Statens haverikommission
Swedish Accident Investigation Board

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Report RL 2008:01e

Aircraft incident to SE-DSP in airspace south-west of Stockholm, AB county, Sweden, on 22 March 2007.

Case L-04/07

SHK investigates accidents and incidents with regard to safety. The sole objective of the investigations is the prevention of similar occurrences in the future. It is not the purpose of this activity to apportion blame or liability.

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Translated by Interpreter Centre, City of Göteborg, from the original Swedish at the request of the Swedish Accident Investigation Board

In case of discrepancies between the English and the Swedish texts, the Swedish text is to be considered the authoritative version.

Statens haverikommission (SHK) Swedish Accident Investigation Board

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Statens haverikommission
Swedish Accident Investigation Board

2008-01-07 L-04/07

The Swedish Civil Aviation Authority

SE-601 73 NORRKÖPING, Sweden

Report RL 2008:01e

The Swedish Accident Investigation Board has investigated an incident that occurred on 22 March 2007 in airspace south-west of Stockholm, AB county, to an aircraft registered SE-DSP.

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

The Board will be grateful to receive, by 8 July 2008 at the latest, particulars of how the recommendations included in this report are being followed up.

Göran Rosvall Stefan Christensen

Duplicate copy to EASA

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L-04/07
Report finalised 7 January 2008

Aircraft; registration and type	SE-DSP, Avro RJ 100
Class/airworthiness	Normal, valid Certificate of Airworthiness
Registered owner/Operator	Trident Jet Limited, P.O. Box 76, Wests Centre, St Helier, Jersey, Channel Islands/Malmö Aviation AB, Box 37, SE-201 97 Malmö, Sweden
Time of occurrence	22 March 2007, at 11:50 hours, in daylight. *Note:* All times are given in Swedish standard time (UTC + 1 hour)
Place	In airspace south-west of Bromma airport, AB county. Climbing through 17 000 to 19 000 feet
Type of flight	Commercial air transport
Weather	According to the SMHI (Swedish Meteorological and Hydrological Institute) METAR at 11:50: wind 010°/10 knots, visibility more than 10 km, broken clouds with a base of 500 feet, temp./dewpoint +2/± 0 °C, QNH 1016 hPa
Persons on board:	
crew members	5
passengers	42
Injuries to persons	None
Damage to aircraft	None
Other damage	None
Captain:	
Sex, age, licence	Male, 44 years, ATPL
Total flying time	8471 hours, of which 1855 hours on type
Flying hours previous 90 days	90 hours, all on type
Number of landings previous 90 days	45
Co-pilot:	
Sex, age, licence	Male, 27 years, CPL-IRME
Total flying time	816 hours, of which 323 hours on type
Flying hours previous 90 days	113 hours, all on type
Number of landings previous 90 days	312
Cabin crew members	Two females and one male.

The Swedish Accident Investigation Board (SHK) was notified on 29 March 2007 that an aircraft with registration SE-DSP had an incident at 11:50 hours on that day in airspace south-west of Bromma airport, AB county.

The accident has been investigated by SHK represented by Göran Rosvall, Chairperson, Stefan Christensen, chief operational investigator, and Henrik Elinder, technical investigator.

The investigation was followed by Max Danielsson, representing the Swedish Civil Aviation Authority.

Summary

The events consist of two independent incidents, where the second incident was a consequence of the first. The events have therefore been described here as *the first incident* and *the second incident* respectively.

The first incident

The aircraft taxied out at Stockholm/Bromma airport for a scheduled flight to Gothenburg/Landvetter Airport. Due to the changing weather conditions, the switches for the aircraft's de-icing system and air

conditioning system (which among other things pressurises the cabin) were switched on and off at various points during the take-off and climb out. The climb checklist did not contain any specific item for checking the air conditioning unit (“pack”) switches, which control the pressurisation of the cabin, only a summary item in respect of the air conditioning system in general.

At about 10 000 feet the “*Avionics fan off*” warning light lit in the cockpit. The pilots began to read the emergency checklist for this warning, which may among other things be initiated by low air pressure, but there were no instructions for checks or measures to be taken related to this warning. At about 18 000 feet one of the cabin crew called and said that the oxygen masks above the passenger seats in the cabin had dropped down. The pilots discovered that the aircraft cabin was not pressurised and immediately began to descend to a safe altitude. The aircraft had reached an altitude of 19 000 feet before the descent began. During the descent, the warning light for high cabin altitude came on, that according to the specifications should have warned the pilots when the cabin altitude exceeded 10 000 feet. On investigation it was found that the relevant pressure sensor was damaged.

The reason why the aircraft climbed to about 19 000 feet without the cabin being pressurised was that the checklist was not defined clearly enough. A contributory factor was that the inspection interval for the cabin low pressure sensor was probably too long.

The second incident

When the oxygen masks dropped from above the passenger seats, the cabin crew could see that a large number of masks on the left side had not dropped. After checking the status of the pilots the chief cabin attendant went along the cabin without oxygen and started to move passengers from the left side to the right side of the aircraft. Shortly afterwards the chief cabin attendant was given a portable oxygen bottle by a colleague and together they tried to open more hatches with oxygen masks for the passengers. A small tool that is meant for manually opening the hatches could not be found during the incident.

The oxygen pressure at an altitude of 19 000 feet is only about half the pressure at sea level, and results in an equivalent reduction of the oxygen level in the blood. Human reaction to this depends on the individual, but even at low altitudes the effects of oxygen deprivation can become apparent in the form of a lowering of both physical and mental capacity.

The reason why 20 of the oxygen mask hatches did not open was that the company’s quality control was deficient in connection with the repacking of the hatches.

Recommendations

The Swedish Civil Aviation Authority is recommended to:

- Ensure that, within applicable areas of civil commercial air transport, checks on the status of the pilots and the institution of cabin-cockpit communication are introduced as obligatory items in the cabin staff emergency checklists in the case of an unannounced decrease of cabin pressure *(RL 2008:01e R1).*

It is recommended that EASA:

- Takes steps to ensure that the inspection interval for cabin pressure sensors in this particular type of aircraft is reduced *(RL 2008:01e R2)*.

