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Report RL 2001:41e

Incident onboard aircraft SE-DRE during flight between Stockholm and Malmö, M county, Sweden, on 12 November 1999

Case L-102/99

Translated by *Dennis Lynn Anderson*

Statens haverikommission (SHK) Board of Accident Investigation

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From the original Swedish at the request of the Board of Accident Investigation. In case of discrepancies between the English and the Swedish texts, the Swedish text is to be considered the authoritative version.

2001-11-23 L-102/99

Swedish Civil Aviation Administration

601 79 NORRKÖPING

Report RL 2001:41 e

The Board of Accident investigation (Statens haverikommission, SHK) has investigated an aircraft incident that occurred on the 12th of November 1999 during flight between Stockholm and Malmö, M county, Sweden, involving an aircraft with registration SE-DRE.

In accordance with section 14 of the Ordinance on the Investigation of Accidents (1990:717) the Board herewith submits a final report on the investigation.

Olle Lundström Henrik Elinder

Contents

APPENDICES

Report RL 2001:41e

L-102/99
Report finalized 2001-11-23

Aircraft: registration, type	**SE-DRE,** BAe 146-200
Class/airworthiness	Normal, valid certificate of airworthiness
Owner/Operator	Mer1dian Trust Company, 35 North Sixth Street, Reading, 00000 PA 19601, USA /Braathens Malmö Aviation AB, Box 37, 201 20 Malmö
Date and time	12 November 1999 approximately 19.00 hours during darkness *Note:* All times in the report refer to Swedish standard time (UTC + 1).
Place of occurrence	In the airspace north of Malmö/Sturup's airport, M county, Sweden between FL[1] 150 and FL 100
Type of flight	Scheduled flight
Weather	Metar Malmö/Sturup's airport: wind 280°/08 knots, visibility 5,000 meters in haze, cloud cover 5–7/8 with the cloud-base at 1,000 feet, temperature/dewpoint +8/+7 °C, QNH 1026 hPa.
Persons on board: crew	2/3
passengers	68
Injuries to persons	None
Damage to aircraft	None
Other damage	None
Commander:	
Age, certificate	39 years old, Airline Transport Pilot's License (Swedish D)
Total flying time	5,613 hours, of which 3,082 hours on the type
Flying hours previous 90 days	89 hours, all on the type
Number of landings previous 90 days	80
Co-pilot:	
Age, certificate	34 years old, Commercial Pilot's License with Instrument Rating (Swedish B)
Total flying time	2,450 hours, of which 2,020 hours on the type
Flying hours previous 90 days	127 hours, all on the type
Number of landings previous 90 days	111

The Board of Accident Investigation (SHK) was notified on the 16th of November 1999 that an incident had taken place on board an aircraft

[1] FL= Flight Level, flight altitude in 100s of feet.

with registration SE-DRE during a flight between Stockholm and Malmö on the 12th of November 1999 at approximately 19:00 hours.

The incident has been investigated by SHK represented by Olle Lundström, Chairman, and Henrik Elinder, Chief investigator.

The Board was assisted by Matts Aldman, Hans Grönkvist, Lars Hagman, and Mark Personne as medical experts and by Christina Östberg as measurement technology expert.

The investigation was followed by The Swedish Civil Aviation Administration through Max Danielsson. Accredited representative from NTSB[2] has been Richard G. Rodriguez. An accredited representative from AAIB[3] has not been appointed.

Summary

The crew was to carry out three return flights between Stockholm and Malmö together. The flying time on the route is approximately one hour. During the first flight the purser experienced an unpleasant feeling of fainting. She told the other two cabin crewmembers about this and they stated that they had also experienced something similar. They did not recognize any special odour. The pilots had not noticed anything abnormal.

During the subsequent flight one of the cabin attendants who was placed in the forward part of the cabin, experienced an odd pressure in the head, nasal itching and ear pain. The other two colleagues in the cabin also felt discomfort and the feeling of “moon walk” while working. The pilots, who did not notice anything abnormal during the second flight either, discussed whether the problem could possibly be due to some fault within the cabin pressure system.

The third flight that same day was flown by the commander. During the flight, which took place at a cruising altitude of FL 280, all three members of the cabin crew experienced similar discomfort as during the preceding two flights, but more pronounced. During the first portion of the flight the pilots did not notice anything abnormal but shortly before they were to leave the cruising altitude the commander began to feel a mild dizziness.

During the approach towards Malmö/Sturup airport when the aircraft was descending through FL 150 the co-pilot suddenly became nauseous and donned his oxygen mask. Then, after an estimated period of ten seconds, the commander also became very nauseous and immediately donned his oxygen mask. After a few seconds of breathing in the oxygen mask the co-pilot felt better and thereafter had no difficulty in performing his duties.

However, the captain felt markedly dizzy and groggy for a couple of minutes. He had difficulty with physiological motor response, simultaneity and in focusing. Finally he handed over the controls to the co-pilot. After having breathed oxygen a few minutes even the captain began to feel better and thereafter the pilots were able to accomplish a normal approach and landing on runway 17 without problems. Subsequent to the

[2] NTSB = National Transportation Safety Board, USA
[3] AAIB = Air Accidents Investigation Branch, UK

incident, the airline performed a trouble-shooting of the aircraft, which ascertained a minor external oil leak on engine # 2.

An extensive technical investigation has been performed on the aircraft and on engine # 2. During engine test in test cell and flight test airspecimens from the bleed air- and the air-condition system and have been taken and analyzed. The samples have not provided any indication of what/which chemical substances caused the symptoms and no technical fault that can explain the incident has been found.

The Board calls the attention to the fact that the location of the customer bleed port for the air-conditioning system is not optimal on the engine type and that knowledge is lacking concerning modern lubrication oils' characteristics at very high pressure and temperatures and their effect on human health. In addition instructions were lacking concerning how crews shall act during flight when suspicion arises about contaminated cabin air.

The incident was caused by the pilots becoming temporarily affected by probably polluted cabin air.

Recommendations

The Swedish Civil Aviation Administration is recommended to work in consultation with the foreign civil aviation authorities concerned to encourage:

- that existing emergency checklists and emergency training programs are complemented regarding immediate steps to be taken when suspicion arises that the cabin air is polluted. The instruction for such occasions shall call for the immediate use of the oxygen mask selected to 100 % *(RL 2001:41e R1);*
- that a plan of action is developed for how crews and aircraft shall be handled directly after landing if an incident with polluted cabin air has occurred *(RL 2001:41e R2);*
- that an international database is established with factual information from flights where suspicion of polluted cabin air exists *(RL 2001:41e R3) and;*
- that research efforts are initiated in regards to the characteristics of modern lubricating oils under very high pressure and temperature and their influence on the health of human beings *(RL 2001:41e R4).*

1 FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Flights prior to the actual flight

The crew met on the 12th of November 1999 at approximately 14.30 hours at Stockholm/Bromma airport in order to carry out three return flights between Stockholm and Malmö together. The flying time on the route is approximately one hour.

During the first flight from Stockholm to Malmö, with route number BU 925, the purser experienced an unpleasant feeling of fainting on one occasion when she had bent down in order to obtain articles out of a cabinet and then stood up straight. She told the other two cabin crew-members about this and they stated that they had also experienced something similar. They did not recognize any special odour. During the ground stop in Malmö the entire crew discussed the unpleasant feeling that the cabin crew had experienced. The pilots had not noticed anything abnormal.

During the subsequent flight from Malmö to Stockholm, with route number BU 932, one of the cabin attendants who was placed in the forward part of the cabin, experienced an odd pressure in the head, nasal itching and ear pain. The other two colleagues in the cabin also felt discomfort and the feeling of "moon walk" while working. During the ground stop of approx. one hour in Stockholm the crew once again spoke about the cabin personnel's discomfort. The pilots, who did not notice anything abnormal during the second flight either, discussed whether the problem could possibly be due to some fault within the cabin pressure system. The matter was not discussed with the ground engineers.

