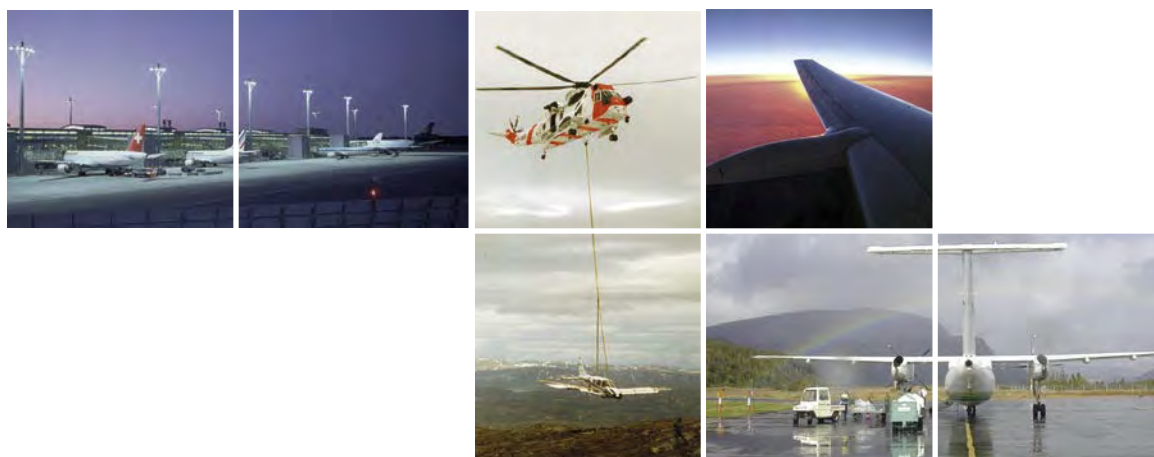


REPORT

SL 2015/09



REPORT ON SERIOUS INCIDENT EN-ROUTE OSLO – TRONDHEIM, NORWAY, ON 25 SEPTEMBER 2014 TO BRITISH AEROSPACE ATP, SE-MAF OPERATED BY WEST AIR SWEDEN AB

The Accident Investigation Board has compiled this report for the sole purpose of improving flight safety. The object of any investigation is to identify faults or discrepancies which may endanger flight safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for flight safety shall be avoided.

*This report has been translated into English and published by the AIBN to facilitate access by international readers.
As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.*

Photos: AIBN and Trond Isaksen/OSL

TABLE OF CONTENTS

| | |
|--|----|
| NOTIFICATION OF THE INCIDENT | 4 |
| SUMMARY | 4 |
| 1. FACTUAL INFORMATION | 5 |
| 1.1 History of the flight..... | 5 |
| 1.2 Injuries to persons | 7 |
| 1.3 Damage to aircraft..... | 7 |
| 1.4 Other damage | 7 |
| 1.5 Personnel information | 8 |
| 1.5.1 Commander..... | 8 |
| 1.5.2 First officer..... | 8 |
| 1.6 Aircraft information | 8 |
| 1.6.1 General information | 8 |
| 1.6.2 Stall warning system | 9 |
| 1.6.3 Autopilot and engine controls | 10 |
| 1.6.4 Systems description – Ice protection | 10 |
| 1.6.5 Winter season preparations | 14 |
| 1.6.6 Troubleshooting and technical findings..... | 14 |
| 1.6.7 Procedures for flying in icing conditions..... | 14 |
| 1.6.8 Safety information from BAE Systems to operators | 16 |
| 1.6.9 General information about icing | 16 |
| 1.6.10 Training program | 16 |
| 1.7 Meteorological information | 17 |
| 1.7.1 General information | 17 |
| 1.7.2 Observed and forecast weather | 18 |
| 1.7.3 Aftercast..... | 18 |
| 1.7.4 Assessment of the intensity of any mountain waves | 23 |
| 1.8 Aids to navigation | 24 |
| 1.9 Communications | 24 |
| 1.10 Aerodrome information | 24 |
| 1.11 Flight recorders | 24 |
| 1.11.1 Introduction..... | 24 |
| 1.11.2 Recorded FDR data..... | 24 |
| 1.12 Wreckage and impact information..... | 25 |
| 1.13 Medical and pathological information | 26 |
| 1.14 Fire | 26 |
| 1.15 Survival aspects | 26 |
| 1.16 Tests and research | 26 |
| 1.16.1 Speed loss and reference speeds | 26 |
| 1.16.2 Aerodynamic assessment..... | 27 |
| 1.17 Organisational and management information | 29 |
| 1.17.1 West Air Sweden | 29 |
| 1.18 Additional information..... | 31 |
| 1.18.1 Previous incidents | 31 |
| 1.18.2 Measures initiated – BAE Systems..... | 32 |
| 1.18.3 Measures planned and implemented – West Air Sweden..... | 33 |
| 1.18.4 EASA Annual Safety Conference 2013..... | 33 |
| 1.19 Useful or effective investigation techniques..... | 33 |