- Takes steps to ensure that the emergency checklist in this particular type of aircraft is complemented with a note in the respect of checking cabin pressure when the “Avionics Fan Off” warning is activated while airborne *(RL 2008:01e R3)*.

1 FACTUAL INFORMATION

1.1 General

The air transport events that are the subject of the investigation reported here consist of two independent incidents, where the second incident was a consequence of the first. The events have therefore been described in certain sections of the report as *the first incident* and *the second incident* respectively. The historical account in the report describes the incidents as being part of the sequence of events during the flight.

1.2 History of the flight

1.2.1 Conditions

The flight was a normal scheduled flight between Stockholm/Bromma and Göteborg/Landvetter, flight number TF 009. The flight was the commander's first duty of the day. The co-pilot had previously been on duty on a flight from Göteborg with another commander. Three CAs[1] were on duty, one being the chief cabin attendant (CC) and another a new employee on route training (CA 2). There was also a third person in the cockpit during this particular flight. A pilot from another airline, known to one of the pilots, had been invited to accompany them as an observer.

On that day there were snow showers in the area, so the crew were mentally prepared for the take-off to be with the engine de-icing activated. This type of aircraft has a relatively limited performance, so that optimisation of engine power is often necessary in order to avoid a reduction in take-off weight. In order to be able to obtain maximum engine power it was therefore planned to keep the bleed valves that supply the cabin with compressed air closed during take-off. In order to obtain air pressure the APU[2]would be started and then supply certain of the aircraft systems with compressed air. For the aircraft cabin to be pressurised it is necessary for at least one of the two "packs" (Air Conditioning Packs) in the air conditioning system to be in operation.

It had been decided that the co-pilot would perform the take-off, i.e. be the pilot flying (PF), and the commander would be the pilot not flying (PNF). While taxying out a snow shower had come in over the airport, so a late decision was made to activate the aircraft de-icing systems. In connection with this process the pilots had no clear recollection of whether the two air conditioning system switches for the packs were on or off while taking off.

1.2.2 Take-off and climb out

The take-off was performed in accordance with normal procedures from runway 30 at Bromma. On passing through 1 200 feet power reduction took place as prescribed by the noise abatement regulations for operation at this airport. In association with this, certain other measures are also normally taken, such as to activate the ordinary pressurisation system with bleed air from the aircraft engines and switch off the APU Air. These measures are to be checked at a later stage of the climb, when the climb checklist is read.

During the first part of the climb the engine de-icing was switched on and off, depending on the current weather situation, with varying icing

[1] CA: Cabin Attendant
[2] APU: Auxiliary Power Unit, to supply, among other things, compressed air and electrical power

conditions. At about 2 000 feet a warning was activated from the ice detection system (Ice Detector), indicating that the aircraft was at that moment in a weather area with the risk of ice accretion. During the remainder of the climb the climb checklist was read, which included the item “Air Supply”. For this item, actions and checks are to be carried out on certain parts of the aircraft air supply system, including the activation of bleed air from the engines, checking that the packs are switched on and that the air supply from the aircraft APU is switched off. These, and certain other checks, were not detailed on the climb checklist, which contained only the summarised "Air Supply" item.

Detailed information concerning which supplementary actions are to be taken for each item in the climb checklist is present in the expanded checklist[3]. The actions and any subsidiary items that are described in the expanded checklist consist partly of the normal work flow that the pilots are expected to know about and be able to perform when reading the ordinary checklist. During interviews with the pilots in this particular case, they only had vague recollections of the positions of the pack switches when reading and checking against the climb checklist.

When the weather conditions meant that de-icing was no longer needed, the systems for engine and wing/tail de-icing were switched off at 6 000 feet. The aircraft was flown with the autopilot engaged. At about 10 000 feet, while still climbing, the “*Avionics fan off*” warning activated, lighting a yellow warning lamp on the air conditioning panel. Among other things, this warning can indicate that the fan that cools the avionics systems has for some reason stopped working, or that a sensor at the fan air intake is sensing low air pressure. In parallel with this warning, the yellow “*Air Cond*” lamp on the warning panel also lit. During continued climb to the planned cruising altitude of 28 000 feet, the pilots began to read off the part of the checklist (Abnormal checklist) where possible actions in connection with the fault that had occurred were described.

1.2.3 *The first incident*

At an altitude of approximately 18 000 feet, the pilots were contacted by the cabin crew via the interphone system, with a message that the oxygen masks had dropped down in the cabin. Initially the pilots acted in accordance with the procedure that was taught for this event and put on their oxygen masks, and then started to go through the prescribed procedure in accordance with the emergency checklist. The climb was interrupted by activating altitude hold (the autopilot altitude maintaining mode). Up to that time the climb rate had been about 1 500 to 2 000 feet per minute.

According to interviews with the pilots it is probable that the aircraft was at about 19 000 feet before a descent was started.

The pilots claimed that the switches for the engine bleed air system were set to on, but that the switches for the packs were off. APU air and the packs were switched on and manual release of the oxygen masks was carried out, using a separate switch, in accordance with the checklist. It was determined that the aircraft cabin was not pressurised, and an immediate emergency descent was initiated towards 10 000 feet.

During the first part of the descent, at about 16 000 feet, the light for “Cabin Hi alt” lit on the warning panel. During the descent the pilots tried to raise the pressure in the cabin, but could see that the outflow valves for the pressure cabin were in their open positions, despite the packs being in operation and the flight deck crew’s repeated attempts to close the valves.

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[3] Expanded checklist: An expanded and detailed description of actions that are to be taken for each item in the ordinary checklist

When the aircraft had reached 10 000 feet it was decided to descend further to 8 000 feet and continue the flight to the destination, Göteborg. During continued attempts to get the pressurisation system to work, the packs were switched off and on again, whereupon the system came into operation and the aircraft cabin could be pressurised in the normal way. The commander decided to complete the flight towards the destination at 8 000 feet and after continuing normal flight the aircraft landed on runway 21 at Göteborg/Landvetter airport.

1.2.4 The second incident

During the climb, the cabin crew served the passengers in accordance with normal procedures. In an interview CA3 said that he had felt dizzy and slightly nauseous as he was moving along the centre aisle of the cabin with the serving cart. When he and the CC came to the front galley[4] CA 2 called via the interphone system from the rear galley and reported that hatches had opened and oxygen masks had dropped down in the cabin. It could not be established at what altitude the aircraft was when the oxygen mask hatches opened.

