cabin air contamination and "aerotoxic syndrome"

There is a different position that maintains that despite the increase in the number of fume/odor events since 1999, the number of crewmembers reporting adverse health effects associated with these events has been small.

An example of this position can be seen in Professor Michael Bagshaw's study titled "Health Effects of Contaminants in Aircraft Cabin Air"[17].

In this study, Professor Bagshaw explains that since 1999, there has been an increase in the number of fume/odor events reported, with a small number of crewmembers reporting adverse health effects associated with these events.

He notes that in the first versions of the BAe 146 and Boeing 757 aircraft, the cause of the contamination of bleed air was identified as engine oil, and suitable solutions were implemented.

As for the toxic effects of organophosphates, he states that these effects are specific and stem from an impairment in neurotransmission in peripheral nerves that can lead to muscular weakness and paralysis. In terms of medical toxicology, it is impossible to explain the wide variety of symptoms reported by some crewmembers as the result of exposure to a TCP.

As noted in his report, a syndrome is defined as a set of symptoms that occur simultaneously during an illness or disorder.

Individuals reporting that they suffer from the so-called aerotoxic syndrome describe a wide range of individual symptoms and signs, with insufficient consistency to fulfil the requirements for the definition of a medical syndrome.

With regard to this "syndrome", he adds that the Aerospace Medical Association reviewed the scientific evidence and concluded it lacked the consistency and objectivity needed to support the establishment of a clearly defined syndrome. Additional support comes from the U.S. National Research Council who concludes that "evidence does not

[17] http://www.gapan.org/file/1277/air-contamination-health-effects-report-oct-13.pdf

warrant the designation of a specific syndrome related to exposure to various physical agents (e.g., mists and smoke) and decomposition products derived from leaks of engine oil and hydraulic fluids. The committee recommends that until such information is available, the designation "aerotoxic syndrome" not be used for symptoms reported in coincidence with cabin air contamination."

The symptoms reported by some crewmembers who had been exposed to fume/odor events in the cabin, especially when they made use of the oxygen masks, are similar to those that occur in cases of hyperventilation. Obviously not every case of "aerotoxic syndrome" is caused by hyperventilation, but it could be a plausible explanation for some of them.

The report argues that based on the scientific evidence available (on the date of the report), the amounts of organophosphates to which crews could be exposed are insufficient to produce neurotoxicity.

Similarly, investigations into cabin air carried out in several countries have failed to detect levels of TCP in excess of well-established and validated occupational limit values.

1.18.7.3. Positions in favor of continued research

In 2012, the Building Research Establishment (BRE) sponsored the BRE Cabin Air Quality Workshop, which was attended by the following aviation, health and toxicology organizations:

- Air Accident Investigation Branch (AAIB), United Kingdom.
- ASD-STAN, Belgium.
- Airbus.
- British Airline Pilots Association BALPA), United Kingdom.
- Association of Aviation Medical Examiners (AAME), United Kingdom.
- The Boeing Company, United States.
- European Society of Aerospace Medicine (ESAM)
- Building Research Establishment Limited (BRE), United Kingdom.
- AsMA Air Transport Medicine Committee.

- Civil Aviation Authority Aviation Health Unit (CAA), United Kingdom.
- Civil Aviation Authority of Singapore (CAAS), Singapore.
- GE Aviation, United States.
- Honeywell, United States.
- Institute of Occupational Medicine (IOM), United Kingdom.
- International Air Transport Association (IATA), Canada.
- Intertox, United States.
- National Poisons Information Service (NPIS), United Kingdom.
- University College London, Dept. of Chemistry, United Kingdom.

The reason for the workshop was to address the concern among crews over the impact that exposure to contaminants in cabin air could have on flight safety and on their short- and long-term health. In the opinion of the crews, the source of the supposed contamination was engine oil and hydraulic fluid entering the cabin through bleed air.

