Statens haverikommission
Swedish Accident Investigation Authority

# *Final report RL 2017:10e*

**Serious incident after take-off from Gothenburg/Landvetter Airport on 7 November 2016 involving SE-DSV an aeroplane of the model AVRO-RJ 100, operated by Braathens Regional Aviation AB.**

File no. L-112/16

7 December 2017

SHK investigates accidents and incidents from a safety perspective. Its investigations are aimed at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigations do not deal with issues of guilt, blame or liability for damages.

The report is also available on SHK´s web site: www.havkom.se

ISSN 1400-5719

This document is a translation of the original Swedish report. In case of discrepancies between this translation and the Swedish original text, the Swedish text shall prevail in the interpretation of the report.



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## Content

## General observations

The Swedish Accident Investigation Authority (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended to clarify, as far as possible, the sequence of events and their causes, as well as damages and other consequences. The results of an investigation shall provide the basis for decisions aiming at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigation shall also provide a basis for assessment of the performance of rescue services and, when appropriate, for improvements to these rescue services.

SHK accident investigations thus aim at answering three questions: *What happened? Why did it happen? How can a similar event be avoided in the future?*

SHK does not have any supervisory role and its investigations do not deal with issues of guilt, blame or liability for damages. Therefore, accidents and incidents are neither investigated nor described in the report from any such perspective. These issues are, when appropriate, dealt with by judicial authorities or e.g. by insurance companies.

The task of SHK also does not include investigating how persons affected by an accident or incident have been cared for by hospital services, once an emergency operation has been concluded. Measures in support of such individuals by the social services, for example in the form of post crisis management, also are not the subject of the investigation.

Investigations of aviation incidents are governed mainly by Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation and by the Accident Investigation Act (1990:712). The investigation is carried out in accordance with Annex 13 of the Chicago Convention.

## The investigation

SHK was informed on 7 November 2016 that a serious incident involving one aeroplane, with the registration SE-DSV, had occurred after take-off from Gothenburg/Landvetter Airport in Västra Götaland County, on the same day at 06:21 hrs.

The incident has been investigated by SHK represented by Mrs Helene Arango Magnusson, Chairperson, Mr Johan Nikolaou, Investigator in Charge, Mr Nicolas Seger, Operations Investigator, Mr Christer Jeleborg, Technical Investigator and Mr Alexander Hurtig, Investigator Behavioural Science.

SHK's investigation team was assisted by Mr Ulf Ringertz, an expert specialized in aeroelasticity, and Mr Daniel Stevens, an expert specialized in de-icing operations.

Mr Bob Vickery from the Air Accidents Investigation Branch (AAIB) has participated as the accredited representative of the UK.

Mr Vickery was assisted by the advisor Mr David Houfe from BAE Systems.

Mr Alberto Fernandez Lopez, EASA, Mr Bengt Holmqvist and Mr Björn Pettersson, Swedish Transport Agency, have participated as advisors.

The following organisations have been notified: International Civil Aviation Organisation (ICAO), European Aviation Safety Agency (EASA), EU-Commission, The Air Accidents Investigation Branch (AAIB) the National Transport Safety Board (NTSB), and the Swedish Transport Agency.

*Investigation material*
Interviews have been conducted with the pilots, the cabin crew and maintenance personnel. Regarding the supplier of ground handling, interviews were conducted with local management, training department and personnel involved in the incident.

A factual information meeting was held with the stakeholders on 27 April 2017. At the meeting SHK presented the facts relevant to the investigation, available at that time.

Statens haverikommission
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## Final report RL 2017:10e

| | |
|---|---|
| Aircraft: | |
| Registration, type | SE-DSV, BAe 146/AVRO 146-RJ |
| Model | AVRO-RJ 100 |
| Class, Airworthiness | Normal, Certificate of Airworthiness and Valid Airworthiness Review Certificate (ARC[1]) |
| Serial number | E3250 |
| Operator | Braathens Regional Aviation AB (BRA) |
| Time of occurrence | 7 November 2016, 06:21 hrs during darkness<br>Note: All times are given in Swedish standard time (UTC[2] + 1 hour) |
| Place | North of Gothenburg/Landvetter Airport, Västra Götaland County, (position 57 72N 012 35E, 3 000 feet above mean sea level) |
| Type of flight | Commercial air transport |
| Weather | According to SMHI's analysis: wind northeast 15 knots, visibility > 10 km, no clouds below 5 000 feet, temperature/dewpoint -05/-07°C, QNH[3] 1011 hPa |
| Persons on board: | 55 |
| crew members including cabin crew | 5 |
| Passengers | 50 |
| Injuries to persons | None |
| Damage to aircraft | No damage |
| Other damage | None |
| Commander: | |
| Age, licence | 49 years, ATPL(A)[4] |
| Total flying hours | 9 994 hours, of which 7 200 hours on type |
| Flying hours previous 90 days | 115 hours, all on type |
| Number of landings previous 90 days | 89 |
| Co-pilot: | |
| Age, licence | 43 years, CPL(A)[5] |
| Total flying hours | 5 584 hours, all on type |
| Flying hours previous 90 days | 77 hours, all on type |
| Number of landings previous 90 days | 60 |

[1] ARC – Airworthiness Review Certificate.
[2] UTC – Coordinated Universal Time is a reference for the exact time anywhere in the world.
[3] QNH – Barometric pressure reduced to mean sea level.
[4] ATPL(A) – Airline Transport Pilot License Aeroplane.
[5] CPL(A) – Commercial Pilot License Aeroplane.

**SUMMARY**

The incident occurred during a commercial flight from Gothenburg/Landvetter Airport. The aeroplane, of the model AVRO 146-RJ 100, was operated by Braathens Regional Aviation AB (BRA). The aeroplane had been parked outside for approximately 40 hours before the incident and was heavily contaminated with precipitation of snow and ice. A one-step de-icing of wings, stabiliser, rudder and fuselage was ordered by the commander. The de-icing was performed by the subcontracted company Aviator Airport Services Sweden AB (Aviator).

Shortly after take-off, heavy vibrations occurred at an indicated airspeed of around 195 knots. The commander took control of the aeroplane and disconnected the autopilot while the co-pilot made a distress call to air traffic control. The indicated airspeed was reduced whereby the vibrations ceased. The crew then decided to abort the flight and return to the airport. Thereafter, the speed was increased again and the vibrations returned until the speed was reduced a second time. The engineers of the company inspected the airplane after landing and discovered extensive ice coverage on multiple flight control surfaces.

According to the investigation, the aircraft type appears to be sensitive to mass balances in the control system. This means that even very thin layers of ice are sufficient to make the flight control system unbalanced beyond the tolerances specified in the aircraft's approved maintenance manuals. In this case, the ice contaminations on the aircraft were relatively extensive. Against this background, SHK has concluded that the vibrations were due to the unbalance of the elevator system that arose due to the ice contamination.

It is apparent from the investigation that the personnel who were to inspect the aircraft prior to the flight did not detect all ice contamination, which meant the de-icing order did not cover all of the ice contamination, and that there were shortcomings in the de-icing actually carried out.

The incident was partly caused by the fact that the operator lacked enough detailed procedures for performing a complete contamination inspection, and that the existing routine's was not fully applied, partly by the fact that the operator had not properly checked, evaluated and controlled the subcontractor's working methods.

A contributing factor was that the de-icing operation had insufficient organisational support to help the staff to resist requests of departure on time and to ensure that the de-icing was properly executed despite actual or experienced time shortage.

**Safety recommendations**

**ICAO is recommended to:**

- Investigate and evaluate the risks of recommended methods for de-icing and post-de-icing check, especially the incorporated method as referred to in the ICAO Annex 6, Part I, Doc 9640, and consider and decide whether the reference should be changed. *(RL 2017:10 R1)*

**EASA is recommended to:**

- Investigate and evaluate the risks of recommended methods for de-icing and post-de-icing checks, especially the incorporated method referred to in the referenced documents in GM3 CAT.OP.MPA.250 of Commission Regulation (EU) No 965/2012, and consider and decide whether the reference should be changed *(RL 2017:10 R2)*

**The Swedish Transport Agency is recommended to:**

- Evaluate the needs of changing their monitoring procedures to better ensure that AOC holders have appropriate procedures for contamination check and de-icing operations. *(RL 2017:10 R3)*

# 1. FACTUAL INFORMATION

## 1.1 History of the flight

### *1.1.1 Preconditions*

The incident occurred during a scheduled commercial flight with passengers after take-off from Gothenburg/Landvetter Airport on the morning of 7 November 2016. The aeroplane, of the model AVRO 146-RJ 100, had the call sign “Scan Wing 1B” (SCW 1B) and was operated by Braathens Regional AB. The intended destination was Stockholm/Bromma Airport. The crew consisted of two pilots and three cabin crew members.

The aeroplane had been parked outside for approximately 40 hours before the incident. During that period, there was precipitation in the form of rain followed by snow and sleet. The temperature varied between a few degrees above freezing down to minus five. The main wind direction during the period meant that the precipitation hit the aircraft from behind. The elevators of the aircraft model are usually angled upwards when it is parked.

The operator’s engineer[6] performed the pre-flight inspection (PFI) which was noted in the aircraft technical log along with a note indicating that the aeroplane needed to be de-iced.

The commander conducted a visual inspection together with the engineer using a personal flashlight because he felt that the flashlight in the PFI kit supplied by the operator was too weak. He noted that the aeroplane had to be de-iced. He contacted the de-icing ground staff through the intercom and ordered a one-step de-icing of wings, stabiliser, rudder and fuselage.

The de-icing process was performed by two persons using a vehicle of the type “Elephant My”: the driver of the vehicle, and one person who performed the spraying of the de-icing fluid. After they had finished, the commander received a verbal report that the de-icing had started at 05:56 hrs and was performed with 516 litres of “Clariant Type-I (Safewing MP I Eco Plus (80)” fluid. The written de-icing report did not specify which surfaces had been de-iced.

The de-icing operation was captured by an airport CCTV. The sequence has been analysed by SHK. Figure 1 shows the positioning pattern of the de-icing vehicle.

1. The basket located in front of the tail section with 38 seconds spraying and 10 seconds pause.

[6] Engineer used throughout the report for certifying staff.

2. Spraying of the right, aft side of the fuselage for 47 seconds. Thereafter, the vehicle was moved directly to point 3 without pause.

3. 15 seconds spraying of the right wing with 11 seconds' pause. 2 minutes and 7 seconds spraying of the mid-section of the wing and front right side of the fuselage with a one-second pause.

4. 40 seconds of spraying the left side of the fuselage without subsequent restraints, moved to point 5.

5. 27 seconds of spraying the left wing with 3 seconds' pause after which the vehicle left the site.

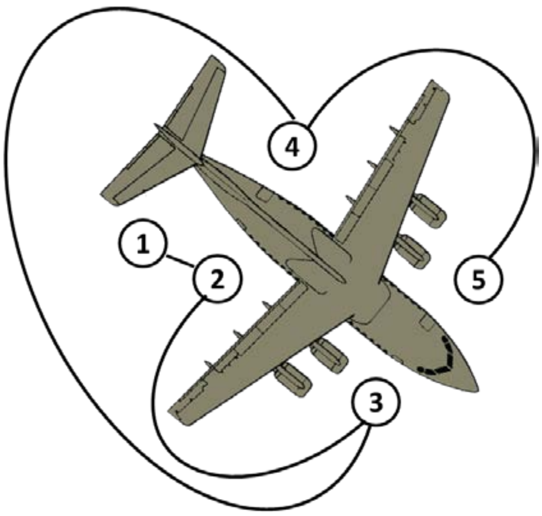

Figure 1. The positioning pattern of the de-icing vehicle.