At the seat for the cabin crew that is associated with the front galley, there are also oxygen masks which should drop down if there is a decrease in cabin pressure. These masks had not dropped down, hence CA3 and CC were not aware of the situation that had arisen.

After being advised of the situation, the cabin crew checked the status of the pilots by looking through the peephole in the flight deck door and also called the pilots via interphone to inform them what had happened. While surveying the cabin the CC could see that many masks on the right side had dropped down, but there were no masks hanging above the left side seat rows. Above each seat row (three passenger seats) there is a hatch which should open in the event of low cabin pressure. There are four masks inside each hatch, one for each passenger plus one spare (see section 1.6.3). The oxygen is produced by special generators and is only intended to last for a short time (about 15 minutes), for example during an immediate descent after loss of cabin pressure. In this particular case 19 of the oxygen mask hatches in the cabin and one hatch above the cabin seats in the front galley did not open, meaning that oxygen was not available to 57 passenger seats and two cabin crew seats.

1.2.5 Events in the cabin

After assessing the situation the CC decided that she and CA3 could manage things themselves and therefore ordered CA2 to remain seated in her seat in the rear galley, wearing an oxygen mask. The CC then went out into the cabin without a portable oxygen unit and began to assist the passengers. Since the aircraft was barely half full, she moved passengers from the seats on the left side that were without oxygen masks to empty places on the right side where masks had dropped and oxygen was available. During her interview she stated that she did not “feel” the lack of oxygen and therefore considered that she could begin working without oxygen.

During this time CA3 had taken down two portable oxygen units and gave one to the CC after starting to use the other one himself. Together they relocated most of the passengers who had no access to oxygen in the seats where they had been. They managed to open some of the hatches by tapping on them, but most remained closed. Underneath each cabin crew seat is also located a small tool to open any stuck hatches manually. The CC did not manage to find a tool, so none of the hatches could be opened

[4] Galley: The working space for the cabin crew, including among other things a pantry

manually. At her interview the CC said that it was very difficult to bend down and look for the tool while wearing a mask, with the oxygen bottle hanging on her back and side.

The incident occurred south-west of Bromma airport, at a height of approximately 18 000 feet.

1.2 Injuries to persons

	Crew members	Passengers	Others	Total
Fatal	–	–	–	–
Serious	–	–	–	–
Minor	–	–	–	–
None	5	42	–	47
Total	5	42	–	47

1.3 Damage to aircraft

None.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 The commander

The commander, male, was 44 years old at the time and had a valid Airline Transport Pilot Licence.

Flying hours previous	24 hours	90 days	Total
All types	0	90	8471
This type	0	90	1855

Number of landings this type previous 90 days: 45.
Flight training on type carried out on 26 September 2006.
Latest PC (Proficiency Check) carried out on 17 May 2006 on a RJ 100.

1.5.2 Co-pilot

The co-pilot, male, was 27 years old at the time and had a valid CPL-IRME Licence.

Flying hours previous	24 hours	90 days	Total
All types	5.5	112.5	815.9
This type	5.5	112.5	323.0

Number of landings this type previous 90 days: 312.
Flight training on type carried out on 13 August 2006.
Latest PC (Proficiency Check) carried out on 13 August 2006 on a RJ 100.

1.5.3 Cabin crew members

Two females and a male were working in the cabin on this particular flight.

1.5.4 The crew members' duty schedule

The commander was on the first day of his duty roster, which had been preceded by four free days. His daily points score was 46 at the time of the incident and the accumulated points were 145 according to the 7 days rolling calculation model.

The co-pilot was on the second day of his duty roster, which had been preceded by three free days. His daily points score was 42 at the time of the incident and the accumulated points were 166 according to the 7 days rolling calculation model.

The maximum permitted daily points are 90 and the maximum permitted points per rolling 7-day period is 270. Both points limits are in respect of duty planning.

1.6 The aircraft

1.6.1 General

The aircraft				
Manufacturer	British Aerospace			
Type	Avro RJ100			
Serial number	E 3242			
Year of manufacture	1994			
Flight mass	Max. authorised take-off/landing mass 44225/41142 kg, actual 34015 kg			
Centre of mass	Within permitted limits (LITOM 44)			
Total flying time	21122 hours			
Number of cycles	20857			
Flying time since latest inspection	60 hours			
Fuel loaded before event	Jet A1			
Engines				
Manufacture	Lycoming (Honeywell)			
Model	LF507-F1			
Number of engines	4			
Engines	*No. 1*	*No. 2*	*No. 3*	*No. 4*
Total operating time, hrs	19024	16907	17010	16064
Operating time since overhaul	4721	2820	680	4321
Cycles since overhaul	4925	3070	423	4531

The aircraft had a valid Certificate of Airworthiness.

1.6.2 Air conditioning system

This type of aircraft has a pressure cabin that is supplied with pressurised and conditioned air from an air conditioning system. The air conditioning system receives its air from the engine bleed system, or from the auxiliary power unit, APU.

Before the bleed air from the engines enters the cabin it is pressure-regulated and cooled in two air conditioning units (Air Conditioning Packs – known as "packs") located under the floor at the rear of the aircraft. The final air pressure and temperature adjustment takes place in these.

The system is controlled by the pilots from two control panels located on the overhead panel the cockpit. From there the pilots can select the source of the cabin air, activate the packs and set the desired cabin pressure and temperature. See fig. 1.

Fig. 1

So that the cabin can be pressurised, air has to be bled from one or more of the engines, or taken from the APU, while the packs are in operation.

The process of taking bleed air from the engines reduces somewhat the maximum thrust of the affected engines. Therefore the air conditioning system is usually supplied with air from the APU during taxying and take-off. While climbing out after take-off, bleed air from the engines is switched in and the APU can be switched off.

The pressure cabin has a warning system that is normally activated if the pressure in the cabin falls too low (High Altitude Warning System). If the pressure in the cabin reduces beyond the pressure that applies at 9 700 feet a warning light is lit on the instrument panel *("Cabin Hi Alt")*, and an audio warning sounds in the cockpit. There is also a gauge in the cockpit that indicates the actual cabin height. This is however very small and according to interviews with the pilots is relatively difficult to read, with a coarse scale.