| | | |
|-------|--|----|
| 2. | ANALYSIS..... | 34 |
| 2.1 | Introduction and delineation | 34 |
| 2.2 | Atmospheric conditions | 35 |
| 2.2.1 | Icing | 35 |
| 2.2.2 | Mountain waves | 35 |
| 2.2.3 | Weather forecast and use of warnings | 36 |
| 2.3 | The loss of control | 36 |
| 2.4 | De-icing system | 37 |
| 2.4.1 | Observations on the operation of the de-icing system | 37 |
| 2.4.2 | The importance of the fault in the de-icing system..... | 38 |
| 2.5 | The recovery phase | 38 |
| 2.6 | Minimum speed in icing conditions..... | 39 |
| 2.7 | Awareness of icing risk and mountain waves..... | 40 |
| 2.8 | Assessment of implemented measures..... | 41 |
| 3. | CONCLUSION..... | 41 |
| 3.1 | Findings of particular importance for air safety | 41 |
| 3.2 | Findings..... | 41 |
| 4. | SAFETY RECOMMENDATIONS..... | 43 |
| | APPENDICES | 45 |

SERIOUS INCIDENT REPORT

Aircraft type: British Aerospace ATP

Nationality and registration: Swedish, SE-MAF

Owner: European Turboprop Management AB, Gothenburg, Sweden

Operator: West Air Sweden AB, Gothenburg, Sweden

Crew: 2 (commander and first officer)

Passengers: None

Injuries: No injuries

Incident location: Approx. 20 NM north-northeast of Lillehammer (61°28'N, 010°33'E) at an altitude of approx. 15,000 ft.

Time: Thursday, 25 September 2014 at 2219 UTC

All hours stated in this report are UTC (local time - 2 hours) unless otherwise indicated.

NOTIFICATION OF THE INCIDENT

The commander reported the incident the day after it happened. Initially, the report was not correctly processed internally by the Operator, and three days elapsed before it reached the Swedish Civil Aviation Authority (Transportstyrelsen). There it was routinely uploaded into the national and European database on 3 October 2014.

The Operator sent a paper copy of a report formula, classifying the occurrence a serious incident, to the Norwegian Civil Aviation Authority (Luftfartstilsynet) on 5 November 2014. Luftfartstilsynet uploaded it electronically on 7 November. Thus the Accident Investigation Board Norway (AIBN) became aware of the incident about six weeks after it took place.

The AIBN considered the occurrence to constitute a serious incident, and decided to initiate an investigation. In accordance with ICAO Annex 13, *Aircraft Accident and Incident Investigation*, the AIBN informed the safety investigation authorities in the UK (Air Accidents Investigation Branch, AAIB) and Sweden (Statens Haverikommision, SHK) for respectively aircraft production and registry, about the incident. The AAIB appointed an accredited representative to assist in the investigation, supported by advisors from BAE Systems. Also SHK appointed an accredited representative to assist in the investigation.