### 1.1.2 *History of the flight*

After pushback and engine start, a specific flight control check was performed according to the checklist "After De-icing check" which meant that the elevators were brought to a drain position for 30 seconds. The purpose of the check is to drain any fluid from the inside of the elevator.

At the time of take-off the reported wind was north-easterly, 10 to 15 knots in good visibility, no low clouds, a temperature of minus 5 degrees and a pressure of 1011 hPa.

The take-off was in a northerly direction from runway 03 with the copilot as the pilot flying (PF).

About two minutes after take-off, the commander, who was the pilot monitoring (PM), reported passing 2 400 feet and received a clearance to proceed directly to the waypoint LABAN and to climb to flight level 150.

According to QAR-data, excessive vibrations occurred during acceleration when the indicated airspeed passed 214 knots at about 3 200 feet.

The commander perceived the vibrations at an indicated airspeed of around 195 knots. He took control of the aeroplane and disconnected the autopilot while the co-pilot, four and a half minutes after take-off, made the following distress call to air traffic control: *"Landvetter Scan Wing One Bravo declare emergency. We would like to come back for landing."*

The crew performed a "Pitch oscillation" procedure which, inter alia, meant that the indicated airspeed was reduced whereby the vibrations ceased. According to the recorded data, the vibrations lasted for 48 seconds.

Thereafter, the speed was increased again, and the vibrations returned for 26 seconds, until the speed was reduced a second time to about 180 knots.

The crew had recently practiced a procedure called "Pitch oscillation" during their latest proficiency check (PC). During interviews they reported that the vibrations experienced during the flight were perceived as significantly stronger, more abrupt and with higher frequency than the vibrations experienced during simulator training.

A descent and an immediate left turn were performed for a straight-in approach in the opposite direction of the take-off.

A normal approach and landing was accomplished without any signs of vibration.

During the last stage of the final approach, the crew announced *"normal operations"* to the tower. By this the crew meant that they no longer considered that the aircraft was in an emergency situation. After landing, the tower asked the crew if they needed the fire trucks to follow the aeroplane to the stand, which was declined by the crew.

A graphical presentation of the event is shown in Figure 2.

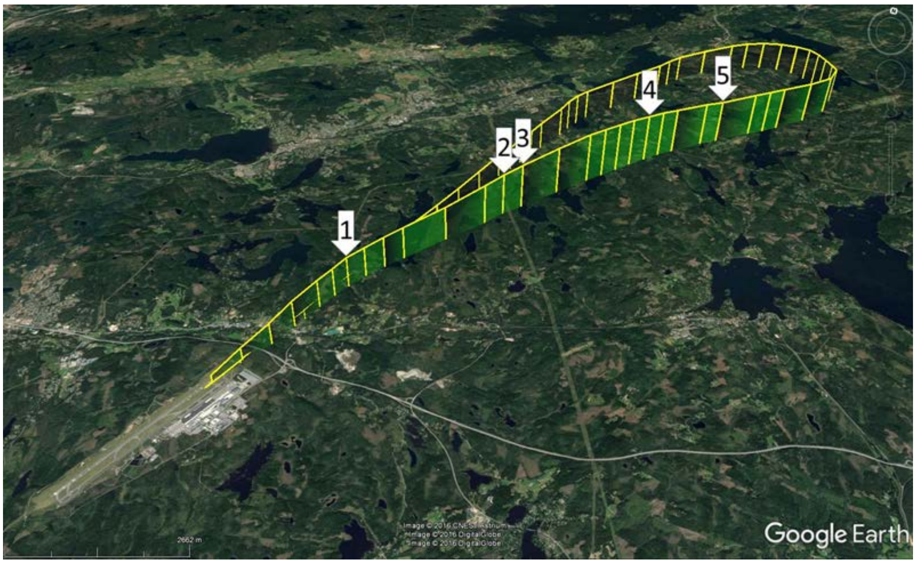


Figure 2. The aeroplane's flight path, according to radar data with take-off from runway 03 and landing on runway 21.

1. The vibrations occurred at 05:20:33 at an indicated air speed of 214 knots at 3 200 feet.

2. The vibration ended at 05:21:21 when the indicated airspeed was reduced to 184 knots at 4 500 feet.

3. A distress call was sent at 05:21:27.

4. Vibrations came back at 05:22:15 at an indicated airspeed of 205 knots at 4 500 feet.

5. The vibrations ended at 05:22:41 when the indicated airspeed was reduced to 184 knots at 4 500 feet. A descend and a left turn was performed for returning to the airport.

### *1.1.3 Actions after landing*

After the aeroplane was parked on stand 52 the commander informed the passengers over the PA system about the event and that he would be available for questions below the aeroplane's stairway.

The pilots have stated that they forgot to perform the procedures to preserve CVR and FDR recordings after the occurrence.

The commander noted the following remarks in the aircraft's technical log:

*Strong sudden vibrations after flap retraction at 200 knots, slowed to 180 knots and vibrations ceased. Approach normal.*

The operator's engineer inspected the aeroplane in order to find the source of the vibrations. The inspection revealed extensive ice contamination on the primary and secondary flight control surfaces, mainly on the elevators, rudder, ailerons and flaps. The ice-covered surfaces were documented with pictures (see Figures 3–5).

Figure 3. The rudder and right elevator after the incident. (Photo Aviator).

Figure 4. The right aileron after the incident. (Photo BRA).

Figure 5. The left flap after the incident. (Photo BRA).

The ice was removed and further maintenance, such as service of the rain repellent system and the replacement of SD cards in QAR, were performed with references to AMM. The engineer also performed an external inspection to find other sources of vibration, such as loose or missing panels, without finding any. The latter measures were performed without reference to AMM. The aircraft was approved for continued operation after a performed testflight and by issuing a certificate of release to service in the aircraft technical log.

### *1.1.4 The de-icing operation*

The de-icing operator person who performed the de-icing of the aeroplane has stated the following, in summary.

That morning he was one of two people assigned to perform de-/anti-icing operations. This was his first de-icing of the season. During the autumn of 2015 he had participated in a refresher course, which is an annual requirement for the de-icing operators. The de-icing operator has also stated that he was usually the one driving, and not the one who sprays the fluid.

As the de-icing operator understood it, the commander of the aeroplane ordered a de-icing of the stabiliser, fuselage and the wings. The de-icing operator clearly remembers that de-icing of the surfaces under the stabiliser and wings was not included.

It was a rushed operation. There is always a pressure to be on time, “every time on time”. Personally, he never wants to delay an aeroplane due to the de-icing procedure. He felt that this was very much a mind-set amongst the senior de-icing operators at Aviator. During the morning in question, he can remember that there were several aeroplanes waiting to be de-iced. This added to the perceived time pressure.

It was windy and that wind blew the steam from the spraying back towards his face. This made it more difficult to see what was happening. He started the de-icing on the stabiliser to save time. This was generally not an issue, even though it was a deviation from the prescribed procedure.

On the aeroplane there was a top layer of snow with ice underneath. He adjusted his nozzle for a more concentrated spraying cone, again to try to hurry the procedure along. He estimates that he was spraying at about 2.5 meters from the surface of the aeroplane.

The de-icing operator has stated that he inspected the result while spraying the liquid, and believed that ice and snow had been removed. But he has also stated that “you can’t really see the surface when you are applying the fluid on a specific area”. In hindsight he concluded that he probably had not inspected the result thoroughly enough. He did not perform a separate check.

The driver remembers that the de-icing of the aircraft was started at the stabiliser. There was a certain time pressure, but the de-icing could be finished without causing a delay. From his position in the vehicle you cannot see the result of the de-icing. During the de-icing, the driver communicated continuously with the de-icing operator confirming that the de-icing had been completed.

The driver also stated that the temperature of the fluid was an appropriate 80–85 degrees Celsius. It was also he who had made the morning checks of the de-icing vehicle, including a check of fluid mixture and fluid freezing point. The fluid freezing point was minus15 degrees Celsius.

## 1.2 Injuries to persons

| | Crew members | Passengers | Total on-board | Others |
|---|---|---|---|---|
| Fatal | - | - | 0 | - |
| Serious | - | - | 0 | - |
| Minor | - | - | 0 | Not applicable |
| None | 5 | 50 | 55 | Not applicable |
| Total | 5 | 50 | 55 | - |

## 1.3 Damage to aircraft

No known damage to the aircraft (see section 1.18.8).

## 1.4 Other damage

None.

### *1.4.1 Environmental impact*

None.

## 1.5 Personnel information

### *1.5.1 Commander*

The commander was 49 years old and had a valid ATPL license with flight operational and medical eligibility. At the time the commander was PM[7] during take-off. During the incident the commander took control of the aeroplane and continued as PF for the rest of the flight.

| Flying hours | | | | |
|---|---|---|---|---|
| Latest | 24 hours | 7 days | 90 days | Total |
| All types | 1 | 7 | 115 | 9 994 |
| Actual type | 1 | 7 | 115 | 7 200 |

[7] PM – Pilot Monitoring.

Number of landings actual type previous 90 days: 21.
Type rating concluded in 2001.
Latest PC[8] conducted on 02 November 2016 on type.

### 1.5.2 *Co-pilot*

The co-pilot was 43 years old and had a valid CPL license with flight operational and medical eligibility. At the time the co-pilot was PF during take-off until start of the event and then continued as PM.

| Flying hours | | | | |
|---|---|---|---|---|
| Latest | 24 hours | 7 days | 90 days | Total |
| All types | 1 | 4 | 77 | 5 584 |
| Actual type | 1 | 4 | 77 | 3 000 |

Number of landings actual type previous 90 days: 60
Type rating concluded on 21 December 2006.
Latest PC conducted on 14 October 2016 on type.

### 1.5.3 *Duty schedule of the crew*

The commander and co-pilot were on duty for the first day of the week after a two-day rest period.

### 1.5.4 *Cabin crew*

The cabin crew consisted of three persons. All had valid operational and medical eligibility.

### 1.5.5 *Other personnel*

*De-icing staff*

The de-icing operator was qualified to perform the actual de-icing operations according to the requirements in Aviator's managements system. He was qualified both to perform and also to supervise the work, see section 1.17.2 subsection *Training*. The de-icing operator had participated in a refresher course provided by the subcontractor on 18 November the previous year. The de-icing operator therefore had operational eligibility for the task until 31 December 2016.

[8] PC – Proficiency Check.

The event occurred early in the morning of 7 November 2016. The work schedule for the week was as follows:

| Date | Working hours | Total |
|---|---|---|
| 1 November | Off | |
| 2 November | 13:15–23:00 | 9,75 |
| 3 November | 15:15–02:30 | 11,25 |
| 4 November | Off | |
| 5 November | Off | |
| 6 November | 05:00–11:45 | 6,75 |
| 7 November | 05:00–15:00 | 10,00 |

Table 1. The work schedule for the actual week.

## 1.6 Aircraft information

The aeroplane of the model AVRO-RJ 100 is a high wing regional jet transport, powered by four turbofan engines mounted below the wings. The engines are designed and manufactured by Honeywell International Inc. The original Type Certificate for this model and series is dated 3 February 1983.


Figure 6. The aeroplane (Photo Andreas Eriksson).

The aeroplane is mainly made of aluminium alloys and has a pressurised fuselage. The aeroplane is almost 31 metres long and its wingspan is just over 26 meters.