The system receives its pressure information via a pressure sensor (Cabin High Altitude Warning Switch). The prescribed interval for functional checking of the system is 15 000 flights, which is equivalent to about seven flying years with this company.

1.6.3 *Oxygen system - passengers*

This type of aircraft has an oxygen system that can provide passengers with oxygen if an abnormal loss of pressure occurs during flight. The system consists of individual oxygen masks that are stowed behind hatches in the ceiling panel above the passenger seats. If during flight the pressure in the cabin falls below that normally applicable at 13 250 ± 250 feet, the hatches should open automatically so that the oxygen masks drop down above the passenger seats. The system is controlled by a pressure sensor in the cabin (Aneroid Switch). The prescribed interval for functional checking of the sensor is 10 000 flights, which is equivalent to about five flying years with this company.

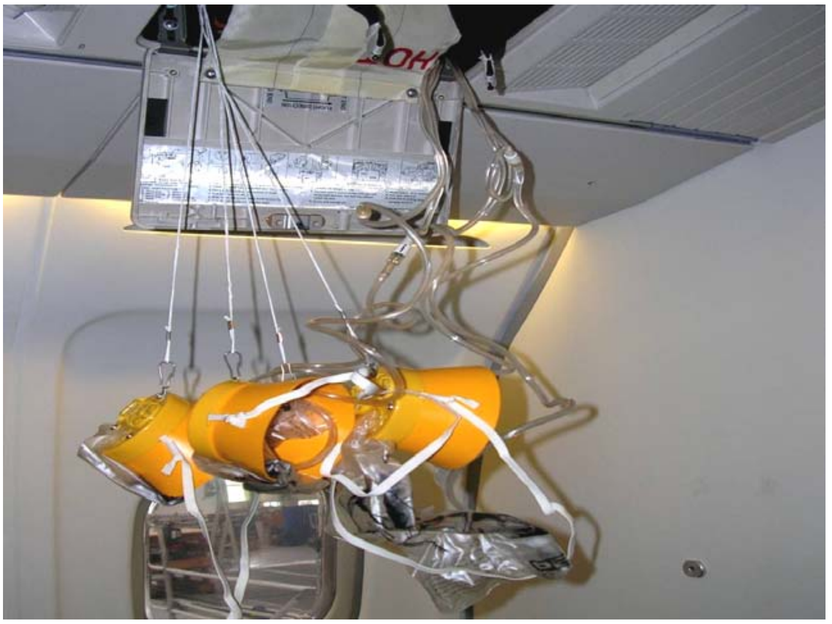


Fig. 2

The hatches have a latching mechanism that consists of a ball-shaped plunger on the hatch cover that projects into the hatch frame and is locked by a spring-loaded catch that can be electrically opened. See Fig. 3 below.

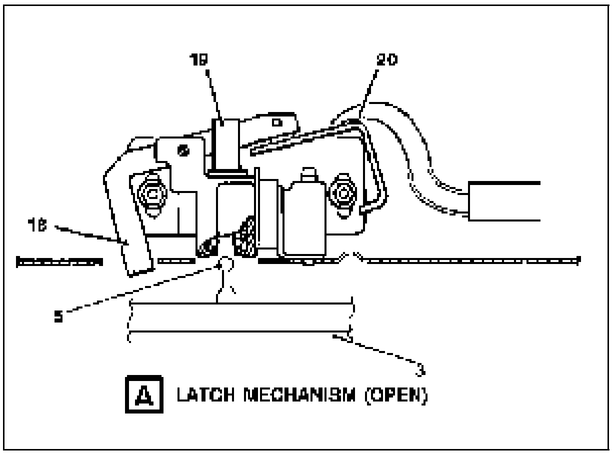


Fig. 3

The hatches can also be operated electrically by means of switches in the cockpit, or mechanically with the aid of a small tool (Oxygen Unit Key) that is inserted into a small hole on the outside of each hatch. There are three keys in the aircraft, located in the cabin under the cabin crew seats. The prescribed interval for functional checking of the latch mechanism is 24 months.

Fig. 4

1.6.4 Oxygen system - crew

In the cockpit there are oxygen masks for the pilots, one at each of the pilots' seats and another at the jump seat. In the case of an emergency with low pressure in the cabin, the pilots must immediately put on their oxygen masks in accordance with a practised procedure. The masks have built-in microphones for external and internal communication and are supplied with oxygen from a fixed oxygen bottle that is provided for the pilots' needs only.

The cabin crew have drop masks of the same type as for the passengers, located above each crew seat. In the case of a sudden drop in pressure on board, a CA who is in the cabin is also able to move around by using the extra mask that is located at each passenger seat row. In addition to these, small portable oxygen bottles with separate face masks are available for the cabin crew. The bottles can be carried in the hand or strapped on to the back, and are intended to enable the cabin crew to assist passengers in the case of pressure loss or smoke on board. The oxygen bottles can also be used for medicinal purposes if this becomes necessary for anyone on board.

1.6.5 Ice warning system

The aircraft is equipped with an ice warning system (*Ice Detector*). If icing conditions are detected on the aircraft a lamp lights and an audible warning sounds in the cockpit. The system registers the icing conditions with the aid of a sensor located on the outside of the aircraft fuselage.

1.6.6 Avionics Cooling Fan Warning

The space in which the computer and avionics equipment is installed is cooled by a fan. If the fan fails (or the electrical supply is interrupted) a warning light is lit on the air conditioning panel in the flight deck, with the text *"Avionics Fan Off"*. This warning is also activated if the air pressure is low at the fan air intake. When the warning is activated a yellow caution light also lights on the warning panel with the text: *"Air Cond"*. The purpose of this is to draw the pilots' attention to the fact that something wrong or abnormal has happened to the air conditioning system or its air supply.

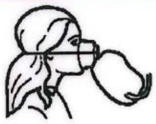
1.6.7 Checklists - cockpit

In relation to the item "*Avionics Fan Off*" in the aircraft Abnormal checklist no actions are stated if this fault condition arises while in flight. Nor is there any information that this warning can be caused by low air pressure at the fan air intake.