The most significant conclusions reached at this workshop were the following:

- After reviewing the evidence associated with fume/odor events in the cabin, they concluded that there are no peer-reviewed studies on acute poisoning from organophosphates with analytical confirmation of the diagnosis after fume/odor events. Similarly, there are also no evaluation reports of delayed neuropathies induced by organophosphates, and no evidence of the association between exposure to fume/odor and short- or long-term neuronal damage.
- There was a lack of clarity and consistency in the definitions and terminology used in the reports that hampers a determination of the true incidence of the events.
- There is a need to standardize the methods and procedures for collecting and analyzing cabin air quality samples.
- Guidelines are needed for medically evaluating crewmembers after a fume/odor event.
- Several recommendations were made, including an evaluation of risks and standardization of the investigations into these events and on the health effects of contaminated bleed air.

- In light of the conclusions by the Committee on Toxicity in its review of the investigation carried out by Cranfield University and the Institute of Occupational Medicine, it was recommended that the need to conduct more in-depth research in this area be considered.

1.18.7.4. The EASA's stance

On 27 January 2012, the EASA issued decision no. 2012/001/R on termination of rulemaking task 25.035 on the cabin air quality onboard large aircraft.

In the preamble of this decision, the EASA states that it is aware of the concerns that various stakeholders (pilots, flight attendants, unions, passenger associations, etc.) have about the risks of contaminated cabin air, and in particular about the risk of contamination by lubricants or hydraulic fluid used in aircraft engines and APUs whose bleed air is used in the air conditioning system.

It also states that there are contradictory opinions among the stakeholders.

It further adds that the Agency is required to update the certification specifications for aircraft taking into account worldwide aircraft experience in service and scientific and technical progress to reflect the state of the art and the best practices in the fields concerned, based on which the EASA queried the stakeholders on a wide range of topics.

The agency also considered the Cranfield University study.

Based on all this information, the Agency concluded that there is no safety case that would justify an immediate and general rulemaking action.

The Agency also understands that a causal relationship between the health symptoms reported and oil/hydraulic fluid contamination has not been established. Since there is no conclusive scientific evidence, the Agency cannot justify a rulemaking task to change certification specifications.

The decision concludes by terminating task 25.035 on air quality onboard large aircraft without amending any EASA regulations.

Although the Agency has not found a justification to launch a regulatory change activity, this topic will be continuously monitored, and some recommendations are provided in the document CRD to A-NPA 2009-10 to further improve the knowledge on exposure health issues and on technologies for bleed air filtering and monitoring.

If in the future new elements become available and show that the occurrences of engine or auxiliary power unit contamination of bleed air are a serious threat to safety or health, then the Agency will take appropriate corrective actions including considering regulatory changes options.

EASA ensures a continued monitoring of the subject in terms of reported occurrences and scientific knowledge development. The primary focus of EASA is safety oriented, however health aspects are also taken seriously into account.

EASA is conducting two studies to improve the knowledge on contaminants present during commercial flights and on the toxicity of turbine engine oils:

1. Flight measurement campaign (reference EASA.2014.OP.16)

Purpose: to compliment relevant available knowledge on Cabin Air Contaminants present during commercial operation.

Duration: From Feb 2015 to 04Q2016.

Activities: 60 flights are planned with measurements of air contaminants (cockpit & cabin) – the flights started in July 2015. Several types of airplanes and engines are involved (short range and long range airplanes).

2. Characterisation of the toxicity of aviation turbine engine oils after pyrolysis (reference EASA.2015.HVP.23)

Purpose: to improve the knowledge on aviation oil toxicity and support the analysis of cabin/cockpit air contamination (e.g. flight measurement campaign mentioned above)

Duration: From November 2015 to September 2016

Activities: Characterisation of toxicity of engine/APU oil after pyrolysis process based on in vitro tests.