### 1.6.1 *The aeroplane*

| | |
|---|---|
| TC-holder | BAE SYSTEMS |
| Model | AVRO-RJ 100 |
| Serial number | E3250 |
| Year of manufacture | 1994 |
| Gross mass, kg | Max take-off/landing mass 44 225/40 142 current 35 584 |
| Centre of gravity | Within allowed limits. 36 % MAC (min 26 max 45) |
| Total flying time, hours | 36 756 |
| Cycles | 36 829 |
| Flying time since latest inspection, hours | 10 |
| Type of fuel uplifted before the occurrence | 2 180 litres JET A1 |
| Deferred remarks | None |

The aeroplane had a Certificate of Airworthiness with a valid ARC.

### 1.6.2 *Description of parts or systems related to the occurrence*

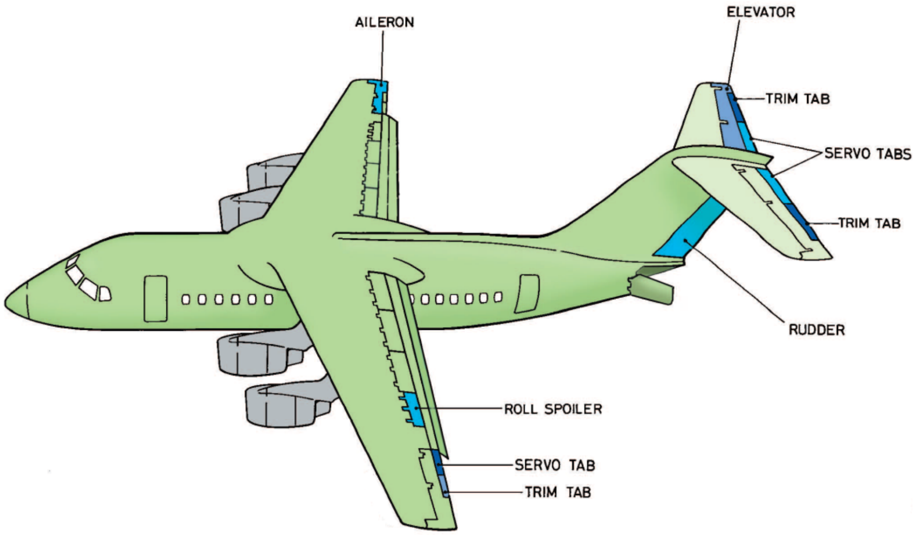


Figure 7. Flight controls

*Primary flight controls*

The primary controls are used to manoeuvre the aircraft. The ailerons affect the aircraft’s roll, which means that the aircraft can be tilted to the left or right. The elevators affect the aircraft’s pitch, which means that the nose position can be raised or lowered. The rudder affects the aircraft in yaw, which allows movement of the nose from left to right.

The primary control surfaces comprise an aileron on each wing, two elevators and a single rudder. The primary controls are operated by a steering wheel type floor-mounted control column and adjustable rudder pedals.

The ailerons and elevators are operated manually by cables, push rods and bellcranks, which operate servo tabs on the control surfaces. The rudder is operated by hydraulic power; the two actuators are controlled mechanically by cables and a gearing unit.

Control cables are segregated for safety reasons; aileron cables are located on each side of the fuselage roof and the trim cables under the floor. Rudder and elevator cables run under the floor.

Two independent mechanical circuits, using cables, rod and levers operate the left and right elevators separately using servo tabs (see Figure 8). The servo tabs and the elevators are mass balanced and aerodynamically balanced.

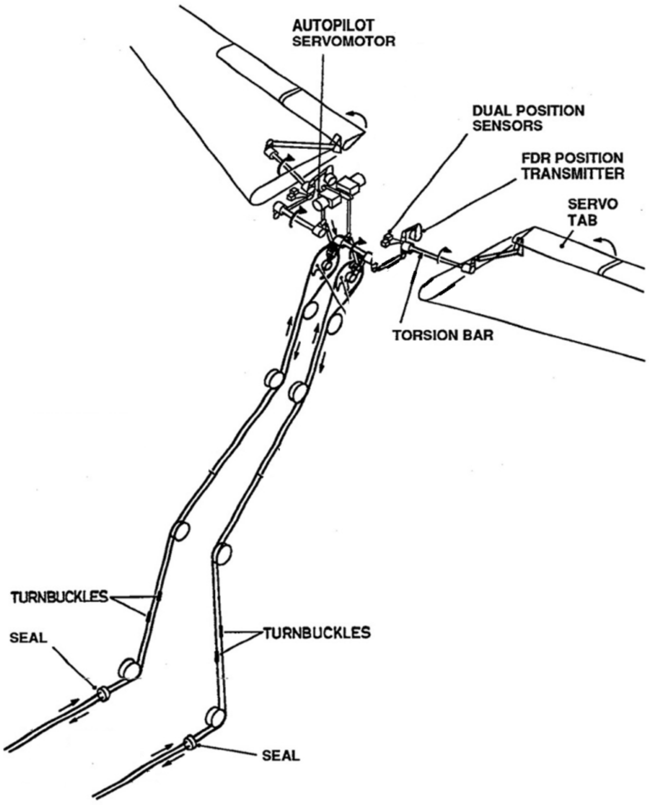


Figure 8. Elevator control system

### 1.6.3 *Details of the current aeroplane configuration*

The aircraft type uses hydraulic actuators for the rudder but a combination of trim and servo tabs for the ailerons and the elevator.

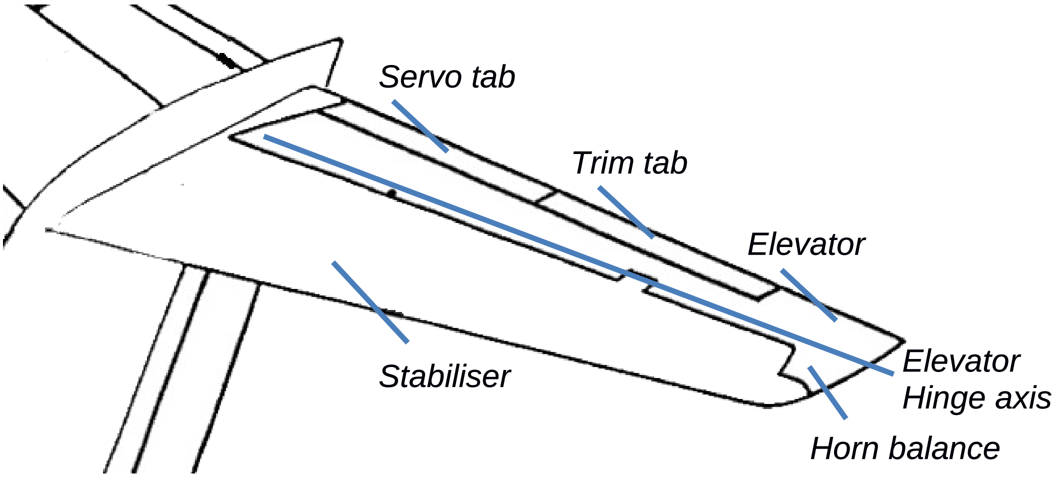


Figure 9 Relevant parts of stabiliser and elevator.

At the tip of the elevator, there is also a horn balance giving significant lifting surface in front of the hinge axis, which usually reduces the required control forces. At the trailing edge of the elevator, there are two smaller control surfaces. The outer one is denoted the trim tab and the inner one the servo tab. The trim tab is adjusted using an electrical actuator and is mainly used to relieve stick forces. The servo tab is the control surface that is directly connected to the control columns.

The actual elevator is not directly connected to the control column meaning that it is essentially floating free in the air stream when in flight. As the pilot moves the control column, the servo tab is deflected which affects the elevator and thereby the lift of the stabiliser.

The aeroplane also has a number of additional components in the flight control system used to limit the control forces in flight and also reduce the risk of overstressing the aeroplane structure due to large pilot input at high speed. Although the control column only moves the servo tab for longitudinal control, it is possible to actually move the elevator if the control column input is above a certain limit. The main purpose of this feature is to ensure that the pilot can check before flight that all control surfaces are free to move.

*Aeroelastic stability and mass balancing*

The main drawback with the use of a servo tab to control a larger elevator is that this design is known to be sensitive to aeroelastic instabilities.

A large free floating control surface, such as the elevator, will move as desired due to changes in aerodynamic pressure distribution but may also move due to inertial forces caused by motion in flight. If the elevator centre of mass is not located on the hinge axis, vertical motion of the aeroplane will cause an inertial force that moves the control surface without pilot input.

If the centre of mass is located behind the hinge axis, a vertical upward motion of the aeroplane will cause a trailing edge downward motion of the elevator which in turn increases the lifting force amplifying the motion possibly creating aeroelastic instability also known as flutter.

If, on the other hand, the elevator centre of mass is located in front of the hinge axis, vertical motion of the aeroplane will result in an inertial force moving the elevator leading edge upwards, which will reduce lift. This means that the control surface movement has a dampening and stabilising effect.

Any given aeroplane must carefully be tested and analysed to ensure that the structural and aerodynamic design is such that the aeroplane is free of any aeroelastic instability throughout the intended operating envelope of the aeroplane.

To reduce the chance of aeroelastic instabilities, it is common design practice to add small ballast weights to control surfaces and control tabs to ensure that the centre of mass of the control surfaces are located on, or close to, the hinge axis. This can be difficult to achieve as there is often limited space in front of the hinge axis.

Current standard methods for analysis of aeroelastic phenomena are not able to account for small details in the aeroplane's design such as the gaps between control surfaces and the wing. Structural dynamics is usually treated as linear in order to perform flutter analysis.

Complex issues such as friction and free-play are important factors influencing aeroelastic stability, but these are very difficult to analyse with sufficient precision for aeroplanes with a complex control system.

A flutter analysis usually first involves modelling the structural dynamics of the aeroplane. A computational model can be used but it is essential that this model is compared and matched to a so-called ground vibration test (GVT) where the aeroplane structural frequencies of resonance are measured together with the deformation of the structure at each frequency of resonance.

This structural dynamics model is then integrated with a numerical model for the unsteady aerodynamic forces. A stability analysis is performed at each relevant flight condition to see if the aeroplane is aeroelastically stable or unstable. Dynamic aeroelastic instability is usually referred to as a flutter condition where a small disturbance will lead to an oscillatory motion of increasing amplitude. In some cases, flutter instability may reach a state of vibration at constant amplitude. This case is referred to as a limit-cycle oscillation (LCO).

Further, ground vibration testing is difficult when control surfaces are free to move. If the excitation force is small, friction may cause the control surfaces to stay in place in terms of motion around the hinge axis. If the excitation force is sufficiently large to overcome the friction forces, the control surfaces may start to move and then affect the overall structural dynamics of the aeroplane.

*Modifications performed on the aeroplane in question*

Following a sequence of vibration incidents in flight with the current aeroplane type, BAE Systems have performed a number of modifications to reduce the risk of undesirable vibrations in flight. All such modifications had been made to the aeroplane involved prior to the incident.

Additional drain holes in the control surfaces have been introduced to reduce chance of residual liquid inside control surfaces. Pre-flight check of elevator controls should drain control surfaces, but is of little use if the liquid is frozen.

A flight damper between the elevator and the fin has been added to reduce the risk of flutter instability if the control system is out of balance. The damper, when correctly tuned, may reduce the risk of flutter instability but also adds to the complexity of the control system, making analysis and testing more difficult. The flight dampers are identified in the MEL[9] and operational restrictions are required if flight dampers are unserviceable.