At the "*Cabin Hi Alt*" item in the aircraft Emergency checklist there are headings for the subsequent procedure: *Loss of cabin pressure.* The subsequent items in the checklist relate to ensuring that the pilots and passengers receive oxygen and then that an emergency descent to a lower height is initiated. If the lamp in the push-button switch *"Pax Oxy Out"*, to indicate that the hatches for the oxygen masks in the cabin have opened is not lit, at a cabin altitude of 13 500 feet, the pilots must manually activate the system by pressing the switch *"Drop Out Ovrd"* which is located on the side panels of each of the pilots' seats. This action activates an electrical circuit that should open all the oxygen mask hatches. In this case no difference could be seen in respect of the number of open hatches before or after the manual activation to open the hatches.

1.6.8 Checklists - cabin

The checklist for the cabin crew that was applicable at the time of the incident, (Issue No. 3, 20 Feb 02), contained items as shown in fig. 5 below:



Decompression

Flight deck will select "Drop out" oxygen.

Immediate action:

- Order ***"Dra en mask till dig - Rök ej".***
  "Pull mask down and use it - Don't smoke".
- C/A take nearest free mask.
- Secure carts.
- C/A sit down and fasten seatbelt.
- Evaluate situation.

When at safe altitude

- Check passengers in cabin and lavatories.
- Check no smoking / fire.
- Re-seat passengers away from any structual damage.
- C/C reports cabin status to Commander.
- C/C briefs passengers over PA when suitable.
- Give supplemental oxygen if needed.
- Assist passengers and advise them to remain inactive.
- Prepare for normal / emergency landing.

Fig. 5

From the checklist it can be seen that instructing the passengers is the first action for the CAs when the masks drop down, after which they should see to their own oxygen supply. The serving carts are to be put away and secured, after which the CAs should sit down with seat belts fastened. No checks or communication with the cockpit are prescribed in this part of the checklist.

When the aircraft has descended to a safe altitude, a number of supplementary actions are to be taken, including reporting “cabin status” to the commander.

1.7 Meteorological information

According to the SMHI (Swedish Meteorological and Hydrological Institute) METAR at 11:50: wind 010°/10 knots, visibility more than 10 km, broken clouds with a base of 500 feet, temp./dewpoint +2/± 0 °C, QNH 1016 hPa

1.9 Communications

Not applicable.

1.10 Aerodrome information

Bromma airport status was in accordance with AIP[5]-Sverige/Sweden.

1.11 Flight data and cockpit voice recorders

Data from the flight data and cockpit voice recorders was not obtained in connection with this incident.

1.12 Incident location

In airspace south-west of Stockholm.

1.13 Medical information

Nothing was discovered to indicate that the psychological or physical condition of the pilots or cabin crew was degraded before the flight. During the flight the crew and passengers were subjected to a lack of oxygen. According to information received, one elderly passenger felt ill during the incident and was in need of a certain amount of assistance.

One cabin crew member, CA3, stated that he felt nauseous during the climb. However no-one on board needed medical treatment after the incident.

1.14 Fire

There was no fire.

1.15 Survival aspects

1.15.1 General

The survival time with a reduced concentration of oxygen (oxygen pressure – see 1.16.4) in the air that we breathe is dependent on the individual person's physical and genetic makeup. There are people who suffer from oxygen deficiency symptoms at low altitudes, while others can climb high mountains without using oxygen.

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[5] AIP – Aeronautical Information Publication

The symptoms and medical conditions that can arise in connection with a lack of oxygen are initially not serious, and return to normal when oxygen pressure is restored. In the case of a continued reduction of oxygen pressure, however, loss of consciousness and eventually death will ensue. It is serious when individuals in decision-making and/or responsible positions, such as pilots of commercial aircraft, are exposed to "insidious" lack of oxygen. During a gradual loss of oxygen pressure the conscious state of an individual reduces up to the point where they become unconscious. During the period leading up to eventual loss of consciousness, the ability of the individual to take in information and make rational decisions also reduces.

The survival factors in a situation with oxygen deficiency as in this case can therefore be said to principally depend on two factors:

- The individual person's physical capability of dealing with the arising oxygen deficiency.
- The capability of the pilots, during their own oxygen deficiency, to be able to evaluate the situation and make rapid decisions in respect of relevant actions.

1.15.2 Actions by the rescue services

Not applicable.

1.16 Tests and research

1.16.1 Functional inspection of the cabin pressure warning system

The pressure sensor (Cabin High Altitude Switch) for the cabin pressure warning system was checked for correct operation by the aircraft manufacturer. The unit was inspected during the check, followed by implementation of a previously determined test programme. During the inspection, when the unit had been opened, it could be seen that there was damage to an electrical connection terminal block and to a ventilation screw for static pressure. The wear and condition of the sensor were assessed during the test to be normal for a unit manufactured in 1995.

The testing checked the insulation and voltage range, overloading and leakage, also whether the circuit was switched on and off at the preset pressure.

The tests showed that the insulation and voltages were in accordance with the specification. The tolerances for activation of the unit are:

- The pressure sensor must activate, i.e. the "*Cabin Hi Alt*" warning light on the panel comes on, while climbing when the pressure has fallen equivalent to a height of between 9 700 and 10 000 feet.
- The pressure sensor must deactivate, i.e. the "*Cabin Hi Alt*" warning light on the panel goes out, while descending when the pressure has risen equivalent to a height of 9 200 feet.

In both the above conditions a tolerance of ± 500 feet applies.
During the tests the pressure sensor fulfilled all the specifications.
The air leakage tests on the unit showed a great deal of leakage at the damaged ventilation screw. An overload test, to be carried out to a simulated pressure altitude of 40 000 feet, was not carried out, because it was adjudged that the unit would not be able to operate at that pressure altitude with the amount of leakage that had been detected.

Fig. 6. The pressure sensor

According to the manufacturer's opinion, the leaking ventilation screw had no effect on the function of the unit. The final assessment was that the pressure sensor operated in accordance with the specifications during testing.

1.16.2 Examination of the oxygen system

In this particular incident 20 of a total of 43 oxygen mask hatches did not open.

The function and release of the passenger oxygen masks were checked in connection with the ordinary C checks that had been performed on the aircraft about three weeks, approximately 60 flights, before the incident. At that time the system had operated correctly and all the masks had dropped down.