SUMMARY

A cargo aircraft flying from Oslo to Trondheim gradually lost speed after reaching cruising altitude. The crew observed ice forming on the aircraft and activated the de-icing system. However, the speed continued to drop. The commander decided to descend to a lower altitude. Before the descent could be initiated, severe buffeting occurred. The nose pitched up and the aircraft banked in an uncontrolled manner. The first officer, who was at the controls, stated that he had to push the nose down by force. The ailerons did not respond properly, and the buffeting was so violent that he could hardly read the instruments. He was able to disconnect the autopilot, and the speed increased as the

nose was lowered. Control was regained after about 30 seconds. The loss of altitude was not critical in relation to the terrain.

Findings made during the investigation indicate that the loss of speed was a result of a combination of icing and mountain waves. A simultaneously occurring technical malfunction in the de-icing system had a minor impact only.

The investigation has also shown that the vibrations and the loss of control most likely were caused by a stall or incipient stall. When control was lost, the speed had dropped to 22 kt below the manufacturer's recommended minimum speed for flying in icing conditions. The crew was not aware that minimum speed in icing conditions existed other than for the approach phase, and believed they had sufficient margin in relation to a stall. The senior operational personnel with the operator seem to have suffered from the same lack of knowledge. The investigation also revealed that the operator's training program did not touch upon minimum speed in relation to icing during the cruising phase.

The AIBN believes the operational personnel's lack of knowledge can partly be traced back to the ambiguity in the authority-approved manuals as regards minimum speed in icing conditions. As a result of the incident, the type certificate holder BAE Systems has implemented measures to improve this.

The AIBN has issued a safety recommendation to make minimum speeds in icing conditions more easily accessible to the pilots in the cockpit.

1. FACTUAL INFORMATION

1.1 History of the flight

- 1.1.1 This was a routine flight to carry mail from Oslo Airport Gardermoen (ENGM) to Trondheim Airport Værnes (ENVA). The planning, loading, fuelling and other preparations were without problems. The crew had already flown the same route and back earlier that evening.
- 1.1.2 The departure was from runway 19R at 2151 UTC (i.e. 2351 local time). The first officer was the pilot flying (PF), while the commander handled the other tasks (pilot monitoring, PM). They reached cruising altitude at flight level FL150 (approx. 15,000 ft) at 2208 hrs. As usual, they maintained climb power for approx. three minutes before selecting cruise power. They seem to remember that the cruising speed stabilised as expected (approx. 195 Kt indicated airspeed, IAS).
- 1.1.3 A strong westerly wind was blowing at their altitude. The flight took place in clouds (instrument meteorological conditions, IMC). The crew had noted forecasts of moderate icing on their route, in connection with an approaching weather front. The propeller and engine air intake heating was on during the entire flight.
- 1.1.4 After a few minutes at cruising altitude, the first officer, who had relatively low experience on the aircraft type, commented that the speed seemed to be dropping gradually. At that time, they had lost an estimated 3-4 kt. The autopilot had been set to altitude hold. They could see that some ice had formed on the window frame and the windshield wiper. The experienced commander considered some loss of speed natural,

but expected that it would stabilise. When it had fallen approx. another 10 kt, i.e. to less than 180 kt, she expressly stated that they should not let the speed drop to below 140 kt.