*Analysis performed of similar events*

BAE Systems have gathered flight data from several incidents involving so-called pitch oscillation events, (see Figure 10). One of the cases presented concerns an instrumented flight test aircraft but the data from the other incidents are based on available data from the flight data recorder. The flight data recorder data is logged at a lower frequency than that of the phenomena so the data has been processed in order to obtain a likely, but not entirely accurate, estimate of the actual frequency. Further, BAE Systems has also developed a numerical simulation model for this type of phenomena. With suitable input data, it appears that the simulation model can reproduce a response that is similar to the events occurring in flight.

[9] MEL – Minimum Equipment List.

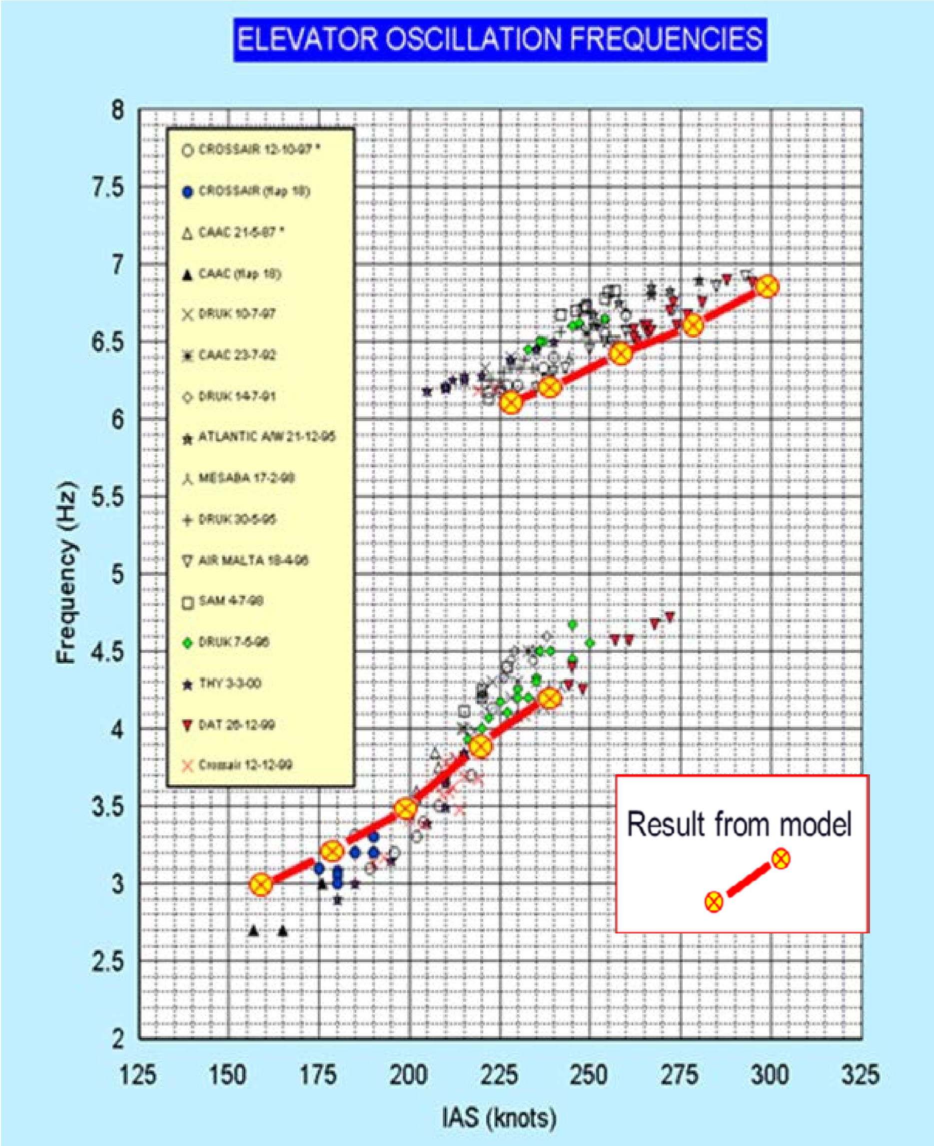

Figure 10. Elevator oscillation frequencies. Picture by BAE Systems.

## 1.7 Meteorological information

In the days leading up to the incident, a low pressure system had passed with precipitation that went from rain to snow and temperatures of two degrees down to minus five.

Over two days prior to the event, about 6 mm of melted precipitation was recorded, which corresponds to a snow cover of about 5 cm. Since it had rained earlier, the cover consisted of snow and ice.

SMHI's[10] analysis for Gothenburg/Landvetter: Wind northeasterly 10 to 15 knots, visibility > 10 km, no clouds below 5 000 feet, temperature/dewpoint -05/-07°C, QNH 1011 hPa.

The incident occurred during darkness.

[10] SMHI – Swedish Meteorological and Hydrological Institutes

## 1.8 Aids to navigation

Gothenburg/Landvetter Airport is equipped, inter alia, with an instrument landing system (ILS).

## 1.9 Communications

The radio communication between the aeroplane and air traffic control have been collected and analysed.

An emergency message was sent to the air traffic control during the event.

Relevant parts of the radio communications is presented in section 1.1.2.

## 1.10 Aerodrome information

Gothenburg/Landvetter Airport is a certified instrument airport according to AIP Sweden. The airport has one asphalted runway with the dimensions 3 299×45 metres and the runway designations 03 and 21.

The runway is equipped with high intensity approach, centreline and edge lights.

## 1.11 Flight recorders

The aeroplane was equipped with DFDR[11], QAR[12] and a CVR.

### *1.11.1 Flight Recorders (DFDR, QAR)*

The QAR-data was downloaded by the operator and forwarded to SHK. The QAR was a L3 Communication, model L3 com µQAR with part number QAR201-02-00.

### *1.11.2 Cockpit Voice Recorder (CVR)*

The recordings from the CVR, which had a recording time of 30 minutes, were automatically overwritten when SHK received notification of the event. Therefore, CVR data has not been used in the investigation.

## 1.12 Site of occurrence

The incident occurred at position 57 72N 012 34E at approximately 3 200 feet above sea level after take-off from runway 03 at Gothenburg/Landvetter Airport.

[11] DFDR – Digital Flight Data Recorder.
[12] QAR – Quick Access Recorder.

## 1.13 Medical and pathological information

Nothing has emerged to suggest that the mental or physical condition of the pilots was impaired before or during the flight. Nor has anything emerged to suggest that the mental or physical condition of the de-icing personnel was impaired during the de-icing.

## 1.14 Fire

There was no fire.

## 1.15 Survival aspects

### *1.15.1 Rescue operation*

A distress call was received by the air traffic unit Gothenburg Control, which contacted Landvetter Tower which in turn activated the alarm according to the following procedure:

The tower personnel pushed the alarm button, which means that the SOS Alarm unit receives a priority alert. SOS Alarm uses the necessary alarm lists and contacts the units listed on it. SOS Alarm calls the Tower back and communication between the relevant units is established and the alarm procedure is effectuated.

The crew notified air traffic control that they were no longer in distress by stating "normal operations" during final approach.

The ELT[13] was of the model KANNAD 406AP with Part number S1820502-02. It was not activated during the incident.

## 1.16 Tests and research

Not applicable.

## 1.17 Organisational and management information

### *1.17.1 The Operator*

Braathens Regional Aviation AB (BRA) is a certified commercial air transport operator for passengers and cargo with an Air Operator Certificate issued by the Swedish Transport Agency.

The certificate's operations specifications include 10 aeroplanes of the actual type.

*Timetable*

The Gate usually closes ten minutes before departure. The crew must have access to documentation for weight and balance seven minutes before departure. Only then can the doors be closed and de-icing begin.

[13] ELT – Emergency Locator Transmitter.

*Ground operations*

According to Regulation (EU) 965/2012, laying down technical requirements and administrative procedures related to air operations[14], the operator may decide to contract certain activities to external organisations. A written agreement shall exist between the operator and the contracted organisation clearly defining the contracted activities and the applicable requirements. The contracted safety-related activities relevant to the agreement should be included in the operator's safety management and compliance monitoring programmes.

The operator shall ensure that the contracted organisation has the necessary approvals and allocates the resources and competence to undertake the task. The ultimate responsibility for the service always remains with the operator. Regardless of the approval status of the contracted organisation, the contracting operator is responsible for ensuring that all contracted activities are subject to hazard identification and risk management. BRA has hired a subcontractor for the de-icing operation, for further details see section 1.17.2.

SHK has not found any specific descriptions in the contracts with the subcontractor or the operator's manuals of how to comply with the recommendations regarding what method will be used to investigate the results of a de-icing. At the time of the event the operator lacked, specific routines handling i.e. the underside of stabiliser. Instructions regarding de-icing procedures were furthermore spread out in various documents and manuals.

### *1.17.2 The subcontracted de-icing operator*

For de-icing operations at Gothenburg/Landvetter Airport, the operator subcontracted Aviator Airport Services Sweden AB (Aviator) according to a simplified procedure to IATA Standard Ground Handling Agreement (SGHA) called Annex B. The simplified procedure is based on IATA's main agreement, SGHA 2013, Annex A. According to this agreement, Aviator shall *"remove frost ice and snow from aircraft using de-icing fluid"* (paragraph 3.16.6) and *"perform final inspection after de-icing/anti-icing operations and inform flight crews of results"* (paragraph 3.16.9).

There was also a Service Level Agreement (SLA) agreement with the same validity as SGHA. In the agreement, which, according to the operator, also applies to the subcontractor, de-icing is not specifically concerned, however safety is pointed out as prior to punctuality.

Aviator has been inspected by Northpool[15] on behalf of BRA. The inspection was closed with a final inspection report on 4 March 2016.

[14] Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008.

[15] Northpool is the auditing pool for de-icing and fuel. The members consist of all Swedish airlines except SAS.

The final report stated that Aviator's quality assurance program had not been implemented before the beginning of the previous season. Aviator then took some measures. Northpool accepted the measures and closed the inspection.

*Organisation*

Aviator's organisation is divided into three parts, Ramp, Operations and Passengers. De-icing Operations is placed under Ramp. Within the organisation, a total 23 out of 45 people are qualified to conduct a de-icing operation. At Gothenburg/Landvetter Airport there is a station manager who has overall responsibility for the day to day operations.

*Training*

Aviator has developed a training course system for the de-icing personnel. It includes a basic training course for de-icing operators and an additional qualification course. The subcontractor has employed the concept of *train-the-trainer*, which means that a representative from the central organisation of the subcontractor trains the local trainers. The local trainers then in turn conduct the training course with the local personnel.

The basic training course is comprised of 14 hours' seminar instruction. The de-icing operator shall also take a written test and achieve 21 training hours to be qualified. To be qualified for the supervisory task, an additional training course of 3 to 7 hours is required. The course includes both theoretical and practical training. Refresher courses are generally conducted in October every year.

*Quality Reviews of the De-/Anti-icing Operations*

Aviator has continuously conducted internal reviews of the de-/anti-icing operations. These were managed and conducted by the central organisation of the subcontractor.

*The de-icing vehicle "Elephant My"*

The "Elephant My" is a de-icing vehicle built on a standard truck chassis. The vehicle features de-icing tanks and a heater for the de-icing fluid. A boom system, which rotates at its base, carries an open manoeuvrable basket equipped with an adjustable de-icing hose.

The vehicle was serviced on 30 August 2016. It also underwent evening and morning checks without any remarks prior to the incident. These checks include examining the freezing point on the liquid. On the morning in question, the liquid had a freezing point of minus 15 degrees, which complies with the specified temperature for conditions at the time.