The subsequent packing of the masks and hatch closing had been carried out during a 24-hour shift, utilising extensive overtime. 75% of the work was done with the aid of externally hired staff. It has not been possible to find out who packed the masks in question or whether those involved had the necessary training for this task.

After the incident all nine aircraft in the fleet were checked in respect of the oxygen system release function. In eight of the aircraft all the masks dropped down satisfactorily. In one aircraft two of the hatches stuck closed. In one case this was due to incorrect packing of the masks, in the other due to a faulty latch.

1.16.3 Examination of the oxygen system manual release mechanism

SHK has carried out practical tests to open some hatches manually using the special "key" intended for the purpose. The tests showed that without training it was difficult to open the hatches in this way.

1.16.4 Medical effects in the case of oxygen deficiency

The air we breathe consists of 21% by volume of oxygen and about 78% by volume of nitrogen, along with smaller proportions of other gases. This composition is generally constant in the atmosphere, regardless of altitude. As altitude increases, the air pressure and thereby oxygen pressure reduces, i.e. the partial pressure of the oxygen gas in the actual air volume. At an altitude of 19 000 feet the air pressure is half that at sea level, so that the oxygen pressure is reduced to about 10%. This means that the number of oxygen molecules per given air volume is reduced accordingly. In practical terms this means that each breath inspiration at 19 000 feet only provides half the amount of oxygen compared to the equivalent air volume at sea level. One way for the body to compensate for the lower oxygen pressure is to increase the rate of breathing.

Symptoms of oxygen deficiency are, apart from an altered degree of consciousness, headache, dizziness, nausea, cramp attacks and temporary restriction of vision. The other immediately noticeable signs are increased heart and breathing rates, and cyanosis, with lips and fingernail beds turning blue.

The degree of influence on the human body of a decrease in oxygen pressure depends to a large extent on individual conditions. In general it can be said that certain functions are affected negatively even at small reductions in oxygen pressure. For example the ability to see in the dark is affected at an altitude of 8 000 feet. At 10 000 feet the cognitive functions begin to deteriorate, i.e. our way to receive, process and use information.

In the case of a rapid reduction of oxygen pressure when breathing normal air the body is less able to adapt to the altered conditions that apply. During for example mountain climbing or hill walking the body gradually adapts to higher altitudes and lower oxygen pressure. The rapid change that occurs as an aircraft climbs, gaining height at between half and one and a half kilometres per minute, can therefore involve much faster medical reactions in the human body in respect of, among other things, the degree of consciousness.

The expression that is used to be able to measure the degree of consciousness is called TUC (Time of Useful Consciousness), and can be defined as the time interval during which one can be considered to act relatively normally. The following table indicates the approximate time intervals during which an otherwise normally performing individual has to adapt to situations with oxygen deficiency. It should be said that the values in the table are derived from a study where the individuals were breathing oxygen through a mask, and the lack of oxygen was caused by taking off the mask. The TUC in situations where the individual is breathing normal air is shorter for any given altitude, than if one at the same altitude removes an oxygen supply. This is due to the higher saturation level of oxygen in the blood attained when breathing pure oxygen.

In this particular incident there was a rapid but gradual reduction in oxygen pressure while breathing normal air, so that the TUC was probably shorter than the time intervals stated in the table.

Altitude (x 1000 ft)	**Immediate mask removal, medium activity**	**Immediate mask removal, no activity**
18	20 minutes	30 minutes
22	5 minutes	10 minutes
25	2 minutes	3 minutes
28	1 minute	1 minute, 30 seconds
30	45 seconds	1 minute, 15 seconds

Fig. 6. TUC table – Time of Useful Consciousness (Carlyle, 1963)

1.17 Organisational and management information

The company operates commercial scheduled traffic with passengers, with operations concentrated at Stockholm/Bromma airport with aircraft adapted to suit the special noise restrictions that apply to that airport.

The head office and technical/operations base are located in Malmö. The crews are mainly stationed in Malmö, Göteborg and Stockholm.

The company has undergone a number of ownership changes over the years, and is currently in Norwegian ownership.

1.18 Other matters

1.18.1 Equal opportunities aspects

This event has also been examined from the point of view of equal opportunities, i.e. against the background that there are circumstances to indicate that the actual event or its effects were caused by or influenced by the women and men concerned not having the same opportunities, rights or obligations in various respects. Such circumstances were however not found.

1.18.2 Environmental aspects

No environmental effects.

1.18.3 Similar events

On 14 August 2005 an accident occurred to a Boeing 737 in Greece. The aircraft began its flight without the cabin being pressurised, which meant that all on board were successively suffering from oxygen deficiency as the aircraft continued to climb. The pilots lost consciousness before the fault could be diagnosed and the aircraft continued to climb to 34 000 feet in accordance with the programmed route planning.

All on board perished. The aircraft crashed after the engines had stopped when the fuel had been used up. According to the investigation, the accident was caused, among other things, by the flight deck crew not observing that a switch for the pressure cabin was in the wrong position and that the audible warning for high cabin altitude was confused with another type of warning.

The investigation also found that there was probably a lack of communication between the pilots and the cabin crew when the masks dropped down in the cabin. A recommendation was therefore issued to secure procedures for communication with and access to the cockpit in similar situations.

1.18.4 Measures taken

After the incident the company revised the applicable climb checklist and added the item “Air Supply”.

The items concerning air supply that previously had only been present in the expanded checklist have now been included in the ordinary checklist.

2 ANALYSIS

2.1 General

SHK considers that the incident that occurred was of a serious nature. To be exposed to an uncontrolled lack of oxygen means, apart from the medical aspects concerning the passengers, that some of the crew's vital functions were gradually inhibited, with the risk of eventually succumbing to unconsciousness unless the conditions were changed.

In this particular case the aircraft reached an altitude of 19 000 feet before the fault could be diagnosed and a controlled descent initiated. It depends on the individual, and is thereby difficult to determine accurately, but probably it would only have been a matter of minutes with continued climbing before serious medical effects would have been experienced by those on board due to the lack of oxygen. In this case a reduced cognitive ability on the part of the pilots must be judged as a serious safety risk, where correct decisions can be delayed – or not taken at all – as a consequence of a continued reduction of oxygen.