EASA is also supporting the European Commission to prepare a call for tenders for a larger scale project. This project, which should be launched in 2016, will follow-up the EASA flight measurement campaign through funding additional flight measurements, and should also investigate other aspects like air conditioning systems contamination, contribution of cabin interiors/equipment to the air contamination level, health risk evaluation methods.

EASA supports the SAE standardization body via active participation in the work drafting Aerospace Recommended Practices and Aerospace Information Reports. EASA contributes to the development of the ARP on the Procedure for Sampling and Measurement of Engine and APU Generated Contaminants in Bleed Air Supplies from Aircraft Engines (SAE

ARP4418). In addition, EASA participates in the European Committee for Standardization project on "Cabin Air Quality on civil aircraft - Chemical Agents" (CEN TC436) which is aiming for a European Standard for suitable limits at which pilots should be notified of the presence of air supply contaminants that may require intervention, and suitable detection limits for measurement.

1.18.8. Fume/odor events in Germany and the United Kingdom

In recent years there has been a growing sensitivity in several European countries, mainly the United Kingdom and Germany, to cabin fume/odor events.

In fact, the number of events reported in these countries has grown significantly during this time, and along with it, so has the concern expressed by crews involving this subject.

An example of this is provided by the "Unabhängige Flugbegleiter Organisation" (UFO), an independent organization of cabin crew in Germany which has published a brochure/guide on cabin fume events aimed at passenger cabin crews. It contains information on the initial symptoms as well as on the long-term health effects of neurotoxicity, and instructions and advice to follow if they are involved in a cabin fume event.

In contrast, in countries like Spain, no significant variation in this trend has been observed, with the number of cabin fume events reported remaining fairly low. Most of the cases reported affect aircraft from operators in countries where there is greater awareness of these events.

1.18.9. Symptoms of poisoning

1.18.9.1. Organophosphate poisoning

Organophosphate compounds are derived from phosphoric acid and they inhibit the enzyme acetylcholinesterase in nerve synapses and in erythrocytes. They also inhibit butyrylcholinesterase (also called plasma cholinesterase), as well as other carboxylesterase hydrolases. Some organophosphates also inhibit neurotoxic esterase (NTE), and it is this inhibition (along with the increase in intracellular Ca2+ due to alteration of the enzyme calcium-calmodulin-kinase ii) that seems to provide the mechanism leading to delayed neuropathy.

The acetylcholinesterase enzyme destroys the neurotransmitter acetylcholine in the synapses. Its inactivation by the OP compound produces an increase in acetylcholine in the receptor, and thus an excess of cholinergic manifestations (both nicotinic and muscarinic, central and peripheral).

The clinical manifestations that can occur are[18 19]:

- Cholinergic syndrome:
  - o Muscarinic effects (general hyperexcitability of the vagus): abdominal pain, vomiting, diarrhea and fecal incontinence; bronchoconstriction and involuntary urination; miosis and paralysis of accommodation; an increase in all secretions (bronchorrhea, perspiration, salivation, lacrimal, gastric, intestinal and pancreatic hypersecretion); peripheral vasodilation with flushing and arterial hypotension; disturbances in atrioventricular conduction and sinus bradycardia.
  - o Nicotinic effects (from stimulation of motor fibers): intense asthenia, fasciculation, muscle spasms, paresis and paralysis; tachycardia, peripheral vasoconstriction, arterial hypertension, myocardial hyperexcitability; hyperpotassemia, hyperlactacidemia and hyperglycemia.
  - o Central nervous system effects: headache, convulsions, confusion, coma, respiratory depression and hemodynamic alterations.
- Intermediate syndrome: appears 24-96 hours after the acute symptoms (up to the 6th day): paralysis of the proximal muscles in the extremities and thorax with respiratory compromise.
- Delayed sensorimotor polyneuropathy, or organophosphate-induced delayed neuropathy (OPIDN), which presents 7-14 days after exposure.
  - o Peripheral nervous system: starts in the lower extremities by way of cramps and painless paresthesia, progressing to symptoms typical of the lower motor neurons, progressing in a retrograde, centripetal and ascending manner (flaccid paralysis and hyporeflexia).
  - o Autonomic nervous system: chills and sweating of lower extremities.
  - o Central nervous system: pyramidal, or upper motor neuron, syndrome, with signs of spasticity and hyperactivity of the deep tendon reflexes, except the Achilles tendon.
- Long-term effects: non-specific, chronic neuropsychological symptoms, unconfirmed.