## 1.18 Additional information

### *1.18.1 Pre-flight inspection*

According to Commission Regulation 1321/2014[16] on continuing airworthiness of aircraft and aeronautical products, etc. and Application M.A. 301 and Appendix V to AMC M.A. 704, the continued airworthiness and functionality of both the aircraft operating equipment and the emergency equipment shall be ensured, inter alia, through a pre-flight inspection, PFI. Furthermore, the operator must provide instructions to maintenance staff, crews and other personnel for the performance of parts of PFI. In these instructions, responsibility for these parts is also to be distributed. Personnel who carry out parts of the PFI shall also receive relevant training. The standard for such training shall be stated in the airline's CAME[17].

Below are the six parts included in the pre-flight inspection in an abbreviated version:

a) A walk-around type inspection of the aircraft and its emergency equipment (also known as External inspection).

b) An inspection of the aircraft continuing airworthiness record system or the operator's technical log as applicable to ensure that the intended flight is not adversely affected by any outstanding deferred defects and that no required maintenance action shown in the maintenance statement is overdue or will become due during the flight.

c) Checking that consumable fluids, gases etc. uplifted prior to flight are of the correct specification.

d) Checking that all doors are securely fastened (also known as Departure check).

e) Checking that control surface and landing gear locks, pitot/static covers, have been removed.

f) Checking that all the aircraft's external surfaces and engines are free from ice, snow, sand, dust etc. (also known as Contamination check).

Mainly relevant to this investigation are the external inspection and the contamination inspection. At BRA, the external inspection is performed by pilots or engineers and signed in ATL[18] as PFI. The contamination inspection is performed by pilots or trained maintenance staff.

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[16] Commission Regulation (EU) No 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.
[17] CAME – Continuing Airworthiness Management Exposition.
[18] ATL – The operators Aircraft Technical Log.

### *1.18.2 Regulatory requirements, guidelines and standards for the de-icing operations*

In accordance with the implementing rules in Annex IV to EU Regulation 965/2012 (CAT.OP.MPA.250[19]) the operator shall establish procedures to be followed when ground de-icing and anti-icing and related inspections of the aircraft are necessary to allow the safe operation of the aircraft.

The commander shall only commence take-off if the aircraft is clear of any deposit that might adversely affect the performance or controllability of the aircraft.

In the guidelines, the operator is referred to certain recommendations issued by ICAO[20] and AEA[21], including:

- ICAO Doc 9640-AN/940 Manual of Aircraft Ground De-icing/Anti-icing Operations
- AEA's "Recommendations for de-icing/anti-icing of aircraft on the ground"

ICAO Doc 9640 prescribes a check to ensure compliance with the Clean Aircraft Concept immediately following the application of de-icing/anti-icing fluids which is to be carried out by a qualified person in accordance with the approved operator plan and procedures. The pilot-in-command has the responsibility to ensure compliance with the Clean Aircraft Concept. The ground de-icing crew share this responsibility by providing an aeroplane that complies with the Clean Aircraft Concept. The commander is responsible for continually monitoring the condition of the aeroplane after de-icing/anti-icing has been completed and for ensuring that the aeroplane complies with the Clean Aircraft Concept at the time of take-off.

Where the de-icing provider is carrying out the de-icing/anti-icing process and also the Post De-icing/Anti-icing Check, it may, according to AEA: recommendations[22], either be performed as a separate check or incorporated into the de-icing operation. The de-icing provider shall specify the actual method adopted, where necessary by customer, in his winter procedures.

The 2016–2017 winter season was the last time these AEA recommendations were published. From now on, the guidelines to the regulation (EU) 965/2012 will make reference to the new SAE[23] Global De-icing Standards AS6285 (De-icing procedures) and AS6286 (De-icing training, including detailed training information).

[19] CAT.OP.MPA – Commercial Air Transport Operations Multi Pilot Aircraft.
[20] ICAO – International Civil Aviation Organisation.
[21] AEA – Association of European Airlines.
[22] Recommendations for De-icing/Anti-icing Aeroplanes on the Ground.
[23] SAE – Society of Automotive Engineers.

There is essentially no difference between the recommendations of the SAE and those of the AEA[24].

De-icing is also included in the Transport Agency ramp inspection program, but is only covered by the check if de-icing is carried during the inspection in question.

### *1.18.3 Other instructions by the operator*

The operators additional instructions can be found in AHM, FDH, CAME and GOM. The regulatory requirements and instructions in AHM shall apply to the operator’s personnel and subcontractors.

According to the operator’s AHM[25], the de-icing is carried out by subcontractors. The subcontractor must follow the instructions in the BAe 146/Avro RJ De-/Anti-icing Application Guide and the latest release of AEA recommendations for airplane de-icing. Chapter 6 of the AHM describes the de-icing process and there is also an application guide with recommendations on how to spray the aircraft and which areas to avoid. However, there is no method for checking the results of the de-icing.

In the operator’s FDH[26] there are checklists describing how pilots should handle systems before and after the aircraft has been de-iced. Furthermore, there are descriptions of the de-icing process, the contamination inspection, the de-icing order, what the report after de-icing should contain and how it should be documented. Checking for clear ice is emphasised in particular.

The contamination inspection and certain other parts of the PFI are also described in chapter 1.11 of the operator’s CAME.

De-icing is also dealt with in the operator’s GOM[27] together with the subcontractor’s process and the operator’s obligation to secure the areas procured by contract.

### *1.18.4 Aviator’s routines and procedures for the de-icing operation*

Aviator has a basic staffing routine for de-icings operations. A team consisting of one de-icing operator and one driver is assigned to the specific task. If there is a greater need for de-icing services than a single team can manage, then there is a readiness to divert additional resources to the task.

[24] SAE have published additional standards on the subject, but there is no references to those standards in the relevant EU-regulation..

[25] AHM – Aircraft Handling Manual.

[26] FDH – Flight Deck Handbook.

[27] GOM – Ground Operations Manual.

Aviator's work is based on orders from the operator. When the de-icing team receives an order they are to contact the commander of the aeroplane for an assessment of the need to de-ice. Aviator does not perform a pre-inspection of the aeroplane before de-icing, since that service is not included in the contract with the operator.

The actual de-icing shall be performed according to the procedures and manuals that are available. The subcontractor has a general De/Anti-icing Manual (DIM). This manual is based on and also in accordance with the AEA's publication "Recommendations for De-icing/Anti-icing Airplanes on the Ground", 31th edition. The manual also takes into account the SAE Aerospace publications SAE ARP 5149 (Aerospace Recommended Practice) "Training program guidelines for de-icing/anti-icing of aircraft on ground" and 4737H "Aircraft de-icing/anti-icing methods".

With the DIM as a starting point, the local organisation of the subcontractor has written local procedures that are applicable to the local conditions and relevant aeroplane types.

*De-/Anti-icing Manual*

The DIM is written in English and relevant segments are presented in this section.

The DIM describes the basic concept *Clean Aeroplane Concepts* (CAC), which states:

> *No person may dispatch, release, or take off an aircraft any time conditions are such that frost, ice, or snow may reasonably be expected to adhere to the aeroplane, unless the aircraft has been de-/anti-iced.*

According to the DIM it is the responsibility of the de-icing operator to ensure that all frozen deposits are removed from the specified surfaces during the de-icing process. However, the ultimate responsibility for deciding that the aircraft is clean and meets airworthiness requirements rests with the commander of the aircraft.

*Contamination and its Removal*

Section 3 of the DIM describes certain definitions and concepts.

Contamination in this document is understood as all forms of frozen or semi-frozen moisture such as frost, snow, ice or slush. Contamination and the contamination check are defined as follows:

> *Check of aeroplane surfaces for contamination to establish the need for de-icing.*

*This check shall include the areas mentioned in section 3.10.1.1 through 3.10.1.8 and any other as recommended by the aircraft manufacturer. It shall be performed from points offering sufficient visibility of these parts (e.g. from the de-icing vehicle itself or any other suitable piece of equipment).*

*Any contamination found, exception of frost which may be allowed on wings lower surfaces and fuselage in accordance with aircraft manufacturer's documentation shall be removed by a de-icing treatment.*

For the maximum effect, the fluids shall be applied close to the surface to minimise heat loss. It is also noted in subsection 3.9.1.2 that:

*The heat in the fluid effectively melts any frost, as well as light deposits of snow, slush and ice.*

*Heavier accumulations require the heat to break the bond between the frozen deposits and the structure; the hydraulic force of the fluid spay is then used to flush off the contamination.*

*The de-icing fluid will prevent re-freezing for a period of time depending on aeroplane skin and ambient temperature, the fluid use, the mixture strength and the weather.*

This is further developed in the subsection *Removal of Ice:*

*Heated fluid shall be used to break the ice bond. The method makes use of the high thermal conductivity of the metal skin.*

*A stream of hot fluid is directed at close range onto one spot at an angle of less than 90º, until the aeroplane skin is just exposed.*

*The aeroplane skin will then transmit the heat laterally in all directions raising the temperature above the freezing point thereby breaking the adhesion of the frozen mass to the aeroplane surface.*

*By repeating this procedure a number of times, the adhesion of a large area of frozen snow or glazed ice can be broken.*

*The deposits can then be flushed off with wither a low or high flow, depending on the amount of the deposit.*

A general de-icing fluid application strategy is described for wings, horizontal stabiliser and elevators:

*Spray from the leading edge to the trailing edge. Do not spray from the rear. Start at the highest point of the surfaces and work to the lowest parts, i.e. on most aeroplanes start at the wing tip and work towards the root.*

For the vertical surfaces, the de-icing operator is instructed to start at the top and work down.

*The Post De- and Anti-icing Check*

The post de-icing/anti-icing check is also described as follows:

> *An aeroplane shall not be dispatched after a de-icing/anti-icing operation until the aeroplane has received the following visual check by a trained and qualified person.*
>
> *This check shall cover wings, horizontal stabiliser, vertical stabiliser and fuselage.*
>
> *This check shall also include any other parts of the aeroplane on which a de-icing/anti-icing treatment was performed according to the requirements identified during the contamination check.*
>
> *The check shall be performed from points offering sufficient visibility of all prescribed surfaces (e.g. from the de-icing operator itself or other equipment suitable for gaining access).*
>
> *Any contamination found, shall be removed by further de-icing/anti-icing treatment and the check repeated. Before take-off the commander must ensure that he has received confirmation that this Post De-icing/Anti-icing Check has been accomplished.*

The manual also specifies the following:

> *Where the de-icing provider is carrying out the de-icing/anti-icing process and also the Post De-icing/Anti-icing Check, it may either be performed as a separate check or incorporated into the de-icing operation as defined below.*
>
> *The de-icing provider shall specify the actual method adopted, where necessary by customer, in his winter procedures:*
>
> *a) As the de-icing/anti-icing operation progresses the De-icing Operator will closely monitor the surfaces receiving treatment, in order to ensure that all forms of frost, ice, slush or snow (with the possible exception of frost, which may be allowed as described in section 3.10.1.1 and 3.10.1.7) are removed and that, on completion of the treatment, these surfaces are fully covered with an adequate layer of anti-icing fluid.*
>
> *b) Once the operation has been completed, the De-icing Operator will carry out a close visual check of the surface where treatment commenced, in order to ensure it has remained free of contamination (this procedure is not required under 'frost only' conditions).*
>
> *c) Where the request for de-icing/anti-icing did not specify the fuselage, it shall also receive a visual check at this time, in order to confirm that it has remained free of contamination (with the possible exception of frost which may be allowed as described in 3.10.1.7).*
>
> *d) Any evidence of contamination that is outside the defined limits shall be reported to the commander immediately.*

*Communication between parties*

The following routine applies to communication before and after the de-icing/anti-icing treatment:

> *i) Before de-icing/anti-icing, the commander shall be requested to confirm the treatment required (areas to be de-iced, anti-icing requirements, and special de-icing procedures).*
>
> *ii) Before fluid application starts, the commander shall be requested to configure the aeroplane for de-icing/anti-icing (surfaces, controls and systems, as per aeroplane type requirements). The de-icing crew shall wait for confirmation that this has been completed before commencing the treatment.*
>
> *iii) For treatments carried out without the flight crew present, a suitably qualified individual shall be nominated by the aeroplane operator to confirm the treatment required and to confirm correct configuration of the aeroplane.*

Post de-/anti-icing communication,

> *An aeroplane shall not be dispatched for departure after a de-icing/anti-icing operation until the commander has been notified of the type of de-icing/anti-icing operation performed (Anti-icing Code).*

*Local procedures at Gothenburg/Landvetter Airport*

Aviator's local procedure document describes the de-icing vehicle operations. All de-icing vehicles are operated as a two man operation, even if one man operation is available. The vehicles are equipped with a headset that is used for communication with the aircraft pilot. The vehicle also has an intercom system for communication between the sprayer in the basket and the driver. A safety helmet is available in each unit when underwing de-icing is performed. In open basket units a safety harness is available and must be used.