2.2 The first incident

2.2.1 *The take-off*

Because of the limited engine power in certain conditions of this type of aircraft, the pilots are often forced when taking off to choose between several alternatives in respect of the air supply to the various systems in the aircraft. This can mean a series of different configurations on the panels in the cockpit, where the system checks are localised. What is common to the different alternatives for supplying pressurisation air is that the air conditioning "packs" must be switched on in order that pressurisation of the cabin can take place.

For this particular take-off it has not been possible to establish whether the packs were switched on or not. It is known however that some switching on and off of system controls did take place, to some extent due to changing weather conditions, with the result among other things that the de-icing system was switched on and off.

2.2.2 *The climb-out*

During the initial stage of the climb power reduction took place and there was a change from APU air to engine bleed air. During the same period of time the engine de-icing was switched on and off several times, as areas with the risk of ice build-up were traversed, and/or there were indications that ice build-up could occur.

On the premise that the packs had been switched on during take-off, there could during this phase of the flight have occurred an inadvertent mistake which meant that they could have been switched off. Even though the de-icing and air conditioning switches are not located in the same area of the panel, SHK considers that it is possible, even though not probable, that confusion could have taken place at some moment.

Nor can it be excluded that the third person in the cockpit could, in some sequences, have distracted the pilots.

2.2.3 *Climb checklist*

Regardless of which positions the various switches were in, the climb checklist is intended to be a "catch-all" whereby certain actions must be carried out, and some checking is done that other actions have been performed. At the item for checking the pressure cabin and air supply "Air Supply", the aim is to check the positions of the switches for both bleed air and the "packs".

These items are not contained in the checklist; they are only present in the expanded checklist, that is not normally used while flying. The pilots are expected to know the sub-items and actions that the summarised term "Air Supply" covers in the ordinary checklist.

In this particular flight this barrier did not work. At the item "Air supply" the PNF did not notice that the switches for the air conditioning packs were in the off position. SHK is of the opinion that the checklist was not clear enough to prevent continued climbing without the cabin being pressurised.

2.2.4 *Discovery of the situation*

If the cabin altitude exceeds 9 700 feet a warning in the cockpit will be activated, consisting of both a warning light and an audio signal. However, the pressure sensor that should activate the warning did not operate as intended, so that no warning was given when the cabin passed the preset altitude. Considering that the outflow valve was later discovered to be open, it is probable that the cabin altitude was all the time virtually identical to the aircraft altitude.

At an altitude of approximately 10 000 feet the "*Avionics Fan Off*" caution light lit on the air conditioning panel, as did the "*Air Cond*" light on the warning panel. It can be said that there was a direct connection between the reducing pressure and the initiation of the warnings. The warnings were however not associated with the change in pressure in such a way that the pilots could interpret them as a sign of low pressure. Nor did the checklist that must be read/relevant actions be taken in the case of these warnings appearing give any indication that a low pressure situation had arisen. Despite the fact that the warnings had very probably been caused by the falling pressure, there was no help for the pilots because information about this was not present in the checklist that had to be followed.

In a calm situation it is conceivable that one of the pilots would have noticed cyanosis or the beginning of oxygen deficiency while passing through 10 000 feet, for example due to increased breathing rate and/or a faster heartbeat. However in this case the attention of the pilots was directed towards the system warnings that activated at about this altitude. The pilots then became focused on diagnosing the warnings and reading the checklist until the moment the CC called and reported that the oxygen masks had dropped down.

SHK considers that the ability of the pilots to detect the dangerous situation that was about to happen was limited. With a warning system for high cabin altitude that did not work ("*Cabin Hi Alt*"), a warning signal that worked but was not used *("Avionics Fan Off")* and two pilots busy with checklists, the fact that the aircraft continued to climb without cabin pressurisation can be categorised as uncontrolled. The barrier that finally worked was that the CC reported to the pilots that the masks had dropped down in the cabin. It may however be noted that communication between the cabin crew and the pilots was not included as an item in the cabin emergency checklist, and only took place as a result of the CC's own initiative.

2.2.5 *Actions in the cockpit*

The actions of the pilots after becoming aware of the situation followed the procedures prescribed by the company and the aircraft manufacturer. The first action according to the company's "by heart" checklist is that the pilots must don their oxygen masks, which was done as advised. The subsequent actions, with an emergency descent as the most important item, were in the opinion of SHK carried out correctly and without delay.

An in-depth analysis of why the cabin could not be immediately pressurised during the descent to 10 000 feet has not been performed by SHK. It is however likely that certain pressure sensors in the system reacted to the low pressure and also to the take-off sequence not being logical compared to the normal take-off procedure for the system.

The commander's decision to continue flying to the destination had no influence on the continued development of the incident. However, in light of the situation that arose with the oxygen masks dropping in the cabin, SHK would like to point out that this could lead to the company discussing a suitable plan of action if such an abnormal situation as this were to be repeated.

2.2.6 Warning system

The pressure sensor that should generate a warning when the cabin altitude is excessive did not activate until the aircraft was descending. The period of time between the pilots being informed and being able to stop the climb (at about 18 000 – 19 000 feet), until the warning was activated (at about 16 000 feet while descending) can be estimated as approximately two minutes. On the premise that the delay in activation of the pressure sensor had been the same during continuation of the climb as it was in the descent, it can be assumed that the pilots would have remained unaware of the situation up to about 22 000-23000 feet if the CC had not informed them of what had happened.

At these altitudes the TUC reduces very quickly, and the cognitive abilities of the pilots would have deteriorated considerably. With reduced cognitive abilities, the chances of the pilots diagnosing both their own status and that of the situation arisen and its consequences would have been reduced. The fact that an aircraft carrying passengers could reach such a height without warnings must be taken very seriously.

The instrument that showed the actual cabin altitude would have been able to warn the pilots that an abnormal situation was arising. However this instrument is not under continuous observation and is quite small, with a scale that is hard to read. At the time when a reading could perhaps have been taken, after passing through 10 000 feet, the pilots were engaged in identifying and reading the checklist for the *"Avionics Fan Off"* and *"Air Cond"* caution lights. The probability that the pilots, without a properly functioning warning system, would detect the non-pressurised situation was therefore in those conditions very low.