1.1.2 The actual flight

The third flight that same day, which returned to Malmö with route number BU937, was flown by the commander. In connection with his starting of the engines he made two mistakes, each of which resulted in his, as he put it, "I shut down the aircraft". During the climb after takeoff, shortly after the sign "Fasten seatbelt" had been turned off, the commander in the cockpit and the purser in the passenger cabin noticed during a short moment an odour which the commander could not describe but the purser associated with burnt sulfur. The purser checked to see if the smell came from the coffee brewer or the toilet but noted nothing abnormal. The smell disappeared rapidly and did not reoccur. The first officer (co-pilot) had not noticed any odour, which according to him could have been due to the fact that he had a cold.

During the flight, which took place at a cruising altitude of FL 280, all three members of the cabin crew experienced similar discomfort as during the preceding two flights, but more pronounced. One of the cabin crew also felt srt of a burning in the scalp. During the first portion of the flight the pilots did not notice anything abnormal but shortly before they were to leave the cruising altitude the commander began to feel a mild dizziness. Even another pilot in the airline, who was sitting in the passenger cabin on passive duty, stated to the cabin crew that he sensed something peculiar about the air in the cabin.

During the approach towards Malmö/Sturup airport when the aircraft was descending through FL 150 the co-pilot suddenly became nauseous and donned his oxygen mask. Then, after an estimated period of ten seconds, the commander also became very nauseous and immediately donned his oxygen mask. After a few seconds of breathing in the oxygen mask the co-pilot felt better and thereafter had no difficulty in performing his duties. However, the captain felt markedly dizzy and groggy for a couple of minutes. He had difficulty with physiological motor response, simultaneity and in focusing. Finally he handed over the controls to the co-pilot. During the approach, when the purser went forward to the pilots to tell them that the cabin was prepared for landing she noted that both of the pilots were using their oxygen masks. In his groggy state the captain even had difficulty in grasping the purser's finger as acknowledgement of her clear signal.

After having breathed oxygen a few minutes even the captain began to feel better and thereafter the pilots were able to accomplish a normal approach and landing on runway 17 without problems.

The pilots considered using the emergency checklist but did not. An emergency was not declared to air traffic control.

When the passengers, of which several were frequent travelers and known by the crew, departed the aircraft after the flight, the cabin crew was of the opinion that several of them seemed passive and more tired than normal to have been on a Friday night flight. However, no one mentioned any complains.

The incident occurred in the airspace north of Malmö/Sturup airport, M County, between FL 150 and FL 100.

1.2 Injuries to persons

	Crew	*Passengers*	*Other*	*Total*
Fatal	–	–	–	–
Serious	–	–	–	–
Minor	–	–	–	–
None	5	68	–	73
Total	5	68	–	73

1.3 Damage to aircraft

None.

1.4 Other damage

None.

1.5 The crew

1.5.1 The commander

The commander was 39 years old at the time and had a valid Airline Transport Pilot's License (Swedish).

Flying hours previous	*24 hours*	*90 days*	*Total*
All types	4	89	5 613
This type	4	89	3 082

Number of landings on this type the last 90 days: 80.
Flight training on type concluded 1992-02-14.
Latest PFT (periodic flight training) was carried out 1999-09-13 in a BAe 146 simulator.

1.5.2 The co-pilot

The co-pilot was 34 years old at the time and had a valid Commercial Pilot's License with an instrument rating (Swedish).

Flying hours previous	*24 hours*	*90 days*	*Total*
All types	4	127	2 450
This type	4	127	2 020

Number of landings on this type the last 90 days: 111.
Flight training on type concluded 1996-03-14.
Latest PFT was carried out 1999-10-06 in a BAe 146 simulator.

1.5.3 Other crew members

There were a purser and two cabin attendants onboard with requisite qualifications.

1.6 The aircraft

1.6.1 General

THE AIRCRAFT

Manufacturer:	British Aerospace
Type:	BAe 146-200
Serial number:	E2051
Year of manufacture:	1986
Gross weight:	Maximum authorized 40,596 kg, actual 34,483 kg
Center of gravity:	Index 46 / Trim3.1
Total flying time:	18,744 hours
Number of cycles:	20,281
Flying time/cycles since last inspections:	A-check 335/378 C-check 469/532
Fuel loaded before event:	Jet A1, 4,500 kg status ramp fuel

ENGINE

Manufacture:	Lycoming
Model:	ALF502R-5

Number of engines:	4			
Engine	*# 1*	*# 2*	*# 3*	*# 4*
Total operating time, hrs.	13,614.2	14,776.3	17,608.3	16,650.6
Total number of cycles	14,501	15,720	18,030	18,812
Time since overhaul	1,639.7	3,984.3	1,646.0	1,626.6
Cycles after overhaul	1,814	4,435	1,819	1,736

The aircraft had a valid Certificate of Airworthiness.

1.6.2 Engine design

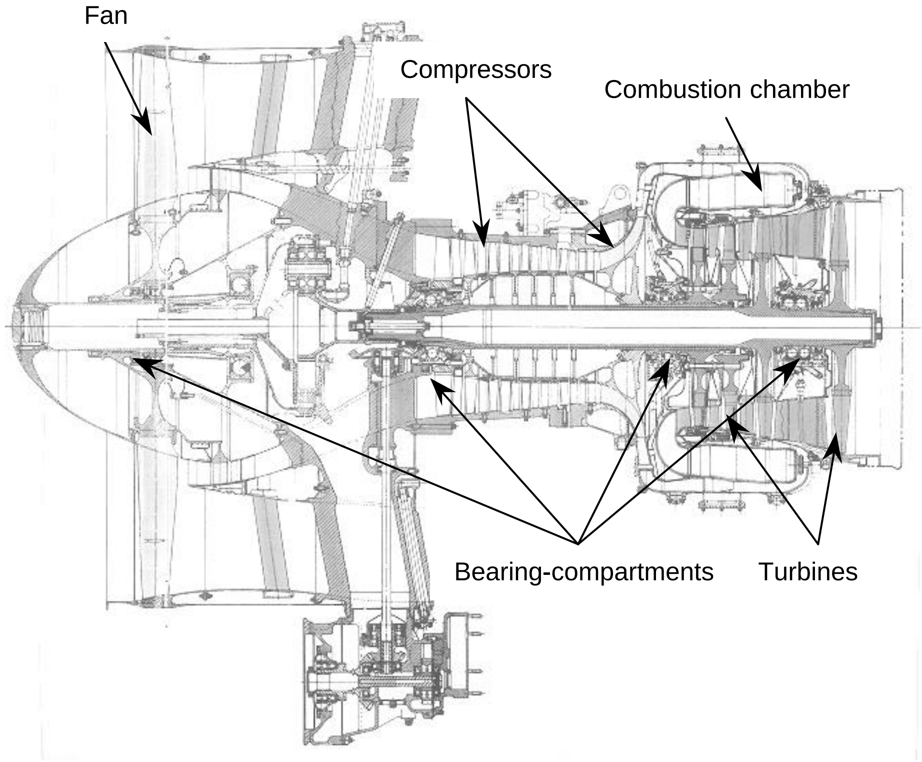
Basic construction

Originally the engine type was developed as a turboshaft engine for use in helicopters. For aircraft use the engine was fitted with a fan section that is driven by the engine's drive shaft via a planetary gearbox. The engine consists of a gas generator and a free-turbine, each one with its own rotor shaft. The gas generator has a compressor section, a combustion section and a turbine section, all mounted on the same rotor shaft. The compressor consists of a seven stage axial compressor followed by a centrifugal compressor. The combustion case has a ring-type combustion chamber (annular). The rotor shaft is driven by a two-stage turbine.

Rotor bearings

The engine rotor shafts are journalled in several oil-lubricated roller- and ball bearings, which are located in bearing-compartments along the centerline of the engine. Drive shafts extending from these compartments are sealed by the use of carbon faced seals as primary seals. The carbon-seals are lubricated and cooled by the oil that is inside the respective bearing compartment. If an oil leak should arise from one of the engine's forward bearing compartments, this is from experience perceived at once as the smell of oil in the cabin, usually before one notices it by high oil consumption.