[18] A. Pino et al. Intoxicación por Organofosforados. Unidad de Cuidados Intensivos Pediátricos y Neonatal del Hospital Clínico Universitario de Valladolid. Sociedad Española de Cuidados Intensivos Pediátricos SECIP: www.secip.com/publicaciones/protocolos/doc_download/204-intoxicacion-por-organofosforados intoxicación por organofosforados

[19] Gervilla Caño J et al. Intoxicación por organofosforados. SEMERGEN. 2007;33(1):21-3

The toxicity is variable, depending on the agent, the dosage absorbed, its affinity for the enzyme and the duration of the exposure. The symptoms combine differently, giving rise to mild, moderate and serious clinical forms.

The gravity can be classified in degrees using the Phone Score of the World Health Organization's International Program on Chemical Safety (WHO IPCS):

- Grade 0: No poisoning
- Grade 1: Mild poisoning: irritative symptoms and/or incomplete muscarinic syndrome.
- Grade 2: Moderate poisoning: muscarinic and nicotinic symptoms.
- Grade 3: Severe poisoning: combine cardiovascular, respiratory and/or CNS compromise, requiring support for vital functions.
- Grade 4: Death.

The mild forms are reduced to nausea with headaches, vertigo, muscle weakness and a possible loss of visual acuity (due to the miosis). The moderate forms can lead to sinus congestion, nausea, vomiting, abdominal cramps, elevated exocrine activity (salivation, lacrimal, perspiration), eye pain, photophobia and muscle tremors.

The diagnosis requires:

- Medical and exposure history.
- Clinical symptomatology and, with some OP, a characteristic garlic odor.
- Additional exams:
    - Reduction in the activity of plasma or intraerythrocytic acetylcholinesterase. There is a bad correlation between cholinesterase levels and the mild or moderate form that is difficult to interpret. The intraerythrocytic cholinesterase correlates better with clinical manifestations.
    - 12-lead ECG (QTc prolongation, sinus bradicardia or tachycardia, AV blocks, ventricular extrasystole, Torsades ventricular tachicardia, PR prolongation, etc.)
    - Blood analysis: electrolytes, glucose, BUN, hepatic transaminase, etc.
    - Blood gas, pulse oximetry.
    - Chest X-ray (severe cases).

Most patients recover with no long-term effects, though in-hospital observation and subsequent monitoring are recommended, especially for symptoms of intermediate syndrome and OPIDN. Cases with prolonged symptoms are usually related with prolonged exposures.

1.18.9.2. Glycol poisoning

The glycol used in deicing liquids is toxic when ingested and can produce symptoms like nausea, vomiting, convulsions, stupor and even coma.

When inhaled it irritates the breathing passages and sometimes the eyes, and can also cause headaches.

1.18.9.3. Use of organophosphates in engine oils

Engine oils contain synthetic hydrocarbons and additives, and use an organophosphate called tricresyl phosphate (TCP) as a high-pressure lubricant.

TCP can be toxic in the short and long term, affecting the nervous and other systems. The neurotoxicity of TCP is due to its ortho isomer, tri-ortho-cresyl-phosphate (ToCP or TOCP). This isomer deteriorates the neuromuscular and peripheral nerve synaptic function, though it does not appear to have any cognitive effects.

Other isomers include MoCP (mono-ortho-4 cresyl phosphate) and DoCP (di-ortho-cresyl phosphate), with similar toxicities. The para and meta isomers are not toxic to humans.