The ordering of the de-/anti-icing treatment should, according to the manual, be made to the subcontractor's coordinator. Communication between the pilot and the de-icing vehicle occurs usually only after the order has been received and allocated to the de-icing vehicle and the vehicle is located next to the aircraft. Aviator staff communicates with the pilot after the order has been made and the actual de-icing position has been clarified.

Determining the need for de-icing is the obligation of the commander. The commander can however request Aviator to verify the need and communicate whatever has been found. In this case the sprayer verifies the contamination by a walk around the aircraft and also from the basket of the vehicle for the upper surfaces. The result of the inspection was communicated to the commander via the driver and a de-/anti-icing decision is made by the commander.

According to the manual it is mainly the sprayer´s task to perform any and all inspections as well as the de-/anti-icing operation. The driver is responsible to communicate any and all information relating to the operation and verify with the sprayer the procedure to be performed. Additionally, the sprayer and the driver also have a common responsability for removing ice on engins and propellers. Fluid quality checks and vehicle fluid filling is also a task for both drivers and sprayers. Responsibility of record keeping for all events and fluid quality is mainly with the driver.

The driving pattern around the aeroplane is described in three different steps, (see Figure 11).

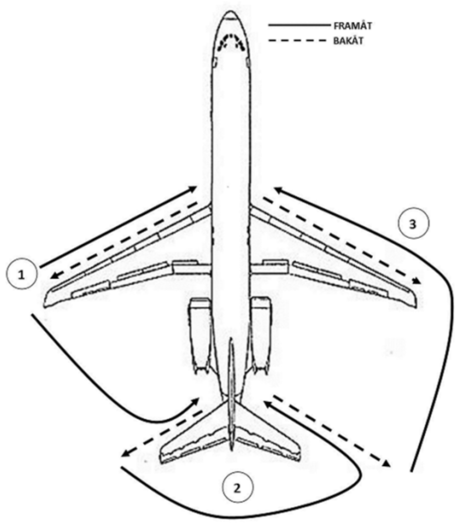


Figure 11 The driving pattern presented in Aviator's Local Procedures for Gothenburg/Landvetter airport.

### *1.18.5 General information from interviews about the de-icing-operations*

A number of interviews were conducted in order to better understand the de-icing operations of Aviator at Gothenburg/Landvetter Airport from the perspective of the de-icing operators. When presented with a specific scenario of an aeroplane of the specific type there was a consensus on the driving pattern for the de-icing operations. Normally the right wing would be de-iced first, then the stabiliser and finally the left wing. According to the interviewees, de-icing of any specified part of the aeroplane shall begin at the highest point, which matches the instructions in the DIM. In a two-step procedure, the de-icing operators could deviate from that instruction by starting from the wing tip rather than the highest point, which would be the wing root.

On some points there were differences in how the de-icing operators positioned themselves along the structure of the aeroplane, how they applied the fluid and the setting of the nozzle of the hose. One de-icing operator described the process of working a specific area of the wing and always moving the basket over the wing to inspect the back of the wing in order to make sure that is was free of ice and snow. Another operator would instead position himself sideways and move the nozzle in a fanning motion from the front to the back of the wing. A third operator would work a specific area of the wing, but regularly spray fluid on adjoining areas to start the melting process on the area that he would work on next. The distance from the area receiving treatment to the de-icing operator and nozzle of the hose vary from 1–3 meters depending on the conditions and the individual operator.

The DIM describes the *post de-icing check* as a procedure to check if there is any remaining contamination on the aeroplane. The de-icing operators' perception of this post de-icing check was that it corresponded to the report to the commander after the de-/anti-icing was finished. After the incident, the operator's pilots have started to request that the de-icing operator verbally confirms that the post de-icing check has been performed.

The DIM and the local procedures are seldom used by the de-icing operators as reference material. None of the interviewed de-icing operators could remember if they had turned to these documents for help with answers to specific questions.

Within the de-icing operator's organisation, there was no structured way for the de-icing operators to get information on the weather conditions of the previous days. The de-icing operators are generally unaware of the degree of contamination on the aeroplane that may have been built up during a ground stop. One of the de-icing operators stated that he could sometimes tell that there would be difficult conditions for the de-icing operations on that day based on scraping ice off the wind shield of his car in the morning on his way to work.

All of the de-icing operators perceived the working conditions as stressful, especially because they are the last link in the chain before the aeroplane is ready to take off. Therefore one can be blamed for a possible delay. There is always an expectation to be on time and there is obvious pressure from pilots, but also from colleagues, to meet that expectation. In many cases they feel that this pressure is unreasonable, since not enough time is allocated to the de-icing procedure. They also feel that the organisation is generally understaffed, as a person who is loading an aeroplane can be suddenly assigned to do the de-icing procedure, without being informed of this task in advance. This adds to the perceived time pressure.

There was, however, a general consensus that management has an outspoken philosophy of “safety first” within the organisation. Yet one of the de-icing operators stated that there had been implicit expressions that led to a perceived focus from the management on being quick and fast. There is, though, a perception of a no-blame culture in the organisation, where one does not risk punitive actions when reporting an incident or mistake.

When asked about the company’s system or procedure to report occurrences no one could describe how they would go about doing so. There is a system however, *Read and Sign*, where the de-icing operator receives pertinent information and is obliged to provide written acknowledgement that they have received and understood the information.

None of de-icing operators could think of a specific change in the procedures as a result of the incident, but they all mentioned that the mind-set of each de-icing operator seems to be more focused on being thorough while they are inspecting the result of the de-icing procedure.

### *1.18.6 Other relevant regulations, recommendations and procedures*

*Pitch oscillation*

As previously mentioned, the aircraft type has a history of so-called pitch oscillations. The type-certificate holder has therefore developed a special operational procedure for handling this. The recommended procedure is described in the operator’s OM-B. The procedure includes the following memory actions:

- Airspeed — Reduce to 200 kt
- FASTEN BELTS — ON
- AP (Autopilot) — Disconnect

OM-B describes pitch oscillation as follows:

The procedure is called “pitch oscillation” because, the pilot perceives the motion to be an oscillation in pitch. In fact, there is very little pitching motion. Most of the motion is a vertical bounce, which is at its strongest on the flight deck and weakest in the cabin near the centre of gravity. The typical “g” variation is between 0.7 and 1.3 g. The frequency is typically between 4 and 6 Hz.

*Preserving of FDR and CVR data*

The procedure for saving FDR and CVR is also described in the operator's OM-B:

*If a serious incident or accident has occurred, the FDR and CVR data shall be preserved by pulling circuit breakers for the units.*

*FDR data is preserved by pulling circuit breaker B-26. CVR data is preserved by pulling circuit breaker B-27. Approval from Flight Ops Department must be received before those circuit breakers can be reset*".

Circuit breakers for FDR/CVR were not pulled according to the instructions in the manual. According to the commander, the flight crew forgot to perform the procedure.

### 1.18.7 Supervision of the de-icing operations

The Swedish Transport Agency is the supervisory authority for the operator. Oversight is performed by ensuring that the operator has approved and safe procedures for de-icing and post de-icing. The oversight includes, inter alia, the operator's procedures, review of subcontractors and compliance monitoring program, which means that the operator ensures that the procedures are in accordance with applicable regulations.

The Swedish Transport Agency performs regular inspections of the operator's system. In addition, regular line inspections are conducted where flight preparations are reviewed. Inspections are also conducted regarding training and procedures of ground handling services. The Swedish Transport Agency also performs inspection of the operator's manuals to ensure compliance with regulations.

One- and two-step de-icing is part of the Swedish Transport Agency's risk directory. This is a register of areas requiring extra supervision, information measures and training.

### 1.18.8 Actions after the event

On the 19th of December, the type certificate holder, BAE Systems, suggested that the operator should consider to perform three different unscheduled inspections, which are described in the Aircraft Maintenance Manual (AMM). These inspections are recommended after this type of incident, including pitch oscillation or heavy turbulence. The inspections look at the integrity of systems that are considered likely to be affected by this type of incident in order to verify that there is no damage to the aeroplane. However, according to BAE Systems, similar events have never previously resulted in aircraft damage that seriously threatened flight safety.

Parts of the recommended inspections were carried out at Gothenburg/Landvetter Airport up to the 12th of January 2017 and others were postponed to a larger maintenance visit at a contracted maintenance organisation in Cologne in late January 2017.

During these final inspections in Cologne, damages were found on one flight damper and one drop link, (see figure 12). According to the engineer that performed the inspection, it is uncommon to find a play larger than limit on the drop links.

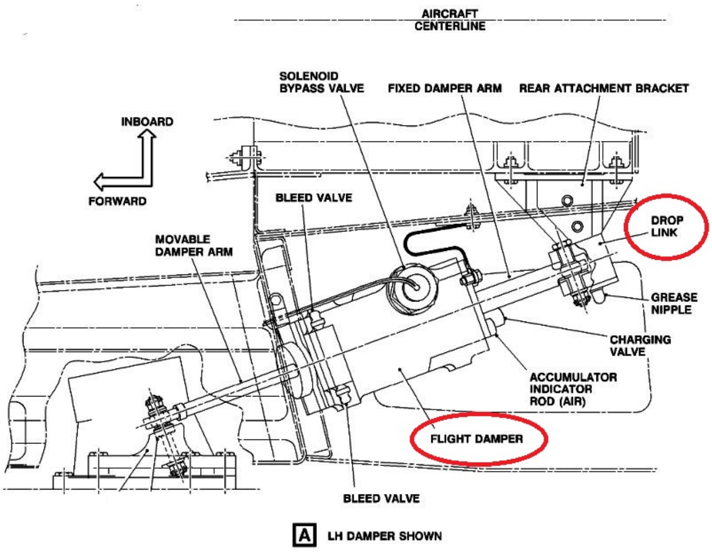


Figure 12. Flight damper and drop link.