- 1.1.5 At the time, an estimated 3-4 cm of white, rough ice had formed on the windshield wiper, and they activated the airframe de-icing system (pneumatic de-icing system - *boots*) in order to remove the ice on the wings and tail (system description in Item 1.6.2). The inspection lights made it easy to see that the ice on the leading wing edges broke off and disappeared as expected.
- 1.1.6 In spite of the de-icing seemingly functioning properly, the speed continued to drop. At one point, the speed decrease accelerated, and they suddenly saw the speed trend indicator go "*all the way down*". The commander decided that they had to descend. She contacted air traffic control immediately, and got clearance to descend to FL130.
- 1.1.7 At this time, the aircraft started vibrating and shaking violently. The nose pitched up slowly and then faster, and the aircraft suddenly banked uncontrolled to the left. The first officer has explained that his first impulse was to avoid stalling. He pushed hard with both hands on the control yoke and trimmed to get the nose down. The commander noticed that the autopilot was still engaged and asked the first officer to disengage it, which he did. The first officer noticed that the flight controls were not responding as they should. He has explained that to avoid entering a spin, he focused on increasing speed while he was careful in correcting the bank, which constantly tended to go left.
- 1.1.8 After a while, the nose came down and the speed stopped dropping. The speed then increased relatively quickly, the shaking stopped and control was regained. The commander saw no need to take over the controls. She verified that they had a sound margin to the terrain and checked the aircraft's TCAS (Traffic Collision Avoidance System), noting that there were no nearby aircraft. The aircraft's change of course during the incident is estimated to approx. 50 degrees to the left compared with the original course.
- 1.1.9 The crew members had no clear opinion on how extreme the flight attitude was during the incident. The first officer estimated 10° pitch up and 10° uncontrolled bank, and believed to remember having seen a descent rate of more than 3,000 ft/min. The commander believed to remember that the speed was somewhat above 130 kt at the lowest. (Data from the flight recorder with exact value readings can be found in Figure 10.)
- 1.1.10 Radar data recordings from the airport operator Avinor shows the aircraft's position, ground speed and altitude/altitude changes with a relatively low level of detail. The recordings show that the ground speed dropped gradually from approx. 220 kt at 2213 hrs to approx. 160 kt at 2219 hrs, when the aircraft left altitude FL150.
- 1.1.11 When SE-MAF was down at FL130, they corrected the track. Everything seemed normal, and they reengaged the autopilot. Directly afterwards, the de-icing warning lights on the CWP (Central Warning Panels) lit up, and the light for de-icing ON went off. In order to troubleshoot, the crew reactivated the boots. They counted "kicks" and concluded that the system generated only four out of a total of six inflations (see 1.6.4 for systems description). The de-icing warning light also lit up during this test. The two last sequences should have de-iced the tail, and the crew concluded that a de-icing system malfunction prevented the tail boots from functioning as intended.

- 1.1.12 The flight continued to Værnes, where the approach and landing proceeded as normal. Nothing abnormal was observed during the external inspection. It was decided that the return flight, with no cargo scheduled, would proceed if they could avoid areas with icing (in accordance with Minimum Equipment List, MEL). They planned a route further east, climbed to FL190 and experienced neither icing, speed reduction nor control problems on the return flight. When they ran a test of the de-icing system on the flight south, it still generated only four kicks and gave the same warning light.
- 1.1.13 The crew has elaborated on their observations in interviews with the Accident Investigation Board. Prior to the incident, on the flight north, the commander had not felt the characteristic vibrations or bumps in the fuselage which are common when ice comes off the propellers. There was no precipitation, and the windshield itself was free of ice. The impression was that the icing was not particularly intense. The boots were operated in normal mode, and had just completed one cycle when the problems occurred. When descending to FL130, the commander believes she remembers that the ice around the windows came off and disappeared, and she heard the sound of ice coming off.
- 1.1.14 The first officer has described the vibrations as so violent that it almost made instrument readings impossible. In retrospect, he has also stated that he at one time perceived the vibrations as an approach to stall, but that they were far more powerful and less regular than stall buffeting in a simulator. There was no doubt that the entire aircraft was shaking, not just the control column. The aircraft's automatic stall warning, the stick shaker, did not activate. Neither the commander nor the first officer was aware that there exist minimum speeds for flying in icing conditions, other than those for the approach phase.
- 1.1.15 None of the crew members considered it natural to manipulate the engine controls to offset the speed loss before control over the aircraft was lost. The engine controls were not touched during the actual loss of control or the recovery phase.
- 1.1.16 The Airframe De-Ice Timer was replaced in Oslo the next morning. The system was then tested without remarks. The same crew flew the same aircraft on the same route the next evening. The de-icing system then worked as it should, with six kicks and without any warnings. (More information on troubleshooting can be found in Item 1.6.6, and on delayed notification and reporting to the authorities in Item 1.17.1.)