The concentration of TCP in aviation engine oils varies, but is typically less than 3%. TOCP, in turn, accounts for less than 0.2% of the total TCP. Thus, the overall concentration of TOCP in engine oil is less than 0.006% of the total engine oil.

Several studies have shown that even in cabin fume incidents, the amount of TCP and its isomers recorded in the air were always below the exposure thresholds recommended by various occupational health and safety organizations. And yet in 2007, the UK's Committee on Toxicity, as part of an evaluation carried out at the request of the Department for Transport, concluded that while the causal relationship between the presence of these contaminant gases and the health of crews could not be established, the fact that there were cases so closely linked in time involving the presence of gases/fumes and acute health effects could indicate a relationship between the two.

There is currently one manufacturer that is researching the development of engine oil without TCP.

In fact, the French company NYCO makes and markets an oil with these characteristics, though it is currently only certified for use in APUs.

1.19. Useful or effective investigation techniques

Not applicable.

2. ANALYSIS

2.1. Of the event

During the aircraft's approach to the Gran Canaria Airport there was a fume event in the cabin that was noticed by all the crewmembers, causing them physical discomfort.

This odor, however, did not seem to have much of an effect on the passengers, since none of them made any complaints while deboarding the aircraft or within the following days. However, there are reasonable explanations for this:

Physiological explanation: Flight attendants are in general physically more active than passengers, i.e. they tend to have a higher respiratory rate. Every breath may then become an inhaled dose of an alleged toxic substance in the air.

Psychological explanation: Passengers tend to attribute an individual malaise either to nausea due to aircraft movements or to an individual event one had encountered before, e.g. late night party. At the time of this accident most passengers would have assumed no connection between a smell in the cabin and an individual malaise.

The medical service at the airport did not treat any passengers, and there is no conclusive evidence that any passengers were affected after the flight.

After the passengers deplaned, the flight attendants were asked about their physical condition, with 5 of the 6 answering that they were still physically affected to some extent by the event.

During the tests that were conducted before starting the return flight to Germany, the odor was noticed again, leading to more severe physical symptoms in some of the flight attendants.

The simultaneous nature of the fume event and the appearance and worsening of the physical symptoms in the crew requires consideration. It could indicate the presence of a cause-effect relationship between them. It could also indicate a nocebo effect.

2.2. Analysis of the aircraft

The cabin odor event could not be reproduced during the operational tests of the air conditioning system carried out at the Gran Canaria airport. None of the people onboard the aircraft noticed any unusual odors, nor did they feel any physical symptoms.

The inspections of the aircraft carried out at the Gran Canaria airport both before and after the operational tests did not provide any information as to the possible source of the odor, nor was any evidence found of an oil or hydraulic fluid leak in the engines or APU. The only finding of note was 5 liters of deicing liquid that was found in the APU tray.

This liquid could have come from the deicing treatment that was performed at the Hamburg airport at the start of the flight in which the event took place.

During the subsequent positioning flight to the Frankfurt airport, the fume event reappeared on three occasions. The first was during the taxi phase, when the occupants noticed a strange odor but without feeling any physical symptoms. The "Greywolf" recorded an increase in TVOC at the time of the odor.

The other two episodes took place during the flight. The occupants' statements indicate that the odor was much stronger than the first one; furthermore, several occupants felt physical symptoms, such as a sore throat and tongue and numb finger tips. These symptoms disappeared shortly after the odor faded. Neither sensor, however, registered any changes.

In light of the differences between the first and the two subsequent episodes, it stands to reason that they may have had different triggers.

The first did not have any physical effects and was detected by the occupants only through its smell, and by one of the sensors, which recorded an increase in TVOC. This episode could have occurred when combustion fumes from another aircraft or some other type of outside air contamination entered the cabin.