### *1.18.9 Measures taken*

*The operator*

The operator has issued a preliminary report regarding the event. The report contains recommendations which they say will be implemented gradually in autumn 2017. According to the operator, the following measures have been or will be taken:

1. The operator has created a graphic document to clarify and assist the parties involved in the de-icing process.

2. Previous definitions and nomenclature have been improved. This is taken care of through paragraph 1. Standard procedure for detailed verbal communication was missing. After an update of the operator's DIM on 15 October 2017, this is now described in detail.

3. Routines for describing and documenting "Post De-icing Check" should have been introduced in the operator's DIM since the 15 October 2017.

4. All information on de-icing will be collected in a single manual, i.e. in the operator's DIM, where all information should be readily available.

5. Information is being developed for the pilots regarding what kind of de-icing service is available. The operator has been working on a proposal for how this system technology can be solved through a single medium.

6. The SGHA is updated to include references that the supplier should follow the operator’s manuals. DIM, in turn, indicates that you must comply with the SAE standard.

7. Strengthened routines are implemented for maintaining CVR/FDR after an event. The simulation training has been supplemented with training on the CVR/FDR routine during evacuation.

8. The operator is working to ensure that the subcontractor of de-icing services monitors their product through regular quality assurance.

9. Training requirements for relevant parts are introduced by the operator’s manuals for the subcontractor, which must also be followed up through the operator’s audit program (AUDIT).

10. Relevant technical manuals for the de-icing process will be updated. The PFI instruction will include the stabilisers upper and lower parts.

11. The operator has evaluated the crew’s qualification level in relation to the requirements for de-icing and the updated training manual. Inspections have been carried out on the training regarding de-icing and corrections have been made.

12. The training material and the implementation of training have been synchronized between the operator’s various departments.

13. The operator has carried out a “winter meeting” to discuss all matters concerning the winter and the de-icing activities.

*The subcontracted de-icing operator*

After the event Aviator has taken the following actions:

1. The Local Procedure for De-/Anti-icing Including Communication 2017–2018 has been updated.

2. The de-icing subcontractor has made a new De-/Anti-icing manual (DIM) with SAE as the new global standard.

3. Training of the instructors has been conducted in 2017 focusing on the actual event and reports from the event have become aware and discussed to raise awareness.

4. Training of the Anti-icing Coordinators was conducted in 2017, focusing on the actual events and event reports have been alerted and discussed to raise awareness.

5. Recurrent training of all de-icers and 30 are ongoing in Aviator and will be completed before 01.12.2017.

6. Training materials are updated and contain this incident with reports and images.

7. Aviator participated in the operator's Winter meeting on September 20, 2017 as preparation for the winter season.

*The Swedish Transport Agency*

The Agency has initiated and planned a number of actions related to the occurrence. According to the Agency, internal cooperation shall be reviewed in order to more clearly ensure responsibility in areas such as oversight and authorization in the de-icing process and associated procedures. In addition, inspectors shall be further trained for the purpose.

Information to operators shall be strengthened. Information bulletins (MFL[28]) shall be published and seminars will be conducted in the area concerned.

Oversight plans and checklists shall be adjusted to ensure that the monitoring of providers of flight safety related services providers is performed by NP[29]. The allocation of responsibilities between CMM[30] and NP OPS[31]/NP GND[32] for the operators shall be ensured, as well as correct procedures for the completion of the de-icing process. Training programs of crew members as well as relevant suppliers shall be secured. Furthermore, the extent of the operators' SMS[33] regarding the services concerned shall be monitored. The question shall be raised whether risk identification and risk classification and associated compensatory measures are also applied to these suppliers.

*EASA*

The Agency published Safety Information Bulletin (SIB No. 2017-11), on 14 July 2017, on global aircraft de-icing standards, recommending that air operators use the 'Global Aircraft De-icing Standards' published by the SAE International as their reference material to establish their ground de-icing procedures. This served as a reminder to EASA Member States' operators and de-icing service providers of the technical industry standards.

[28] MFL – Information bulletins from the Swedish Transport Agency regarding aviation.
[29] NP – Nominated Person.
[30] CMM – Compliance Monitoring Manager.
[31] NP OPS – Nominated Person Flight Operations.
[32] NP GND – Nominated Person Ground Operations.
[33] SMS – Safety Management System.

### 1.19 Useful or effective investigation techniques

Not applicable.

## 2. ANALYSIS

### 2.1 The incident

As noted, severe vibrations occurred shortly after take-off. The commander took control of the aircraft while the co-pilot called the air traffic control, declared emergency and decided to abort the flight. The crew performed the procedure for pitch oscillation, except that the speed was reduced to a lower speed than prescribed according to this procedure. The vibrations ceased when speed was reduced but an increase in speed caused them to return. During interviews the crew reported that the vibrations were perceived as significantly stronger, more abrupt and having higher frequency than the vibrations experienced during simulator training of pitch oscillation.

### 2.2 What was the cause of the vibrations?

As previously described the aeroplane returned with remaining contamination in the form of ice on several of the critical surfaces of the aircraft, mainly on elevators, rudder, ailerons and flaps. Contamination was also found on the underside of several flight control surfaces.

The aircraft had been parked outdoors for about 40 hours before the incident. During that time there had been precipitation in the form of rain followed by snow and sleet. SHK therefore concludes that the ice contamination on the aircraft probably consisted of several layers of ice and snow.

Ice contamination on the underside of rudder surfaces is relatively unusual. It was probably due to the fact that the aircraft was parked with the tail section to the wind and that those parts that had ice on the underside had been angled towards the wind.

#### *2.2.1 Effect of ice on control surfaces*

According to documentation from the type certificate holder BAE Systems, there has been a number of previous incidents involving vibrations during flight on this type of aircraft. These have been referred to as “pitch oscillations” but this description is somewhat misleading since pitch oscillations usually implies a rigid body motion in the pitch plane of the aeroplane. However, the incidents described have a reported vibration frequency in the 6–7 Hertz range which is too high to represent a rigid body motion of an aeroplane of this size.

Furthermore, the ground vibration test results presented to the investigation lists a fuselage two-point bending mode at 6.5 Hertz. This is close to the frequencies measured in the above-mentioned incidents during flight, where the vibrations have been said to be of large amplitude in the cockpit and tail of the aeroplane but of less amplitude in the middle.

Consequently, it appears from the available reports and data that the most likely cause of the vibrations is an unbalance in the elevator control system interacting with aerodynamic forces and the structural vibrations modes of the entire aeroplane to give a flutter instability with limited amplitude, a so-called “limit-cycle oscillation” (LCO).

The crew’s description of the incident dealt with in this report corresponds to previously documented events. It is therefore likely that this too was an LCO.

The available data describes in detail how control surfaces must be checked during maintenance and repairs to ensure that mass balancing is within certain prescribed tolerances. In particular for the servo tab on the elevators, the prescribed tolerances are very narrow. For example, if a mass larger than 23 grams is required to be placed on the trailing edge of the elevator servo tab in order to balance the tab on the hinge axis, the tab is out of balance and must be modified. This means that a very thin layer of ice is sufficient to bring control surface mass balance out of the approved range stated in the aeroplane’s maintenance instructions.

For the servo tab, a uniform ice sheet of a thickness less than one millimetre is enough to create an unbalance larger than the specified limit in the maintenance manual. The indicated analysis methods do not appear detailed and accurate enough to predict with any precision the ice thickness that may actually cause flutter instability. However, it appears that BAE Systems have carried out analysis and testing for this type of aeroplane, including a prescribed ground test in accordance with the requirements set out in the certification regulations. The description of the methods and tools used also appears reasonable and adequate for an aeroplane of this generation. It also appears that more detailed analyses have been conducted after the incidents of vibration during flight described above.

### *2.2.2 Conclusions concerning the aeroelastic stability of the aeroplane*

The aeroplane has a fairly standard control system design, perhaps with some more unusual details of the configuration. The concept is well-established and is used in many aeroplanes, in particular smaller aeroplanes where powered controls, typically hydraulics, are considered too heavy and complicated.

However, it is well known that this type of system can be sensitive to mass unbalances and are thus at an increased risk of aeroelastic instabilities such as flutter.

This particular type of aeroplane appears sensitive to mass unbalance in the control surfaces and there is no obvious modification that would improve the situation significantly. New modifications could improve the situation, but would likely make analysis and testing more difficult.

In conclusion, the flight control surfaces must be completely clean from ice and other contamination prior to flight.

#### *2.2.3 Cause of the vibrations*

In this case, the ice contamination on the aircraft was relatively extensive. Based on the above, SHK concludes that the vibrations were caused by the unbalance in the elevator system that arose because of the ice contamination.

### 2.3 Why was the aeroplane dispatched with remaining ice on critical surfaces?

As stated, the commander may only initiate a take-off if the airplane is free of any contamination that may adversely affect the performance or manoeuvrability of the aircraft (see section 1.18.4). SHK finds it highly unlikely that the ice formed on the aircraft after de-icing, as there was no precipitation and the aircraft did not fly through clouds at the time. SHK therefore concludes that the aircraft took off with remaining ice contaminants on several surfaces. The question is then why the flight would take off despite the ice.

#### *2.3.1 Inspection of the aircraft before take-off*

As previously stated, the engineer inspected the aircraft during the night. He entered the inspection as a pre-flight inspection (PFI) in the aircraft’s technical logbook, and noted at the same time that the aircraft needed de-icing. The same engineer, together with the commander, made an additional inspection of the aircraft during the preparations on the ramp. The commander also noted the contamination of snow on the aircraft. The investigation reveals, however, that they did not detect the ice on the underside of elevators and ailerons.

The commander has stated that he orally ordered a “Type I” de-icing of the wings, stabiliser, rudder and aircraft fuselage. According to the de-icing operator, the order included only wings, stabilisers and elevators. Both agree that de-icing of the underside of elevator and ailerons was not specifically mentioned in the order, however, according to the de-icing log, de-icing of the vertical stabiliser was included.

As shown, residual ice was found on the undersides of ailerons and elevators after the event. It can be noted that none of the people involved noticed this. Neither the engineer nor the commander detected the ice contamination on these surfaces. Consequently, these surfaces were not covered by the de-icing order. The commander has stated that if he had discovered the ice, he would have specifically mentioned it.

Nor did the de-icing operators discover these contaminants. However, the de-icing of these surfaces was not specifically mentioned in their order. Aviator cannot be considered to have been commissioned to specifically remove ice on these areas. However, had they discovered the ice, they would have been obliged to inform the commander about it.

The reason why the contamination on the underside of the elevators was not detected could be that the elevator is located relatively high up. The investigation also reveals that no action was taken to get closer to better inspect this area. According to the commander, the visibility conditions were good and, in his opinion, he should have been able to see the contamination. This applies even more to the contamination on the underside of the aircraft's ailerons, which are not as high up as the elevators.

One reason why the contamination was not noted could be that the ice contamination at the time of inspection had a shape and appearance that was difficult to detect. It can be that the contamination then changed during the de-icing and flight and thus became easier to observe at the inspection of the aeroplane after its return to Gothenburg/Landvetter Airport than it was for the personnel who performed the inspection prior to the flight.

Another explanation could be that it is relatively unusual to get contaminations on the underside of the aircraft surfaces, and that neither the commander nor the engineer put much focus on checking these surfaces. It is also unusual for a specific order of de-icing of these surfaces to be made.

At the time, the operator also lacked sufficiently detailed routines for checking the underside of the elevator. According to the SHK, this has been a contributing factor to the fact that the contamination was not detected.

#### *2.3.2 The de-icing of the aircraft*

The investigation further shows that after landing there was also ice on surfaces undisputedly covered by the commander's de-icing order and which had actually been treated.