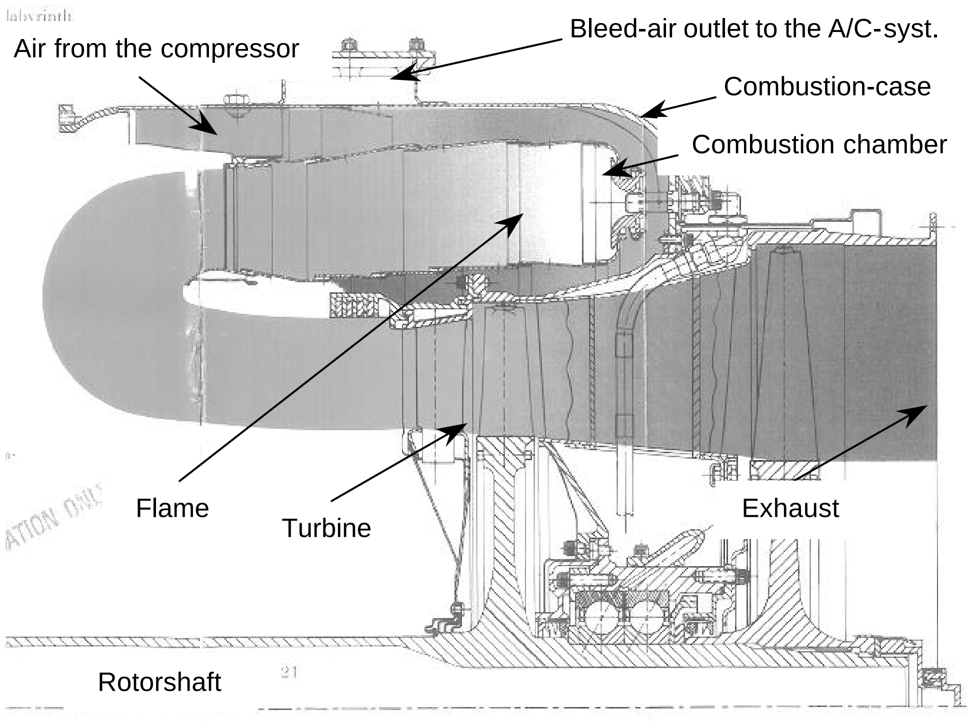
This engine type does not have so-called knife-edge seals to back up the carbon seals at the number one bearing compartment (inlet to high-pressure axial compressor). Knife edge seals are found in many engine types and are a non contact method of maintaining the desired pressure distribution within an engine, one function of which is to reduce oil and oil mist entering the gas flow.



Engine schematic

Bleed air system

The engine has bleed air valves partly for deicing, partly for the aircraft's air-conditioning system. The bleed air for the air-conditioning system takes place via a ring-formed duct in the outer shroud of the combustion case abreast of the engine's combustion chamber. The outlet is placed on the upper portion of the combustion case shroud. Depending upon the thrust setting of the engine, the temperature of the engine bleed air varies between 100 °C and 400 °C. On most modern jet engines, the bleed air outlet is located farther forward on the engine, i.e. somewhere on the compressor section of the gas generator.



Burner section

1.6.3 The air-conditioning system

In addition to air from the engines' bleed air system, the air-conditioning system can be supplied with air from the aircraft's APU[4]. Normally, during taxi and during takeoff and landing, air from the APU is utilized. During all other phases of flight all air supply takes place via the engines. With normal setting of the air distribution, 30% of the bleed air from engine #1 and #2 (on the left wing) goes to the flight deck and 70% of the air to the passenger cabin. From engine #3 and #4, 100 % of the bleed air goes to the passenger cabin.

Prior to the bleed air from the engines entering the flight deck and passenger cabin it is pressure regulated and cooled. The cooling takes place in two stages. The first is a heat exchanger (Pre-cooler) placed in the respective engine nacelle. The cooling takes place with air from the engines' fan stages. Downstream of the heat exchanger the temperature of the air is 220–230 °C. The next stage in the cooling takes place in the Air Conditioning Packs placed below the floor in the aft section of the aircraft. In the packs the final pressure and temperature adjustments take place prior to the air entering the cabins. *(See Appendices 2 and 3).*

During operation, oil and other contamination in the air that passes through the engine can accumulate in the Air Conditioning Packs and cause a disagreeable odour in the cabin air. The aircraft manufacturer initially prepared a special procedure for burning these undesirable products when necessary, so-called Burn Out. During "Burn Out" one allows hot bleed air from the APU to flow at maximum rate through the unit during approx. 15–20 minutes. Later the aircraft manufacturer has subsequently withdrawn approval for this procedure.

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[4] APU = Auxiliary Power Unit

Historical account

During the years the aircraft type has been in service, some operators have reported intermittent events when unpleasant smells were found to be coming from the air-conditioning system. The air in the cabin has been experienced as stale or as smelling of oil. In order to overcome this problem some aircrafts have been retrofitted with catalytic converters, one on each engine within the bleed air system. The incident aircraft was not equipped with catalytic converters.

Among operators and crews of the aircraft type, it is a known phenomenon that even a slight internal oil leakage in one of the engines can be manifested in a distinct smell of oil in the cabin. When this happens, the cabin air can also assume a somewhat bluish tone.

Possible health risks through prolonged exposure to foul cabin air have been the subject of several international actions on the part of cabin crews in relation to the BAe 146. In this context the aircraft type in question is over-represented.

1.6.4 Technical maintenance

The aircraft was maintained in accordance with applicable regulations. No complaints concerning the air-conditioning system had been noted prior to the flights in question. None of the engines showed any evidence of unusually high oil consumption. It is not documented when the latest Burn Out of the Air Conditioning Packs was performed prior to the incident.

1.7 Meteorological information

Metar Malmö/Sturup airport at 18.50 hrs: wind 280°/08 knots, visibility 5,000 meters in haze, cloud cover 5-7/8 with the cloudbase at 1,000 feet, temperature/dewpoint +8/+7 °C, QNH 1026 hPa.

1.8 Aids to navigation

Malmö/Sturup airport's runway 17 is equipped with ILS[5]. The aircraft was equipped for instrument flight.

1.9 Communications

Customary radio communications between the pilots and the air traffic controller occurred. The pilots did not notify air traffic control about what had taken place.

1.10 Aerodrome information

Malmö/Sturup airport had operational status in accordance with the Swedish AIP (Aeronautical Information Publication).

[5] ILS – Instrument Landing System

1.11 Flight recorders

1.11.1 Flight data recorders (FDR, QAR)

The aircraft was equipped with a flight data recorder from GEC-Plessey Avionics, Type PV1584J. A transcription of recorded information was not performed subsequent to the incident.

1.11.2 Cockpit voice recorder (CVR)

The aircraft had a cockpit voice recorder of type Fairchild, Model A100 installed. A transcript of recorded sound was not performed until the aircraft was test flown after the engine change (*see 1.16.1*).

1.12 Accident site and aircraft wreckage

Not applicable.

1.13 Medical information

With the exception of the fact that the purser had not had time to eat lunch and that the co-pilot and one of the cabin attendants had colds, everyone in the flight crew felt completely healthy at the beginning of the duty time. After the incident the commander was shaking and in a cold sweat. He did however fall asleep quickly that evening and slept well the entire night. He experienced symptoms for up to 24 hours afterwards. No medical examinations were performed after the incident.

1.14 Fire

There was no fire.

1.15 Survival aspects

All onboard were subjected to a serious risk during the flight in that both pilots were partially incapacitated.

1.16 Tests and research

1.16.1 Trouble-shooting the aircraft

Subsequent to the incident, the airline performed a trouble-shooting of the aircraft, which ascertained a minor external oil leak on engine # 2. The leakage was preliminary localized to a carbon-steel sealing on bearing #2 and as oil leakage from this area, from experience, can cause oil fumes in the cabin, it was assumed that this was the complete explanation for the feelings of sickness. It was not possible to rectify the oil leak in question when the engine was mounted on the aircraft; therefore it was decided to exchange the engine. In conjunction with the engine change a so-called Burn Out of the Air Conditioning Packs was performed in order to burn away possible oil that might have collected there as a consequence of the oil leakage.