In the other two episodes, however, the odor seems to have been much stronger, though the sensors did not detect any changes. As for the physical effects, they were temporary, disappearing completely once the smell faded. Some of the symptoms perceived, like the throat and tongue irritation, could be compatible with glycol contamination of the air. It is possible that deicing liquid could have remained in another part of the aircraft in addition to the APU tray, and that it moved during the flight until it entered the air conditioning system.

The glycol, however, could not have produced the numbing sensations described. Also, if deicing liquid had found its way into the cabin, it should have been detected by the "aerotracer" sensor, which it was not. This would rule out the deicing liquid as the source of either the odor or the physical symptoms.

The fact that the symptoms disappeared as soon as the odor faded could point to a psychosomatic cause[20].

In this regard, it is worth remembering that the aircraft's occupants were aware of the event that had occurred in the previous flight, as well as of the physical symptoms de-

[20] A psychosomatic process is one in which physical symptoms appear for psychological reasons.

scribed by the affected crewmembers. The appearance of a strong odor and irritation could have resulted in a stressful situation that induced the affected individuals to "feel" the remaining symptoms, that is, the numbing sensation.

A further contributing factor could be the heightened awareness of fume events in Germany.

These symptoms could have been real, however, though if they had, the mechanism that produced them must have been different from the one involved in the accident flight, given the large difference between the symptoms occurring in the two cases.

The operator ran a test after a deicing treatment that showed that the liquid used in the treatment could find its way into the cabin through the air conditioning system. Though this test proves that this type of contamination is possible, and consequently it can adversely affect the cabin air quality, it does not conclusively identify deicing liquid as the source of the fume event since this compound, in its original state as well as heated up to 200ºC, does not produce the symptoms that affected the crewmembers.

The remaining inspections and tests conducted at the operator's facilities, aided by the manufacturer, did not produce any clues as to the possible cause of the odors.

Following these tests many of the air conditioning components were replaced as a precaution and the cabin was cleaned.

The aircraft was later returned to service.

This situation could lead to the conclusion that the source of the odor was in one of the air conditioning components that was replaced, or in a compound that was deposited on panels in the cabin combined with some other circumstance, like the smell of the adhesive used when the rug was replaced. It could also have been a one-time event.

In conclusion, the tests conducted on the aircraft did not offer clear evidence as to what might have been the source of the odor.

In addition, the tests carried out with the sensors, as well as the analysis of the cabin air samples, the APU tests and so on, did not detect the presence of any compound in a high enough concentration, based on currently accepted thresholds, to produce the physical symptoms described.

2.3. Medical information on the crew

One of the most notable circumstances is the large difference between the symptoms that affected the crewmembers, both in terms of the acute and long-term symptoms.

This could be due to multiple causes, such as, for example, different sensitivities to specific compounds, previous exposure, physical condition, psychological differences, etc. It could also be that the supposed contaminant was not mixed thoroughly with the air in the system. As a result, there could have been large differences in the concentration of the contaminant at the system's outlets, which could have caused it to affect some crewmembers more than others.

The symptoms reported by the crewmember in position 2R, especially after the second episode, are compatible with an exposure to organophosphates.

The second single-fiber EMG done on the crewmember in the 2R position detected a slight dysfunction in neuromuscular transmission.

The single-fiber EMG is a test that is carried out using a special needle that is capable of exploring an isolated muscle fiber (a normal EMG analyzes motor units consisting of several muscle fibers). The two main readings detect changes in the motor unit structure and neuromuscular transmission. In order for the muscle to contract, the nerve has to be stimulated. This releases a quantity of acetylcholine at the nerve-muscle interface, the neuromuscular junction. In normal conditions, there is enough acetylcholine to contract the muscle several times. What the single fiber, or jitter, study does is stimulate the nerve near the muscle repeatedly and measure how long it takes for the muscle to contract. In a normal muscle the contraction always occurs a certain period of time after the nerve is stimulated because there is enough acetylcholine to produce each contraction. If there is not enough acetylcholine, after a few stimulations the muscle contraction can be delayed or even not take place. This phenomenon, called jitter, leads to increased variability in muscle contraction and is evident in practically every case involving problems with the neuromuscular junction.