The caution concerning the avionics fan was very probably triggered by the low pressure at the fan intake. However, in the checklist there is no note informing the pilots that this caution light could be initiated as a result of low cabin pressure, which is why this indication continued to be of no value as to the possibility of detecting the problem.

2.2.7 The malfunction of the pressure sensor

During testing it was found that the unit was physically damaged and that there was a major leakage of air at a ventilation screw.

Even though the damage did not in a laboratory environment show any measurable effect on the tests, it is not unlikely that in its operational environment in the aircraft, this contributed to incorrect functioning of the unit. It cannot be considered very surprising that a 12-year-old unit that does not need to be functionally tested more often than every 15 000 flying hours, and that does not normally operate in the outer pressure area where the warning should activate, does not perform its intended function when in a damaged condition.

SHK has not been able to find out how the damage to the sensor occurred, or how long ago, but considers that a shorter inspection interval for these units probably provides a greater possibility for discovering damage and thereby preventing incorrect operation.

2.3 The second incident

2.3.1 The masks dropping

When the CC was informed via the interphone by CA2 that the masks had dropped in the cabin, she and CA3 were in the front galley. The CA3 had already begun to experience some dizziness and nausea, probably because of oxygen deficiency. Neither of these two cabin crew members had had any reason to suspect that anything was wrong, since no masks had dropped down over their seats in the galley.

The initiative taken by the CC to check the status in the cockpit and to establish communication with the pilots went beyond the procedures that were described in the cabin emergency checklist. Considering, among other things, the severe accident that happened in Greece in similar circumstances, SHK does however believe that this action was well motivated and should be added to the applicable regulations.

The reason for the CC going out into the cabin without oxygen can probably be explained by a partial loss of cognitive functions, possibly in connection with a high level of motivation to help the passengers in this unexpected situation. This is however not in accordance with the checklist, where the CAs after giving instructions to the passengers should immediately ensure they have oxygen themselves and thereafter evaluate the situation. Since the oxygen pressure halves at 19 000 feet and the time until possible loss of consciousness is limited, an otherwise well motivated effort may have serious consequences, both for the cabin crew and the passengers. The company should therefore consider the possibility of implementing continuation training in respect of the hazardous condition of oxygen deficiency, in its recurrent crew emergency training.

When CA3 arrived with the portable oxygen bottle, the repositioning of the passengers could be completed. The decision to move them was, in the circumstances, wise, but it should be borne in mind that this action was only possible due to the fortunate fact that the aircraft cabin was only half full of passengers. The CC’s decision not to involve CA2 in the work in the cabin during the incident was probably based on the fact that CA2 was new to the job and thought not to be able to provide further assistance. SHK has no comment to make on this decision.

2.3.2 The malfunction of the hatches

The pressure sensor in the cabin is supposed to give a signal to open the hatches if the pressure falls below the equivalent of 13 250 ±250 feet. It has not been possible to determine at what altitude the hatches opened, but the activation probably took place at greater than the predetermined altitude. Taking into account the delay in reporting to the cockpit, via the observation from CA2 in the rear galley, contact with colleagues in the front galley and eventually to the pilots (at about 18 000 feet), it is feasible to assume that the activation altitude for the hatches was at around 15 000-17 000 feet. This indicates that the pressure sensor in the cabin (Aneroid Switch) also operated with a delay.

In accordance with the checklist the pilots also activated the manual release of the hatches. Since this action made no difference, it is not likely that the faulty 20 hatches did not receive a current pulse to release the opening mechanism. Tests have shown that hatches may remain closed after the opening signal has been applied, if the packing has been performed incorrectly. The hatches in this particular aircraft had been repacked about three weeks before the incident, with the employment of external personnel for the job. The investigation has revealed that the company had difficulty in documenting this task, in respect of both the quality of the work and the relevant training. SHK finds it probable that this quality deficiency had as a consequence that a number of hatches were packed incorrectly and thus would not open during the incident.

The tool that is to be used to open the hatches could not be localised by the cabin crew during the incident. It is conceivably difficult when under stress, with an oxygen bottle hanging across one's back, to find a small tool secured beneath a seat. Tests performed by SHK also showed that it was difficult to get the tool to work in the intended manner. It would be advantageous if practical training in performing this task was implemented in the recurrent emergency training.

3 CONCLUSIONS

3.1 Findings

a) The pilots were qualified to perform the flight.
b) The aircraft had a valid Certificate of Airworthiness.
c) A climb to about 19 000 feet was performed without pressure in the cabin.
d) The climb checklist did not contain detailed information concerning actions relating to the air supply system.
e) The warning system for high cabin altitude did not activate at the preset altitude.
f) Damage and leakage were found on examination of the pressure sensor.
g) The checklist for *"Avionics Fan Off"* did not include a note that this fault could be caused by low cabin pressure.
h) The pilots were made aware of the situation by the cabin staff informing them that the masks had dropped in the cabin.
i) 20 of the 43 oxygen mask hatches did not open during the incident.
j) The CC began to act in the cabin without having ensured her own supply of oxygen.
k) The tool to open the oxygen mask hatches manually was difficult both to find and use.
l) Most of the packing of the oxygen mask hatches was carried out by hired personnel without documented training.

3.2 Causes of the incidents

3.2.1 The first incident

The reason why the aircraft climbed to about 19 000 feet without the cabin being pressurised was that the checklist was not defined clearly enough. A contributory factor was that the inspection interval for the warning system's cabin low pressure sensor was probably too long.

3.2.2 The second incident

The reason why 20 of the oxygen mask hatches did not open was that the company's quality control was deficient in connection with the repacking of the hatches.

4 RECOMMENDATIONS

The Swedish Civil Aviation Authority is recommended to:

- Ensure that, within applicable areas of civil commercial air transport, checks on the status of the pilots and the institution of cabin-cockpit communication are introduced as obligatory items in the cabin staff emergency checklists in the case of an unannounced decrease of cabin pressure *(RL 2008:01e R1)*.

It is recommended that EASA:

- Takes steps to ensure that the inspection interval for cabin pressure sensors in this particular type of aircraft is reduced *(RL 2008:01e R2)*.

- Takes steps to ensure that the emergency checklist in this particular type of aircraft is complemented in the respect of checking cabin pressure when the "*Avionics Fan Off*" warning is activated while airborne *(RL 2008:01e R3)*.