After these measures were taken the aircraft was test flown. During the flight no smell of oil or other unpleasantness could be noticed in the cabin air. Air-samples were taken during the flight from flight deck, forward galley, cabin and rear galley with a carbon monoxide indicator of type Auer PRP 5146-701 (DIN33883). The measurements gave no deflection. The aircraft then was released to service. No complaints concerning foul cabin air have been reported since.

1.16.2 Operational conditions

In addition to the engine change and the other measures as stated above, an extensive audit was accomplished by the airline immediately following the incident of other possible sources that could have given rise to any substance or gas in such a concentration that the crew was affected. This audit included conceivable sources outside as well as inside the aircraft; such as de-icing fluid, sanitary fluids, cargo, baggage, cleaning agents, fire-extinguishing equipment, hydraulic equipment etc. Nothing in the investigation indicates that any of the investigated sources could have had other than a possible marginal significance in the discomfort the crew experienced.

1.16.3 Test-run of the engine in test cell

As the cabin air in the aircraft was free from odours after the engine change and no complaints were subsequently reported about the quality of cabin air; it was assumed that the incident was caused by a fault on engine # 2 and the bleed air that the engine delivered to the aircraft. In consultation with SHK, the airline, the aircraft manufacturer and the engine manufacturer, it was decided to ship the engine (ALF502R-5, S/N LF05311) to the engine manufacturer Honeywell in Phoenix, USA, for test running in a test cell under the supervision of SHK. The test should be performed with the engine in the same condition as it was when removed from the aircraft. The intention was to take amples of the engine’s bleed air during various operating conditions in order to attempt to determine the possible existence of a high concentration of any poisonous substance. An engine test plan was developed and approved by the parties concerned *(Appendix 4)*.

In connection with the arrival inspection, which was carried-out prior to the mounting of the engine in the test cell, another minor oil leak was found in the fan stages of the engine and was localized to a leaking seal for bearing #9. A bearing compartment pressure check was not performed.

Several different methods were used for collection and analysis of the bleed air. The ordinary equipment for the test run of the engine in the test cell was therefore complemented with special equipment for collection of the engine bleed air in tanks for subsequent analysis in a laboratory. The concentration of certain gases and substances could however be read directly.

The engine was thereafter run in the test cell according to the specially prepared engine run schedule below. This was intended to simulate the two last flights on the day of the incident with regard to engine thrust settings and run duration. Limited measurements of the bleed air quality were even done in connection with immediate power advance and retardation.

Test points

Flight Phase	*~Bleed Temp °F*	*~NH*	*Dwell (minutes)*	*Bleed Conditions* *Engine*	*ECS*	*AC/AI*	*Nacelle*	*Summa Canister*
Start	–	–	–	On	Off	Off	On	–
Idle/Taxi	220	10 000	15	Off	Off	Off	Off	–
Take-Off	700	18 900	3	Off	Off	Off	Off	1
Climb 1	590	17 600	5	On	On	On	On	1
Climb 2	590	17 600	15	Off	On	Off	Off	1
Cruise	550	16 500	20	Off	On	Off	Off	2
Decent 1	450	13 000	10	Off	On	Off	Off	3
Decent 2	340	10 000	5	On	On	On	On	3
Decent 3	330	10 000	5	Off	Off	Off	Off	3
Taxi/Idle	220	10 000	3	Off	Off	Off	Off	–

A description of the testing methodology used for the air tests performed and the results of the analyses completed have been summarized in section 1.16.4.

The average oil consumption during the two test runs was calculated to be 0.65 quart (0.62 l) per hour. Maximum allowed oil consumption according to the manufacturer is 0.5 quart (0.47 l) per hour. The exceedence of the maximum allowed oil consumption was judged to be due to an unreliable method of measurement and that a new minor oil leak appeared from bearing #4 during the test run, probably in connection with one of the rapid thrust advances or retardations that were carried-out.

1.16.4 *Air quality test results taken during engine run in the test cell.*

Analytical results of the air specimens that were taken during the engine test run have been stated in *Attachment 2 Air Quality Test Report* (CMR 99248A) in *Engineering Investigation Report Customer Bleed Air Testing Engine Model ALF502R-5, S/N LF05311* (Honeywell 21-11156, dated the 3rd of March 2000).

The results have been summarized according to the following

- For the confirmation of airborne chemical substances (gases, vapors and aerosols) in the bleed air from the engine, 20-minute samplings were accumulated during the three phases of each simulated flight: *climb, cruise at altitude, and descent*. Furthermore an accumulated collection of gas specimens was taken during both simulated flights.
- Gas specimens for gaschromatographic/masspectrometic analysis (GC/MS) of volatile organic substances, carbon monoxide, carbon dioxide and methane were collected with the help of evacuated canis-

ters. For analysis of non-volatile gaseous substances and aldehydes air was suctioned through canisters with polyurethane foam (PUF/XAD-2) respective 2,4–Dinitrophenyl-hydrazine (DNPH) as an absorbent.

– The specimens that were accumulated were later analyzed in a laboratory with the help of GC/MS- respective HPLC-technique (high performance liquid chromatography). With the help of a mobile laboratory a continuous analysis of carbon monoxide, nitrous gases, carbon dioxide and organic compounds was also accomplished.

– The results from the first test indicated an increased level of organic substances (i.e. oil and fuel) in connection with maximum power application. Approximately two minutes after the climb had been initiated the content returned to normal levels. The subsequent measurements showed levels within the specifications that are stated for this engine model.

– The measured content of carbon dioxide, carbon monoxide, nitrous gases, hydrocarbons and degradation products from oil (such as formaldehyde) was within the limits that have been stipulated by the CAA[6] in England and by the FAA[7] in the USA.

1.16.5 Dismantling and inspection of the engine

As the continuous air quality tests that were accomplished during the engine run in the test cell did not show the presence of any unusually high concentrations of poisonous gases or substances, it was decided that the engine would be dismantled and inspected. At the request of the airline this inspection was done at Honeywell's maintenance facility in Luton, England, which is the airline's ordinary maintenance authority for their ALF502R-5 engines.

The job was initiated on the 10th of January 2000 and was carried-out under the supervision of SHK and representatives from the airline, the aircraft manufacturer and the engine manufacturer. The engine was dismantled step by step in modules. The participants decided upon the dismantle sequence and the pace. Special interest was devoted to attempting to find any fault or abnormality in the engine that could have resulted in exhaust gases or other undesirable substances entering the air-conditioning system.

The general condition of the engine was better than normal, taking into account the operating hours that it has accumulated after the latest overhaul. With the exception of the oil leak found by the operator and the minor defects listed below, no fault or abnormality could be found that could have explained a possible discharge of poisonous gases or substances into the bleed air system. The flatness of the carbon seals and carbon seals plates was not checked.

<u>Observed defects and discrepancies</u>

– Presence of coking on carbon seals for bearing #1. Indication of the occurrence of minor oil leak.

[6] CAA = Civil Aviation Authority
[7] FAA = Federal Aviation Administration

– Two minor cracks in the oil return line for bearing #2.
– Presence of coking on carbon seals for bearing #2. No indication that any oil leak occurred.
– Presence of coking on carbon seals for bearings #4 and #5. Indication of the occurrence of oil leak.
– Presence of coking on carbon seals for bearing #9. Indication of the occurrence of oil leak.
– Indication of a certain degree of contact (”rubbing”) between impeller and impeller housing in the radial compressor. (According to the engine manufacturer not unusual for engines in operation).

1.16.6 *Test flight with the aircraft*

As a compliment to the investigations that were performed on the engine according to the above, it was decided to undertake a flight test with the aircraft in question, SE-DRE. The test flight was done without the investigated engine because it had been overhauled and was therefore no longer representative of the occurrence in question. The intention was to prepare a quality analysis during flight of the additive air from the air-conditioning system to the flight deck and the passenger cabin.

The test flight was undertaken in the form of two flights where earlier representatives participated. The test took place on the 11th of March 2000 according to the test program: *BAe 146-200, SE-DRE Flight Test Plan March 11–12, 2000 (Appendix 5)*, which was prepared and approved by the authorities concerned. The objective was that the test as far as possible should simulate the two last flights on the day in question. During both flights, which were flown by the pilots involved in the incident, air samples were taken and air analyses were performed during the following phases; taxi prior to takeoff, climb, cruise at altitude, descent and taxi after landing.