The battery of tests and medical reports available at this time for this crewmember seem to verify the existence of physical and cognitive symptoms compatible with poisoning by some kind of neurotoxin.

2.4. Poisoning. Cause-effect relationship

The diagnosis from the hospital in Berlin where crewmember 2R was treated indicates tricresyl phosphate (TCP) as the source of the poisoning, based solely on the fact that the poisoning symptoms of this compound are similar to those exhibited by the crewmember. The same diagnosis, however, acknowledges that, it is difficult, if not impossible, to prove that TCP caused the poisoning.

The report by Dr. Abou-Donia corroborates the diagnosis of neuronal damage due to the presence of antibodies for nervous system proteins. However, complete details of Dr.

Abou-Donia's testing are unavailable. And as Dr. Abou-Donia himself states, this test is entirely non-specific, meaning that it would only serve to verify the effect (neuronal damage due to poisoning), but not to identify the cause (toxin).

The blood tests done on the first officer and crewmembers 2R and 2L on the day of the accident at the Clínica del Perpetuo Socorro included a determination of serum cholinesterase, with the results for all three being normal.

As noted in Section 1.18.19.1, organophosphoric compounds such as TCP inhibit the enzyme acetylcholinesterase in the nerve synapses and in erythrocytes. They also inhibit butyrylcholinesterase, also called plasma cholinesterase.

The fact that the plasma cholinesterase values determined during the analyses done on the day of the accident were normal would tend to rule out the involvement of organophosphoric compounds in the poisoning.

It should be noted, however, that plasma cholinesterase values are not definitive indicators of organophosphate involvement, which is why the analysis results should be taken with some reservation, as they cannot be used to fully rule out the presence of this type of compound.

In contrast, the erythrocyte cholinesterase values are regarded as representative. In this case the cholinesterase values are obtained from cells (erythrocytes) instead of plasma. Determining these values is much more complex than for plasma cholinesterase, and the procedure is only done at certain specialized laboratories. As a result this value is not usually available.

The tests done in Gran Canaria did not determine the erythrocyte cholinesterase value. There is no record of this test having been performed subsequently in Germany either.

None of the available data could be used to identify the toxic agent; it was thus impossible to verify or rule out tricresyl phosphate as the cause of the poisoning.

2.5. Events in which a cause-effect relationship was suspected

Most, if not all, of the cases in which a direct cause-effect relationship between the aircraft and the health effects on individuals was suspected involved events in which a one-time contamination or cabin air occurred due to a leak of one of the fluids used in the aircraft. These leaks were caused by material failures, such as broken seals, or by improper maintenance practices or other reasons.

Some of these cases involved aircraft of the same type as in the event analyzed in this report and led to the issuance of a safety recommendation. As a result, measures were adopted to improve maintenance practices so as to avoid having leaked engine oil contaminate the bleed air due to incorrect maintenance operations.

There is no record of any event having taken place to date in which physical effects in individuals were determined to have resulted from repeated exposures to normal cabin air, i.e. the air supplied by the air conditioning system from the engine or APU bleed with these components operating normally and without any oil, hydraulic fluid or other leaks.

2.6. Current situation

As noted in various sub-sections in point 1.18, there is currently a great controversy as to the potential contamination of aircraft cabin air and its effect on people's health.

The information available shows an increase in the number of cases reported in recent years in which an alleged exposure to contaminants in cabin air resulted in physical and cognitive symptoms. This could be due to an actual increase in the number of cases or to increased reporting due to crews' heightened awareness of this issue.

None of the parties seems to call into question the toxicity of certain compounds present in engine oil, such as TCP. The differences mainly involve the cumulative effects of exposures to small concentrations of these compounds, to the effects of altitude and to the toxicity thresholds, which some argue are based on exposure to a single toxic agent, while cabin air can contain many of these agents.