1.2 Injuries to persons

Table 1: Injuries to persons

| Injuries | Crew | Passengers | Others |
|------------|------|------------|--------|
| Fatalities | | | |
| Serious | | | |
| Minor/none | 2 | | |

1.3 Damage to aircraft

None.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 Commander

- 1.5.1.1 The Commander (age 41) was trained as a commercial pilot in the US and Sweden. She became an employee of West Air Sweden in 2000 and flew Hawker Siddeley HS 748s as a first officer until 2006, when she took the Commercial Pilot Licence ATPL(A) with type rating for ATP, and flew as a commander from then on. She had a valid class 1 medical certificate without limitations. The last OPC/PC was on 24 July 2014.

Table 2: Flying hours commander

| Flying hours | All types | Relevant type |
|---------------|-----------|---------------|
| Last 24 hours | 2 | 2 |
| Last 3 days | 2 | 2 |
| Last 30 days | 32 | 32 |
| Last 90 days | 88 | 88 |
| Total | 4,500 | 2,400 |

- 1.5.1.2 The commander had been on standby for a total of 13 hours without being called out for a flight on the two preceding days. She stated that she was rested and in good shape, and that she had eaten normally on the day of the incident.

1.5.2 First officer

- 1.5.2.1 The First officer (age 29) was trained as a commercial pilot in the Netherlands in 2010. He became an employee of West Air Sweden and received type rating for ATP in his CPL(A) licence in May 2014. He had a valid class 1 medical certificate without limitations.

Table 3: Flying hours first officer

| Flying hours | All types | Relevant type |
|---------------|-----------|---------------|
| Last 24 hours | 6 | 6 |
| Last 3 days | 10 | 10 |
| Last 30 days | 35 | 35 |
| Last 90 days | 129 | 129 |
| Total | 560 | 200 |

- 1.5.2.2 The first officer stated that he was rested and in good shape, and that he had eaten normally on the day of the incident.

1.6 Aircraft information

1.6.1 General information

- 1.6.1.1 The ATP is a low-wing aircraft with a conventional tail and two turboprop engines. It was first certified in 1988, and 63 aircraft were produced before production ceased in 1996 (Source: [BAE Systems General Data brochure](#)). SE-MAF is the oldest of its kind still in daily operation.



Figure 1: SE-MAF. Photo: http://www.aviaphoto.ru/by/Ignatiy_Savranskiy

A further development of the aircraft type, British Aerospace Jetstream 61, was built and commencing test flight program when the project was scrapped for commercial reasons in 1995.

| | |
|--|--|
| Manufacturer and type: | British Aerospace (BAe) ATP |
| Serial no.: | 2002 |
| Production year: | 1988 |
| Airworthiness Review Certificate (ARC) valid until | 31 December 2014 |
| Engines: | 2 Pratt & Whitney 126 turboprop engines |
| Propellers: | 2 Hamilton Standard 6/5500/F-1 |
| Total time/cycles: | 29,848 hours/38,030 landings |
| Maximum permitted takeoff mass: | 23,678 kg |
| Actual takeoff mass: | Approx. 22,930 kg |
| Mass at the time of the incident: | Approx. 22,519 kg |
| Location of the centre of gravity: | Index at departure = 60. (Permitted area 55-85.) |

1.6.1.2 The mass and the location of the centre of gravity were, according to the presented load sheet, within the relevant limitations throughout the flight (load sheet in Appendix B). The mail pallets that are loaded on board are weighed, and real mass is used in the calculations. The load is placed in specially adapted sections to avoid displacement during the flight.

1.6.2 Stall warning system

1.6.2.1 The aircraft is equipped with a stick shaker, which means that the control yokes starts shaking if the angle of attack¹ exceeds a set value. This artificial warning is activated

¹ The angle between the chord of the wing and the relative wind. Measured indirectly.

before an aerodynamic stall occurs, provided that the wing is “clean” i.e. free of ice. If the wing is contaminated by snow or ice, the aircraft will stall at a lower angle of attack than the angle that activates the stick shaker. There is no indicator in the cockpit to show the aircraft's angle of attack.

1.6.2.2 ATP has been approved for flying in areas with known or forecast icing conditions. For flying in icing conditions the approval is based on natural indications, such as buffeting, giving the crew sufficient forewarning that a stall is imminent. The aircraft flight manual recommends holding a higher minimum speed in icing conditions, cf. 1.6.7.4.