In the same manner as during the engine test in Phoenix, several methods were used for the collection and analysis of the air. A total of 29 passenger seats were removed in order to provide room for the required measuring equipment. Parallel with the measurements that the engine manufacturer took during the flights, measurements were taken with the assistance of personnel and measurement equipment from the then existent FOA[8].

A description of the tests performed and the results of the analyses done have been summarized in section 1.16.7.

1.16.7 *Air quality test results taken during test flights*

The analysis results of the air quality tests that were taken during the flights have been accounted for in two separate reports:

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[8] FOA = The Swedish Defence Research Establishment.
From 2001-01-01 FOI = The Swedish Defence Research Agency

A. ”Test Report Air Quality Test Performance on BAe 146-200 Aircraft Registration Number SE-DRE for the Swedish Board of Accident Investigation” (Honeywell 21-11509)

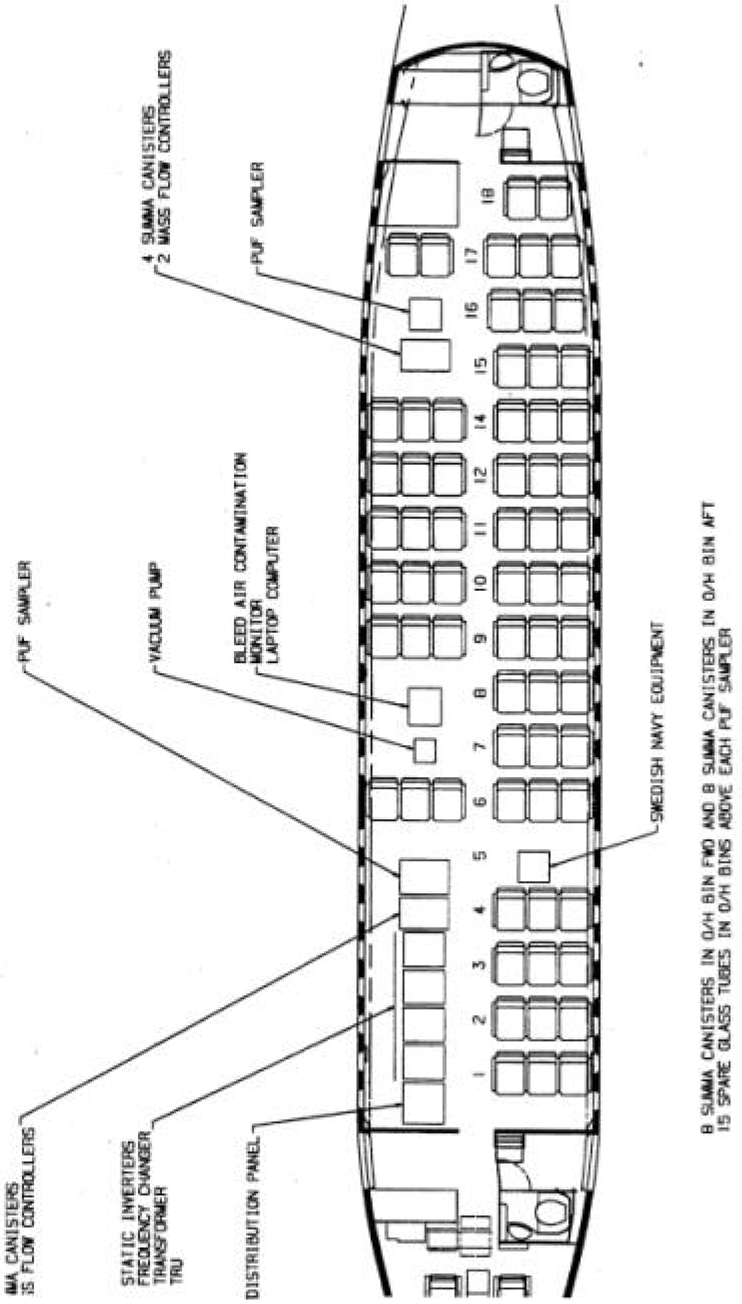
Summary

The samples were collected at ventilators on the flight deck (air intake from engine 1 and 2) and in the aft section of the passenger cabin (air intake from engine 3 and 4).

For an analysis of the volatile organic substances, carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4) air samples were collected in evacuated canisters. For analysis of non-volatile gaseous substances and aldehydes, cabin air was suctioned through canisters with polyurethane foam (PUF/XAD-2) respective 2,4–Dinitrophenylhydrazine (DNPH) as an absorbent. The samples were then analyzed in a laboratory with the same technique that was used during the engine test cell run (see section 1.16.4). Carbon dioxide and organic substances (i.e. oil and fuel) were continuously analyzed during the entire test. The concentrations of ozone, formaldehyde, and the temperature and relative humidity were measured with hand-held dosimeter counters and sensors.

The results showed that the concentrations of carbon dioxide, carbon monoxide, hydrocarbons, oil degradation products (such as formaldehyde) and ozone were within the stipulated and generally accepted limits respectively. The concentrations of aldehydes, semi-volatile gaseous substances, and volatile organic substances were consistently low. There are no limits established by the FAA or the JAA[9] for these substances. A review of “the ventilation equipment’s various settings” did not show any noticeable changes in the results of the cabin air analysis whether it was ventilated with fresh air or if the cabin air was re-circulated.

[9] JAA = Joint Aviation Authorities



Installation of measuring equipment in the aircraft

B. "Air Quality Investigation, BAe 146-200" (FOA-R-00-01656-720-SE)

Summary

FOA´s task in connection with the test flights was to complement the air quality analyses that were performed by Honeywell.

Oxygen- (O_2), carbon dioxide- (CO_2), and carbon monoxide concentrations (CO) in the cockpit, cabin pressure, and relative humidity were continuously logged. Ammonia (NH_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and nitrous gases (NO_x) were

analyzed intermittently with the help of colorimetric measurement technique (Drägers CMS). Sampling for analysis of volatile organic substances in the bleed air from the engines to the cabin was accomplished during the different phases of flight with the help of adsorption tubes (TENAX TA). The samples were later analyzed in a laboratory with the help of GC/MS-technique.

The cabin pressure varied between 740 and 1010 hPa. The lowest oxygen partial pressure that was recorded was 15,2 kPa and the partial pressure for carbon dioxide never exceeded 0,2 kPa. The concentration of ammonia, carbon monoxide, sulfur dioxide and nitrogen dioxide never exceeded the lowest detection threshold of the instruments. On two occasions an increased content of nitrous gases (>15 ppm) was measured that could not be explained. The Total concentration of Volatile Organic Compounds (TVOC) was very low during climb, cruise at altitude, and descent. During taxi the concentrations were slightly elevated compared to the lower limit where problems with indoor air quality begin to appear (0.2 mg/m^3 toluene equivalents). This general limit is established through comparisons with the so-called Örebro questionnaire. The air quality tests that were taken in other connections during the flights have shown mainly the existence of the isomeric hydrocarbons hexane, heptane, and glycolates. The elevated concentration of TVOC can be due to the ventilation system in the aircraft, especially the position of air intakes and possibly the heating system.

None of the parameters recorded showed results that deviated from generally accepted limits. Some of the TVOC analyses showed, as mentioned, elevated concentrations, but based upon so few measurements, it is not possible to specify a source of the contamination. Also it is not possible to rule out that the elevated No_x content which was read, was caused by a deficiency in the measurement equipment or cross sensitivity for other gases.

1.17 Organizational and management information

Braathens Malmö Aviation AB has its headquarters in Malmö and pursues heavy domestic and international air traffic. At the time of the incident the airline operated with 10 aircraft of type BAe 146-200. In addition the company operated 4 aircrafts of type F-100 and 2 aircrafts of type B-737. The company had approx. 940 employees.