*Execution of the de-icing*

The de-icing operator has given several explanations as to why there was remaining ice on the surfaces of the aeroplane. The main reason was that he felt a need to hurry and perform the de-icing operations quickly in order to avoid a delay. As previously described, the de-icing procedure usually begins only a few minutes before departure. In this case, though, it was only a one-step treatment ordered. However, in view of the amount of ice on the aircraft, it can be assumed that an appropriate de-icing would have taken a longer time than usual to complete, which may have increased the time pressure.

From the surveillance camera recordings, SHK can conclude that very little time and in some instance no time at all was dedicated to inspecting the results of the de-icing. The de-icing operator himself has concluded that the check may not have been sufficiently meticulous and well executed. SHK shares this view and believes that this is one of the reasons why the remaining ice was not detected.

*General about de-icing time pressure*

Generally there is always a tight time limit when de-icing an aeroplane. In order to dispatch aeroplanes according to schedule the de-icing operators have to be fast. This specific de-icing operator has also said that he considers it a matter of personal pride to dispatch aeroplanes on time.

Against this background, SHK has investigated whether time constraints are a general problem for the de-icing operations. Other de-icing operators have denied pressure from superiors or any sort of competition or rivalry in terms of dispatching aeroplanes on time. However, they have very clearly stated that there is an obvious time pressure working in this environment. There are also indications that there was an implicit expectation to work fast.

The interviewed de-icing operators all felt that the de-icing organisation was understaffed. Even though there are always at least two persons assigned to de-icing duty, these persons are at the same time tasked to handle other assignments. This leads to situations where there will be delays. In some cases, the staff is not informed that they will also be in charge of de-icing, when they are assigned other tasks. If they are suddenly asked to take on the de-icing, it increases the stress for the personnel.

The interviewed de-icing operators further agreed that there was not enough time reserved for the de-icing. The time it takes to carry out a de-icing also varies greatly depending on the degree of contamination and frost, snow or ice. The operator’s timetable does not take into account these variations. In order for the airlines to catch up with a number of rotations in the morning and evening, the timetable is set with short rotations that are not adapted to the disturbances that the weather can cause. Nor the de-icing operators working hours are adapted to the weather conditions. It can be noted that the aircraft in this case had unusually extensive contamination of ice and snow. In SHK's opinion, it is not reasonable to require that the timetables and working hours generally take something into consideration that happens on a few occasions each year. However, the operator must be aware and accept that such interference occurs and that it may lead to delays.

A de-icing operator is furthermore the last person in a chain of people and activities that will make sure that the aeroplane departs, and as the last person in that chain it is easy to get, or feel that you get, the blame for delays. In addition, pilots and other employees try to speed up the de-icing to ensure that the timetable is kept.

Some individuals are able to accept that an aeroplane will be delayed and stand firm against other individuals' expectations and requests that the aeroplane shall leave on time. These persons will still take the time to perform the de-icing operation to satisfaction. Other individuals might feel the pressure and expectations more intensely and be influenced to adjust the degree of accuracy risking that the result will be affected negatively. It is therefore important that the organisation is extremely clear on prioritising the aeroplane being free of ice. This event shows that this has not been sufficiently clear within the organisation.

In order to help the individual to withstand individual or organisational pressure, it is also important that there are distinct routines and robust procedures and that these are properly implemented in the de-icing operations. The investigation has shown that such procedures have not been fully understood and implemented, one example being that the meaning of the post de-ice-check has not been sufficiently well-established among the de-icing operators.

*Training regarding post-de-icing inspection*

Aviator uses a train-the-trainer system where local trainers are trained centrally. Aviator thus has great opportunities to control the content of the education. Aviator also provides continuous refresher courses. Aviator thus has good opportunity to pay more attention to what the post-de-icing inspection means and how it should be done.

*Experience and education*

This was the first de-icing operation of the season that the de-icing operator performed, and he has also stated that he normally drives the truck. Therefore a lack of recent experience and knowledge could be one possible explanation for the occurred incident. Additionally it had been almost a year since the de-icing operator had taken the refresher course. It is however the assessment of the SHK that the de-icing operator had the basic knowledge and know-how to apply the de-icing fluid and carry out the prescribed check, even though there was a lack in current knowledge and know-how. It seems rather be the time constraints, including ones that were self-imposed, that have led to a hurried de-icing operation of the aeroplane.

*The incorporated method of de-icing inspection*

Aviator's de-ice manual explains how a de-icing inspection is to be carried out. There is a list of bullet points (a to d) in the manual (see 1.18.4), which describes various ways to carry out the inspection. However, the manual lacks a clear explanation of which item in the list corresponds to a separate and incorporated inspection. According to the manual only one of these methods is chosen. However, alternative "a" in the list can be said to correspond to an incorporated inspection and "b" to a separate inspection. Using the incorporated method, the inspection is performed while the work is being performed, and thus no further inspection is made after the work is completed.

Both the surveillance film and the interview data show that the de-icing operator used the method of spraying the de-icing fluid and check the results of the de-icing at the same time (the incorporated method). This method is in accordance with the de-icing manuals and complies with applicable regulations and recommended standards. However, SHK considers it more likely for the de-icing operator to miss remaining ice and contamination when using the incorporated method than during a separate inspection.

By comparison, a separate inspection can be said to focus more on inspecting the results. The risk of distraction is also reduced if you divide the tasks into two separate steps rather than performing them simultaneously.

On the surveillance tapes, it is also clear that the application of the fluid produces steam, which could make it more difficult to see the result of the de-icing. The de-icing operator in this case has also stated that the steam did make it more difficult for him to verify the result.

Furthermore, in order to inspect the result, the de-icing operator would have to view the sprayed area from different vantage points, since remaining ice could be difficult to spot from a single position.

According to SHK, it is reasonable to assume that the risk of missing residual ice or other contamination is greater when using the incorporated method than when using a separate control.

Against this background, SHK considers there to be potential risks with the incorporated method. As noted, however, this method is consistent with the AEA guidelines. Both ICAO and EASA refer to the AEA guidelines. Although these guidelines are not binding, they have become normative for both operators and regulators through ICAO's and EASA's references to them. It is therefore important that the guidelines referred to by these organisations are properly evaluated and secured. With this in mind, SHK is of the opinion that ICAO and EASA should be recommended to investigate and evaluate the risks involved in the methods described in the guidelines and guidance they refer to.

## 2.4 Other observations

### *2.4.1 Damage to aircraft*

The fact that this aeroplane type has a history of pitch oscillations has led to the type-certificate holder issuing procedures for the crew to handle this type of situation. These procedures are known and implemented in the operator's flight manual system.

The investigation reveals that the operator's engineer inspected the aircraft after the event in order to find the cause of the vibrations. The operator then returned the aircraft into service. No special inspections to ensure that the vibration had not caused any damage to the aircraft have been recorded in the aircraft's technical log. The operator also did not consult the type-certificate holder at this stage regarding the need to carry out such inspections.

The AMM contains special inspections that should be carried out after a pitch oscillation event. As stated, the type-certificate holder recommended sometime after the event that BRA would carry out these inspections as well as two additional types of inspections. SHK believes that it could have posed a safety risk that the operator kept the aircraft in service without performing the recommended inspections. It was subsequently found that an elevator damper and a drop-link had glitches that exceeded tolerances, resulting in the replacement of these components. However, it has not been possible to determine whether these damages occurred before, during or after the event. It has thus been impossible to determine whether the damage was caused in connection with the investigated event or not.

### *2.4.2 Actions after landing*

The investigation shows that the crew did not pull the circuit breakers and thus did not secure the CVR recordings from the flight. The registration of CVR was thus erased, which led to the absence of CVR information as a basis for the investigation. SHK cannot emphasise enough the importance of ensuring that CVR data and other recorded data from accidents and incidents are secured in order for safety investigations to be based on as much information as possible.

### *2.4.3 The instructions for PFI*

Section 1.18.1 states that a pre-flight inspection is to be performed in order to ensure that the aircraft is safe for the intended flight. It is therefore important that the training requirements, responsibilities and standards to which all tasks are to be performed are clearly described in the operator's manuals. As already stated, there were deficiencies in the instructions for the contamination inspection, which, according to SHK, has contributed to the fact that some contamination on the aircraft was not detected. SHK considers that there are also other ambiguities and uncertainties regarding other aspects of the operator's instructions for pre-flight inspection. These ambiguities cannot however be considered to have affected the current incident. The investigation also reveals that the operator has identified several of these shortcomings and has taken or will take action to improve manuals and instructions. It will be a task for the regulatory authority to follow up on this work and ensure that the operator has appropriate procedures for the operation.

### *2.4.4 De-icing instructions*

There also appears to be some ambiguity in the instructions for the de-icing operation. For example the main perception of the interviewed de-icing operators was that the post-de-icing check is the same as reporting to the commander that the ice has been removed and the amount of liquid that has been used. Most of the de-icing operators therefore seem to be unaware of the actual purpose and meaning of the post-de-icing check. It should also be noted that the operator has not specified what method of checking after de-icing should be used despite the applicable regulatory requirements. It will be a task for the regulatory authority to follow up this issue.

# 3. CONCLUSIONS

## 3.1 Findings

a) The crew was qualified to perform the flight.

b) The aeroplane had a Certificate of Airworthiness and valid ARC.

c) The aeroplane had been parked outside in adverse weather conditions for about 40 hours.

d) No ice was observed on the underside of elevators and ailerons.

e) The de-icing order did not contain all relevant surfaces.

f) Defective de-icing and control after de-icing resulted in the airplane taking off with remaining ice.

g) The operator had not clearly instructed the subcontractor of which post-de-icing check method that should be used.

h) Circuit breakers for recorders were not pulled according to applicable procedures.

i) The remaining ice was detected on the aircraft after the incident.

j) The operator returned the aircraft to service without consulting the type-certificate holder regarding the need to carry out inspections to ensure that no damage had occurred to the aircraft.

k) Later inspections of the elevator system detected play in the elevator dampers and drop-links that where beyond tolerances. However, it has not been possible to determine whether these damages occurred before, during or after the actual incident.

## 3.2 Causes/Contributing Factors

The incident was partly caused by the fact that the operator lacked enough detailed procedures for performing a complete contamination inspection, and that the existing routines were not fully applied, partly by the fact that the operator had not properly checked, evaluated and controlled the subcontractor’s working methods.

A contributing factor was that the de-icing operation had insufficient organisational support to help the staff to resist requests of departure on time and to ensure that the de-icing was properly executed despite actual or perceived time shortage.

## 4. SAFETY RECOMMENDATIONS

***ICAO is recommended to:***

- Investigate and evaluate the risks of recommended methods for de-icing and post-de-icing check, especially the incorporated method as referred to in the ICAO Annex 6, Part I, Doc 9640 and consider and decide whether the reference should be changed. *(RL 2017:10 R1)*

***EASA is recommended to:***

- Investigate and evaluate the risks of recommended methods for de-icing and post-de-icing check, especially the incorporated method referred to in the referenced documents in GM3 CAT.OP.MPA.250 of Commission Regulation (EU) No 965/2012, and consider and decide whether the reference should be changed. *(RL 2017:10 R2)*

***The Swedish Transport Agency is recommended to:***

- Evaluate the needs of changing their supervisory procedures to ensure that AOC holders have appropriate procedures for contamination inspection and de-icing operations. *(RL 2017:10 R3)*

The Swedish Accident Investigation Authority respectfully requests to receive information, **by 12 March 2018** at the latest, regarding measures taken in response to the safety recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Helene Arango Magnusson Johan Nikolaou