1.6.3 Autopilot and engine controls

The autopilot on SE-MAF was set to Altitude Hold when the incident took place. The engine is controlled electronically, using Engine Electronic Control (EEC). When the aircraft has accelerated to cruising speed, the crew changes the engine setting from climb power to cruise power and keeps this setting for as long as the aircraft is cruising. ATP is not equipped with autothrottle.

1.6.4 Systems description – Ice protection

1.6.4.1 The propeller blades, the engine's air intake and the airspeed indicator/altimeter probes (pitot/static system) are equipped with electrical heating to prevent ice from forming. These were on throughout the flight (‘ALL ON’).

1.6.4.2 The airframe de-icing system is shown in Figure 2 and Figure 3. The leading edges on the wing outboard of the engine nacelles, and the horizontal and vertical stabilizers are equipped with pneumatic boots (inflatable rubber tubes) that are used to remove ice. The system is divided into three groups:

- Group 1: the two sections closest to the nacelles.
- Group 2: the two outer sections of the wings.
- Group 3: the sections on the tail surfaces.

1.6.4.3 The three groups are controlled by five valves (see Figure 3). Each valve is connected to two sets of tubes (A TUBES and B TUBES). The system is operated by pressure-regulated bleed air from the engines.

1.6.4.4 When the system is in operation, the valves inflate the A TUBES and deflate the B TUBES. Then, the B TUBES are inflated and the A TUBES are deflated. This causes a group by group sequential inflation (corrugation) of the surfaces of the rubber-covered leading edges on wings and stabilizers. This deformation of the leading wing edges normally breaks off the ice. Between inflations and when the system is not activated, all tubes are deflated using suction.

1.6.4.5 The system can be controlled automatically by an electronic Airframe De-ice Timer, or manually using switches in the cockpit. When the system is set to automatic operation, the timer controls a sequential operation of the different sections so that the A TUBES in Group 1 are inflated first and the B TUBES in Group 3 are inflated last. This amounts to six operations taking 38 seconds. The normal function in automatic mode can be

monitored through a pressure gauge in the cockpit, showing six pressure pulses, so-called kicks.

- 1.6.4.6 The system can be operated automatically in «NORMAL» or «HEAVY» mode. In NORMAL mode, there is a pause of 231 seconds between each six-step operation. A full cycle therefore takes approx. 4.5 minutes. In HEAVY mode, the pause is only 29 seconds, and a full cycle takes approx. 1 minute. HEAVY mode must be used if NORMAL mode does not remove the ice. In manual mode, the switches for the A TUBES and B TUBES must be pressed in turn. It is recommended to press each for 10 seconds, with 10-second breaks in between.
- 1.6.4.7 The system can be activated by the crew as needed. It should be turned off during takeoff and during the last part of the approach (below 200 ft). Inspection lights make it possible for the crew to observe the leading wing edges in the dark. It is not possible to observe the tail surfaces during flight on the freighter aircraft.
- 1.6.4.8 The system is monitored by a warning system. If failures are detected, an amber DE-ICING light is flashing on the central warning panel (CWP) combined with a warning sound, and the system switches off the previously illuminated ON switch on the Airframe De-icing system panel. One reason for the activation of the warning can be that the timer did not start a new cycle at the correct time (after 4.5 minutes in normal mode). If the pressure gauge shows less than six kicks per cycle while it is observed that the boots on the wings are working as intended, this indicates that the de-icing of the tail has failed (cf. ATP Operations Manual Abnormal Procedures Aircraft General 4.20.1 p. 6).
- 1.6.4.9 The manufacturer's system description provides more detail on several possible failures, including the following:
- If the gauge is fluctuating at the wrong rate or is not fluctuating at all, the failure is in the timer, and the de-icing should be operated manually.*
- If the pressure gauge is showing the correct steady pressure but less than six kicks per cycle, a distributor valve is suspect and the affected airfoil section may no longer be fully de-iced.*
- 1.6.4.10 The modification status for SE-MAF was that three filters in the de-icing system, which experience had proven to be prone to collecting moisture and freezing, had been removed, and the distribution valves were heated (Service Bulletins SB ATP-30-16 and SB ATP-30-22 implemented).