1.18 Additional information

1.18.1 SHK´s investigation

The occurrence was not initially handled as a serious incident but as an engine fault. For this reason SHK was not informed of the occurrence until four days later. Therefore the corrective measures that were performed on the aircraft during this period took place without the participation of any representative from the SHK. However SHK has complete confidence in the trouble-shooting steps that were taken and in the factual information that the airline provided concerning these tasks and the observations that were made during this time.

The continued investigation of the incident has, as evidenced previously, taken place in close cooperation with representatives from SHK, the airline, the aircraft manufacturer, and the engine manufacturer.

1.18.2 Cabin air quality

During the last few years the quality of the cabin air in modern airliners with pressurized cabin has been the subject of great attention within the airline industry. The reports are not the exclusive preserve for the BAe 146 types of aircraft. They also refer to other types, e.g. MD80 and B757 etc. This interest concerns both the possible damaging influences to health during prolonged exposure to poor air quality and acute impairment of performance capability of crews during transitory exposure to temporarily polluted air. There are quite a number of reports about incidents that threatened the safety of flight in that the pilots were suddenly affected with temporarily more or less substantial capacity impairment as a result. Some of the incidents have been associated with the smell of oil, other odours, or smoke in the cabin. In other cases such indications have been absent. There are several cases concerning suspected damaging or disabling effects due to prolonged exposure to contaminated cabin air. This is a problem that has created a certain apprehension within the airline industry.

Several investigations have been done and many scientific articles have been written about this subject. This complex problem is not yet solved. Current regulations in JAR[10] 25.831 and FAR[11] 25.831 concerning cabin air do not specify in detail what requirements are to be placed on the quality of cabin air and how this is to be verified.

A suspect component in this matter is engine oil. Since the aircraft engines or APU usually provide the cabin air during flight, a minor internal oil leakage in an engine can result in contamination of the additive air to the pressurized cabin by some form of undesirable oil products.

In the publication ”Rayman et al AsMA 1983” 89 cases from different parts of the world with suspected presence of oil in the cabin air have been summarized. The symptoms in these cases have usually been irritated mucous membranes (eyes, mouth, throat, and respiratory passages) but also serious symptoms such as headache, feelings of void, upset stomach, confusion, disorientation, distortion of vision etc.

The report *Van Netten Appl. Occup. And Env. Hygiene 2000* describes – by the heating of synthetic lubricating oil of the types in question – the formation of a large number of new substances, such as hydrocarbons, carbon monoxide and low concentrations of organic phosphoric compounds, that are known nerve poisons. The report, however, does not state if the concentrations were at levels, which would be a threat to human health. Tests performed by SHK and, on behalf of the aircraft manufacturer, by other independent experts have not detected organic phosphoric compounds at levels, which approach internationally accepted safe norms. In most cases, no traces at all of these compounds have been found.

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[10] JAR = Joint Aviation Requirements
[11] FAR = Federal Aviation Regulations

Large demands are placed on the lubricating characteristics of modern lubrication oils and the precise recipe is often a company secret. This obstructs the determination of the degree of toxicity of different oils. Furthermore the toxicity of the ingredient substances is not known.

The manufacturer of BAe 146 has attempted to eliminate the effect of minor oil leakage from the engines by, as earlier mentioned, the introduction of catalytic converters in the bleed air system, similar to the type on gasoline driven automobiles. In order for this to function optimally high temperature is required, the degree of contamination must be relatively constant and it cannot exceed certain values. In the case of a direct oil leakage, these catalyzers do not seem to be capable of transforming all the different existing hydrocarbons to carbon dioxide and water, as is the case with automobile exhaust. The incident aircraft was not fitted with catalytic converters.

To the knowledge of SHK no or a very limited medical examinations have been documented covering the reported cases of sickness that are presumed to have been caused by contaminated cabin air. None of the few medical tests that have been made on crew members after actual incidents seem to have shown any large deviations from normal values.

The quality of cabin air has been discussed in a senate interrogation committee in Australia. There are several recommendations in a report from that interrogation about the authorities concerned taking co-ordinate measures in order to overcome the problem. The general opinion is that there is a lack of fundamental research concerning the degradation products of lubricating oils and their biological effects. It is also requested that the respective civil aviation authority take the initiative to introduce a more systematic system of reporting and follow-up of actual incidents. However the committee refrained from any opinion about possible long-term effects on cabin crews, something thatis the subject of several legal proceedings in courts and under scrutiny by insurance companies

Similar initiatives are in progress in England and the USA. Committees within AsMA[12] and ASHRAE[13] are also working with these questions.

1.18.3 Measures taken by the airline

In addition to the trouble-shooting measures that were taken by the airline as earlier mentioned, the company flight crews have been informed about the actual incident. A plan of action has been developed as to how the crew shall act after landing, should a similar situation arise again. The plan entails that in such a case the crew shall immediately contact a doctor and undergo a medical examination according to a stipulated program *(Appendix 6)*. The intention is to, if possible, acquire information about which components that can be contributory to the symptoms before the body has to recover from the effects. At the time of publication of this report no further event has taken place within the company.

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[12] AsMA = Aerospace Medical Association

[13] ASHRAE = American society of Heat, Refrigeration, and Air conditioning Engineers

1.18.4 Measures taken by the aircraft manufacturer

The aircraft manufacturer continuously follows-up submitted reports of disturbances from operators of the BAe 146 type of aircraft. The following information has been provided by the manufacturer.

During the period from June–92 until January-01 a total of 22 cases were reported where the flight crew's capacity had been impaired. Of these, seven have been judged as serious since they affected flight safety negatively (MOR[14]).

During the period from January-96 until September-99, 212 reports were submitted by a specific airline to the aircraft manufacturer concerning tainted cabin air. Of these, 19 reports concerned the impairment of the crew's capacity. Seven of the reports were submitted directly by the crewmembers.

From another 36 operators of the aircraft type a total of 227 occurrences relating to contaminated cabin air were reported during the period from May-85 until December-00. Of these, 11 reports concerned the impairment of the crew's capacity.

On account of the problem, the aircraft manufacturer has, among other things, published the following document for operators of the aircraft type. The following is a summary of the contents:

<u>All Operator Message (AOM)</u>

AOM Ref 99/020V
Risk of affection by CO_2 in connection with the handling of dry ice.

AOM Ref 99/024V
Immediate use of oxygen mask when smoke or abnormal smell appears in the cabin.

AOM Ref 00/030V
Measures to take when smoke or smell from the air-conditioning system is sensed.

AOM Ref 01/003V
Recommended maintenance steps on the air-conditioning system in order to diminish the risk of sub-standard cabin air.

AOM Ref 01/004V
Revision of the Emergency Checklist concerning contaminated cabin air.

<u>Service Information Leaflet (SIL)</u>

In SIL Ref 21-45 (26 pages) measures to be taken to guarantee the required quality of cabin air are treated, as are different trouble-shooting steps with regard to foul air.

<u>Inspection Service Bulletin (SB)</u>

In Inspection Service Bulletin, 21-150 periodic inspection and cleaning of components in the air-conditioning system is prescribed to diminish the risk of foul cabin air.

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[14] MOR = Mandatory Occurrence Report

1.18.5 Measures taken by the CAA, UK

CAA has issued an AD (Airworthiness Directive) No 002-03-2001, wherein it is directed that measures according to BAe SB 21-150 shall be taken on the aircraft type.

1.18.6 Safety recommendations from the AAIB, UK

On the 5th of November 2000 a serious incident occurred with an aircraft of type BAe 146-200 during flight from Paris CDG Airport in France, to Birmingham International Airport in England. The AAIB is investigating the incident.

When the aircraft had left its cruising altitude and initiated the approach to Birmingham the commander began to feel ill. He then asked the co-pilot, who was the flying pilot, how he felt and received the answer that he also felt ill (“felt dreadful”). His face was pale and his pupils were dilated. The commander then took over the co-pilot’s duties and instructed him to don his oxygen mask. He himself did not don his oxygen mask. During the continued flight the co-pilot was conscious but was not capable in any way to participate in the flight.