While the use of engine oil without TCP would minimize the risk of contaminating the cabin air with organophosphates, it would not completely resolve this problem, since the possibility remains that other toxic agents can contaminate the air.

The tests and research carried out to date do not offer any definitive conclusions on the effects that cabin air has on human health; moreover, several studies recommend additional research and there are several such initiatives ongoing.

There also have not been any epidemiological studies that offer a scientific perspective on the real impact that cabin air has on human health.

In light of the concern that various aviation stakeholders have in this area, as well as of the increased number of cases of physical symptoms allegedly caused by contaminated cabin air and the little real knowledge on the effects that cabin air quality has on health, it seems prudent to continue the studies and research needed to gain an adequate understanding of this subject.

Several countries have already carried out studies and research in this area, though no definitive conclusions exist. This has resulted in several recommendations to continue the research, and, indeed, several studies are currently underway.

As a result, a safety recommendation is issued to the International Civil Aviation Organization (ICAO) to monitors research and/or studies conducted by organizations representing civil aviation, authorities, the industry, and academic and research institutions to determine the real impact that exposure to contaminated cabin air has on human health and takes actions to improve safety, as necessary.

3. CONCLUSIONS

3.1. Findings

- The crewmembers had valid licenses and were qualified for the flight pursuant to applicable regulations.
- The maintenance records show that the aircraft was equipped and had been maintained in accordance with applicable and approved regulations and procedures.
- During the approach to the Gran Canaria Airport a fume event occurred involving the cabin air.
- Coinciding with this event, several crewmembers felt physical symptoms.
- After landing and disembarking the passengers, the aircraft was inspected. Nothing unusual was detected and no indications as to the source of the fumes was found.
- The crew decided to test the aircraft's air conditioning system before the start of the next flight.
- During this test the odor returned, even stronger than before.
- During this second event, the crew felt the same physical symptoms, though they were much more pronounced.
- The first officer and two flight attendants were taken to a hospital where they were treated for several hours.
- The two flight attendants had neurological symptoms (difficulty walking and balancing, cognitive impairments).
- The first officer was asymptomatic.
- The tests and analyses carried out on the crewmembers until the writing of this report provided no information as to the agent that caused the physical and cognitive symptoms.
- Subsequent inspections of the aircraft likewise revealed no signs or indications as to the source of the odor.
- Smell and Aerotracer/GreyWolf indications do not always correlate.

- Till this day there is no proof that de-icing fluid (glycol) may have caused the odor or symptoms.

- The aircraft was returned to service after parts of the air conditioning system and the APU were replaced and after the cabin was cleaned.

- Immediately after the crew returned to Hamburg a third flight attendant became ill. All three flight attendants´ health worsened in the days after the accident. One of them had to be admitted to a hospital three times. The first one was from 24 April until 28 of April. Two of the flight attendants became unfit to fly/work, the other one terminated her career as flight attendant after having suffered a relapse.

- There is currently a heated controversy regarding the possible contamination of aircraft cabin air and its effect on people's health.

- The tests and research conducted to date have not provided sufficient information to assess the quality of cabin air and its effect on human health.

3.2. Causes and contributing factors

The investigation into this event revealed circumstantial evidence suggesting that several crewmembers were affected by contaminated cabin air that was being supplied by the aircraft's air conditioning system.

After several tests and analyses have been carried out till this day, the investigation yielded no conclusive findings as to the possible source of the contamination or the hypothetical toxic compound involved.

4. SAFETY RECOMMENDATIONS

REC. 15/2016. It is recommended that the International Civil Aviation Organization (ICAO) monitors research and/or studies conducted by organizations representing civil aviation, authorities, the industry and academic and research institutions to determine the real impact that exposure to contaminated cabin air has on human health and takes actions to improve safety, as necessary.