The commander, who now felt worse, instructed the purser to regularly look-in on the flight deck and check on the pilots’ condition. The commander had a rapid pulse and a dry mouth, but judged that he was capable of completing the approach and landing the aircraft himself. When he obtained visual contact with the runway he was seeing double and had difficulty in judging his altitude. After the landing, which was ”firm”, both the commander and the co-pilot began to feel better.

Earlier during the flight a few passengers had expressed to a flight attendant that they thought they smelled oil in the cabin. None of the crewmembers have been able to verify this.

No technical fault on the aircraft that could explain the occurrence has been found. The assessment is however that oil by-products from the aircraft’s engines, together with other contaminants in the air, probably had accumulated in the aircraft’s air-conditioning system and under the influence of high temperature and pressure, formed poisonous components, which were momentarily introduced into the cabin air.

Because of this and several similar incidents which affected aircraft types other than the BAe 146, the AAIB on 4 May 2001 made five recommendations (Ref: EW/C2000/11/04) as summarized below:

<u>Recommendation No 2001-4</u>
It is recommended that the CAA in conjunction with BAe develop the required maintenance and modification standards for the aircraft type BAe 146 which shall ensure that oil by-products cannot accumulate in the air-conditioning system and pollute the cabin air.

<u>Recommendation No 2001-5</u>
It is recommended that the FAA, in conjunction with Boeing develop the required maintenance and modification standards for the aircraft type Boeing 757 which shall insure that oil by-products cannot accumulate in the air-conditioning system and pollute the cabin air.

Recommendation No 2001-6
It is recommended that the CAA initiate high priority research efforts with the intention of determining the substances that can enter the cabin air on the aircraft type BAe 146, should oil leakage arise from the engines.

Recommendation No 2001-7
It is recommended that the CAA investigate whether any of the components that are identified according to recommendation 2001-6 above, can negatively affect the persons onboard physiologically and/or neurologically. In the recommendation the Flight Operations Department Communication (FODCM) 17/2000, which was issued by the CAA on 28 December 2000 is referred to. Herein are described the immediate steps to be taken if any crewmember appears to be affected by contaminated cabin air during flight.

Recommendation No 2001-47
It is recommended that the CAA consider issuing additional instructions about how the crew should react to the suspicion of unhealthful cabin air. The instructions shall call for the pilots use of oxygen masks selected to 100% oxygen and that the cabin personnel shall actively and regularly observe the state of health of the pilots.

The recommendations in full are enclosed in *Appendix 7*.

1.18.7 Synthetic oils

High demands are placed upon the physical lubricating and cooling characteristics of synthetic hydraulic and lubrication oils used in modern jet engines. These oils consist of a blend of esters with additives of varying types of organic phosphorus compounds in order to achieve the desired characteristics. In many cases the characteristics of the oils are unknown, if they are subjected to pressure and temperature considerably higher than they are specified for. They can be transformed into different types of hydrocarbons, carbon monoxide, carbon dioxide, and organic phosphorus compounds etc. depending upon the type of oil as well as the circumstances under which the decomposition and transformation takes place. Sufficient knowledge is lacking about these reactions and about the newly created substances' affect on humans.

1.18.8 The airline´s emergency routines

SHK has surveyed the airline's applicable instructions and emergency procedures, valid at the time of the incident. SHK has not found any clear instructions about how the crew shall act if anyone onboard is suddenly affected by contaminated air, that neither smells nor is discernible visually. This does not seem to be addressed during the pilots' or the cabin attendants' respective training programs either.

2 ANALYSIS

2.1 The flight

2.1.1 The crew

As early as on the first of the three flights the day in question, one of the cabin crewmembers reacted to the fact that she did not feel well and even the other two felt strange. Thereafter during the next flight, in different ways, they experienced that they felt strange and thought that there was something peculiar about the cabin air.

They discussed the problem both during the flights and during the ground stops. Of course it cannot be ruled out that in this way they influenced each other and perhaps became more observant about how they felt. However during the last flight for the day, even passengers reacted to the fact that they felt uncomfortable and the feelings that the cabin crew had experienced on the two earlier flights were reinforced. Furthermore both the commander and the purser sensed a peculiar odour a short moment during the climb after takeoff. The commander could not identify what he smelled but the purser thought that the odour reminded her of burnt sulfur. These circumstances indicate that already before the incident itself there was something abnormal about the cabin air which caused them to feel ill. This possibly also explains the mistakes that the commander made in connection with engine start.

SHK has attempted to find factors other than contaminated cabin air that could be the explanation for the experiences of the crew. Nothing during the investigation has however demonstrated such factors, other than some, that possibly had a marginal significance in the course of events; such as the purser not having time to eat lunch and that two crewmembers had colds. Instead everything indicates that the quality of the cabin air had a crucial significance.

All of the crewmembers felt sick during the last of the three flights, during which the pilots were acutely affected. Whether this was due to an accumulated effect of something in the cabin air – or if the air just then was at its worst – has not been able to be determined.

2.1.2 The landing

The pilots had discussed the cabin air with the others in the crew earlier that day and one can presume that they were mentally observant for possible abnormal odours or other characteristics of the air that could affect them. When the co-pilot suddenly became ill he reacted quickly and correctly, by immediately donning his oxygen mask. If one assumes that it was some substance in the air emitted by the air-conditioning system that caused his feeling of sickness, his promptness in initiating oxygen breathing can explain why he recovered so quickly. The commander donned his oxygen mask approximately 10 seconds later and by doing so could have been exposed to unhealthy air during a longer period of time, which could be the reason why it took significantly longer for him to recover.

There are several indications that the pilots' expeditious and correct action contributed to avoiding a situation that could have had very serious consequences. During the similar incident in England in November of 2000, none of the pilots used oxygen. When the aircraft was landed one of them was completely indisposed and the other obviously ill, something that may have been able to be avoided if both pilots had used oxygen.

As the commander transferred the control of the flight to the co-pilot, who after having donned his oxygen mask felt well, the landing could be accomplished without difficulties. SHK have some understanding that the pilots did not declare an emergency as the situation was unusual and something they had not been trained for or dealt with in the process of flight training. Another reason could be that they where affected by something in the air.

SHK calls attention to the fact that this type of incident where the crewmembers, without forewarning of abnormal smell or other indication, can instantaneously become very sick from the air they are breathing was not addressed in the emergency checklists valid at the time nor in emergency training programs. Therefore apparently the need exists to revise the checklists for all applicable types of aircraft and insure that these order the immediate use of 100 % oxygen at the slightest suspicion that unhealthy air may have entered the aircraft. (For BAe 146 this is already reinforced by AOM Ref 99/024V).

2.1.3 Medical considerations

As mentioned there were never any medical examinations performed nor specimens taken from the crewmembers, which is regrettable. This could have perhaps provided a hint about what the crew had been subjected to, or the possibility to rule out certain causes of the symptoms they experienced. The airline has however after this incident taken the required measures in these respects in the event that something similar should once again occur.

SHK's medical experts have attempted to find some possible explanation to what took place on the basis of the crew's symptoms and the discomfort they experienced. Without going into any details it can be stated that certain observations have been considered indicative of a certain type of toxicity while others were considered not to be. The experts have not been able to detect any common denominator that could possibly cover the entire picture that the crew has provided about what they experienced.

2.2 Technical investigations

As is evident from section 1.16, SHK has together with involved parties of interest, performed a very comprehensive technical investigation of the aircraft in question in order to attempt to explain the degradation of the crew's state of health. Also a number of operational factors – as mentioned in 1.16.2 and not dealing directly with the aircraft – have been considered.

Since an oil leak was found on engine #2, and after that engine was changed, the aircraft could return to service and there were no complaints concerning foul cabin air thereafter; it was natural to suspect that the exchanged engine was the source of the contaminated cabin air. Without taking any mechanical measures on the engine, it was mounted into a test cell and was test run with extra equipment for measuring the quality of the bleed air to the aircraft air-conditioning system. However none of the samples that were taken indicated the presence of any substantial concentration of poisonous gas or other poisonous component. Instead the results of the analyses indicated that the concentration of all the identified substances was below both the stipulated limits.

During the subsequent dismantling and inspection of the engine nothing abnormal was noted. The engine was in relatively good condition considering its operating hours. Indeed a few minor oil leaks were found but they were of the type and extent that is not unusual on this type of engine after a time in service. These leaks were of such character and extent that they were from experience judged incapable of resulting in any problem with the quality of the cabin air. Also there was not any smell of oil reported during the flight.

Nothing was found that could shed light on what caused the incident during the investigation of the cabin air; this carried out during the flight test, where the two last flights of the day of the incident were simulated. The results of the analyses of all the air samples that were taken indicated concentrations below the stipulated and accepted limits for those gases and substances that were measured.

SHK can only state that the above mentioned investigations and the air samples that were taken have not led to any clear-cut explanation to what caused this serious incident. The measurement techniques that have been applied and the knowledge that exists within this area have perhaps not been sufficient to reveal the facts. An equally possible alternative is that the contamination that caused the symptoms only appears during very special conditions that did not exist during the engine test cell run or during the aircraft test flight.

In spite of this, everything points to the fact that the quality of the cabin air was of crucial significance for the incident in question and for other similar incidents that have occurred in other airlines.

2.3 Cabin air quality

2.3.1 General

As is evident from section 1.18 the quality of cabin air has attracted increasing attention within the airline industry during past few years. The interest concerns both the flight safety aspect and the possible long-term influence on health. The authorities, aircraft and engine manufacturers and operators have taken several measures in order to overcome the problem. Despite this the problem is not yet solved. Several of the steps that have been recommended are directed at the initiation of research efforts within the area.

2.3.2 Flight safety

The risk that crews can, without warning, be subjected to poisonous cabin air that can substantially reduce their capabilities, or that can temporarily disable an individual crewmember, constitutes a serious threat to the safety of flight. Despite this one must note that the frequency of such events is exceedingly small relative to the annual number of air transports that are performed worldwide.

On the other hand, this fact makes it extra difficult to find an explanation for these events and to arrive at suitable measures to prevent a similar occurrence in the future. Foul cabin air also seems to be able to arise suddenly without forewarning and disappear just as quickly. When the aircraft is subsequently inspected no certain explanation is found. During the measurements that have been accomplished the results of the analyses have indicates normal values.

Due to the fact that the frequency of events is low across all aircraft types, a systematic worldwide collection of data from these incidents, encoding of specific circumstances and the establishment of an international database is required. With access to such a database it should,within the foreseeable future, be possible through basic research to find the explanation for the problem or at least procure some guidance about which areas further research should be concentrated upon.

In respect to this, it is very essential that a plan of action exists in the airlines as to how the crew and the aircraft shall be treated immediately after landing if an incident of this type occurs. Otherwise there is a great risk that important information can be lost.

2.3.3 The health of air crewmembers

The risks of permanent health problems as a result of prolonged exposure to more or less unhealthy cabin air might be less difficult to overcome. Additional fundamental research within the area may be necessary. For example, it should be possible with the help of permanently installed measurement equipment on a few representative aircraft to survey most of the basic factors that can be significant in this matter. Such factors as normal composition of cabin air, humidity, pressure, temperature etc. From such information is should also be possible to establish relevant limits and exposure times for flying personnel so that the risk of residual health problems is minimized.

2.3.4 The influence of turbine oils

Although to this date, it has not been possible to prove that such is the case, many evidence indicates that turbine oils and the additives in it are of great significance in this matter. For example, leaking oil from an engine's bearing casing can enter the compressor air and subsequently end-up in the aircraft's air-conditioning system. When passing through the combustion-case there is a risk that such oil can be exposed to higher temperatures than allowed for by the specification.

As mentioned earlier overheated oils can be transformed into a large number of different types of hydrocarbons, carbon monoxide, carbon dioxide, organic phosphor compounds and so on. Information about what substances are included in petroleum products, knowledge of toxicology and the medical basis on which to state a distinct limit between harmful and non-harmful content is often lacking. Even less is known about the substances that are formed at high temperatures and what possible interactive effects arise through the simultaneous exposure to several air pollutants. It is even possible that an eventual poisonous affect can be intensified by the reduced oxygen partial pressure that normally occurs in a pressurized cabin during flight.

Large pressure and temperature differences take place in aircraft air-conditioning systems from the engines to the air outlets in the cabin (approx. 400 °C /12 bar that is reduced to approx. 50 °C /1 bar). It should therefore be investigated if a risk exists that the air ducts can serve as distillation columns for air containing oil products. If this is the case it could lead to the accumulation of poisonous substances in the system during an extended time and then momentary be released into the cabin producing large amounts and high concentrations during short periods.

There is obviously a need for research in this area also.

2.3.5 Design of the engine bleed air system

In most modern airliners with pressurized cabins, the air-conditioning system is supplied, as mentioned earlier, with air from the aircraft engines or the APU. This means that there is always a risk that something that is ingested into an engine, or oil from an internal leakage within an engine can be burned and the by-products of the combustion end up in the cabin air.

The design of the bleed air system for cabin air is, as earlier mentioned, different for different engine and APU types. In some constructions the air is extracted far forward on the engine where the compressor air is not so hot and where oil leakage from a bearing casing many times does not have a physical possibility to end up in the bleed air system. In other engine constructions, the air is extracted farther back in the compressor where both pressure and temperature are higher and the risk of leaking oil possibly finding its way out via the bleed air system is greater.

In this context the engine type in question, the ALF502R-5 is special in two respects:

– The air extraction takes place unusually far back on the engine. The drawing off takes place directly from the combustion case shroud that is mounted aft of the compressors. As depicted in the figures in section 1.6.2 the combustion chamber is situated in the combustion case. Inside the combustion chamber the temperature can reach up to approximately 850 °C.
– The seals for the engine bearing compartments do not all have knife-edge seals that are supposed to take care of the possible oil that normally can leak out in small amounts from oil lubricated carbon-seals after a certain time of operation.

Both of these circumstances are disadvantageous for the quality of cabin air and could provide an explanation why the BAe 146 series of aircraft, with this type of engine installed is over-represented concerning reports of contaminated cabin air.

The combustion case and the combustion chamber are designed so that air that is bled off to the air-conditioning system shall not be able to contain any combustion gases or air that has been in contact with hot surfaces in the combustion case. In the engine that the SHK has investigated no physical fault was found in the combustion case that could indicate that this had taken place.

Even if such a fault was not found in the engine, SHK nevertheless considers that a momentary ingestion of oil-mist or overheated oil-product into the aircraft's air-conditioning system might have been a contributing factor to the problem. This because oil-leak is possible and the bleed-air outlet is located very close to the combustion chamber.

Recommendation No 2001-4 and Recommendation No 2001-6 from AAIB also suggest measures within this area.

3 CONCLUSIONS

3.1 Findings

a) The pilots were qualified to perform the flight.

b) The aircraft had a valid Certificate of Airworthiness.

c) Air samples taken during engine testing and aircraft test flights provided no indication of what/which chemical substances caused the symptoms.

d) No technical fault that can explain the incident has been found.

e) The location of the customer bleed port for the air-conditioning system is not optimal on the engine type.

f) Knowledge is lacking concerning modern lubrication oils' characteristics at very high pressure and temperatures and their effect on human health.

g) Instructions are lacking concerning how crews shall act during flight when suspicion arises about contaminated cabin air.

3.2 Cause of the incident

The incident was caused by the pilots becoming temporarily affected by probably polluted cabin air.

4 RECOMMENDATIONS

The Swedish Civil Aviation Administration is recommended to work in consultation with the foreign civil aviation authorities concerned to encourage:

- that existing emergency checklists and emergency training programs are complemented regarding immediate steps to be taken when suspicion arises that the cabin air is polluted. The instruction for such occasions shall call for the immediate use of the oxygen mask selected to 100 % *(RL 2001:41e R1)*;
- that a plan of action is developed for how crews and aircraft shall be handled directly after landing if an incident with polluted cabin air has occurred *(RL 2001:41e R2);*
- that an international database is established with factual information from flights where suspicion of polluted cabin air exists *(RL 2001:41e R3); and*
- that research efforts are initiated in regards to the characteristics of modern lubricating oils under very high pressure and temperature and their influence on the health of human beings *(RL 2001:41e R4).*