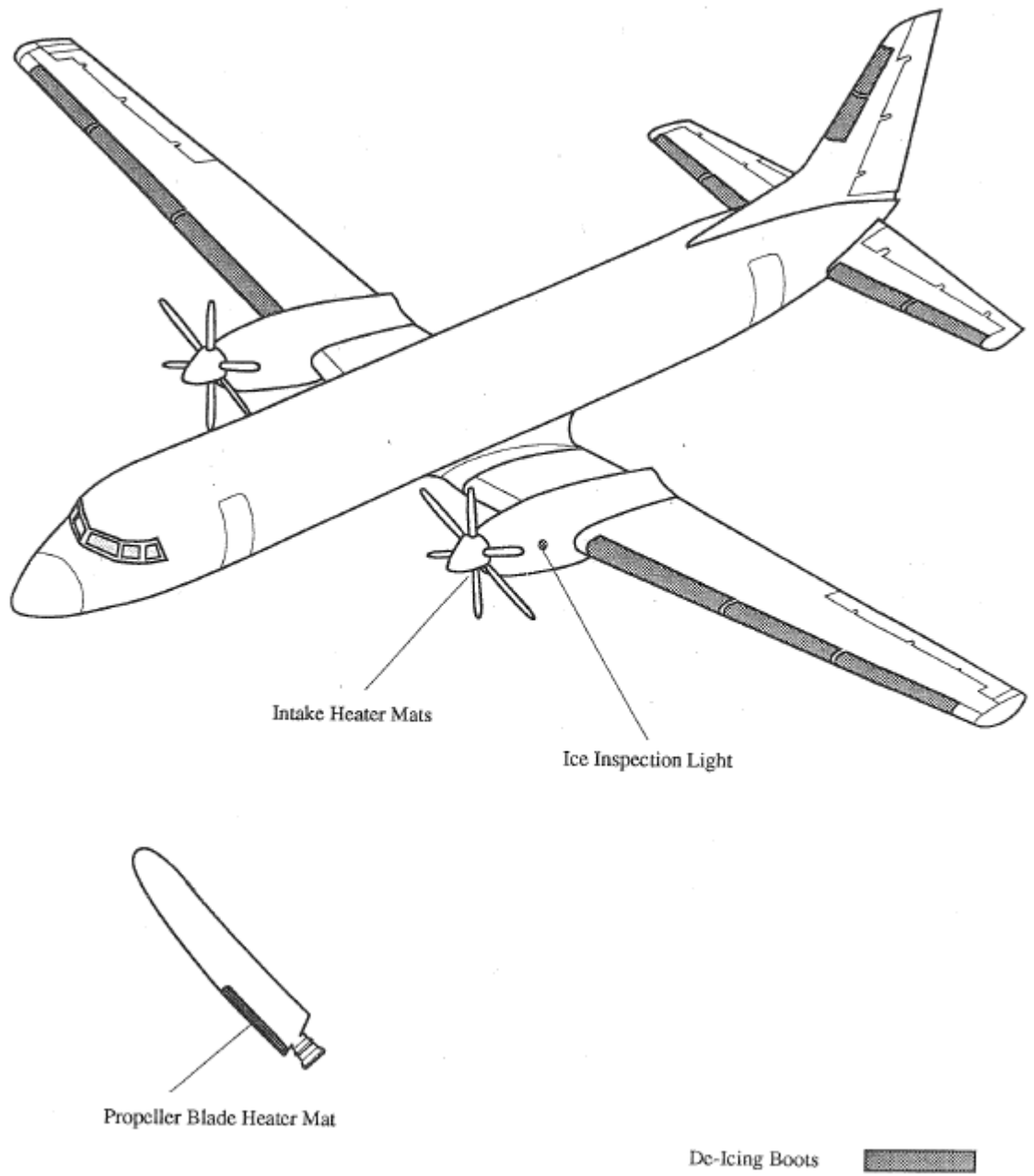
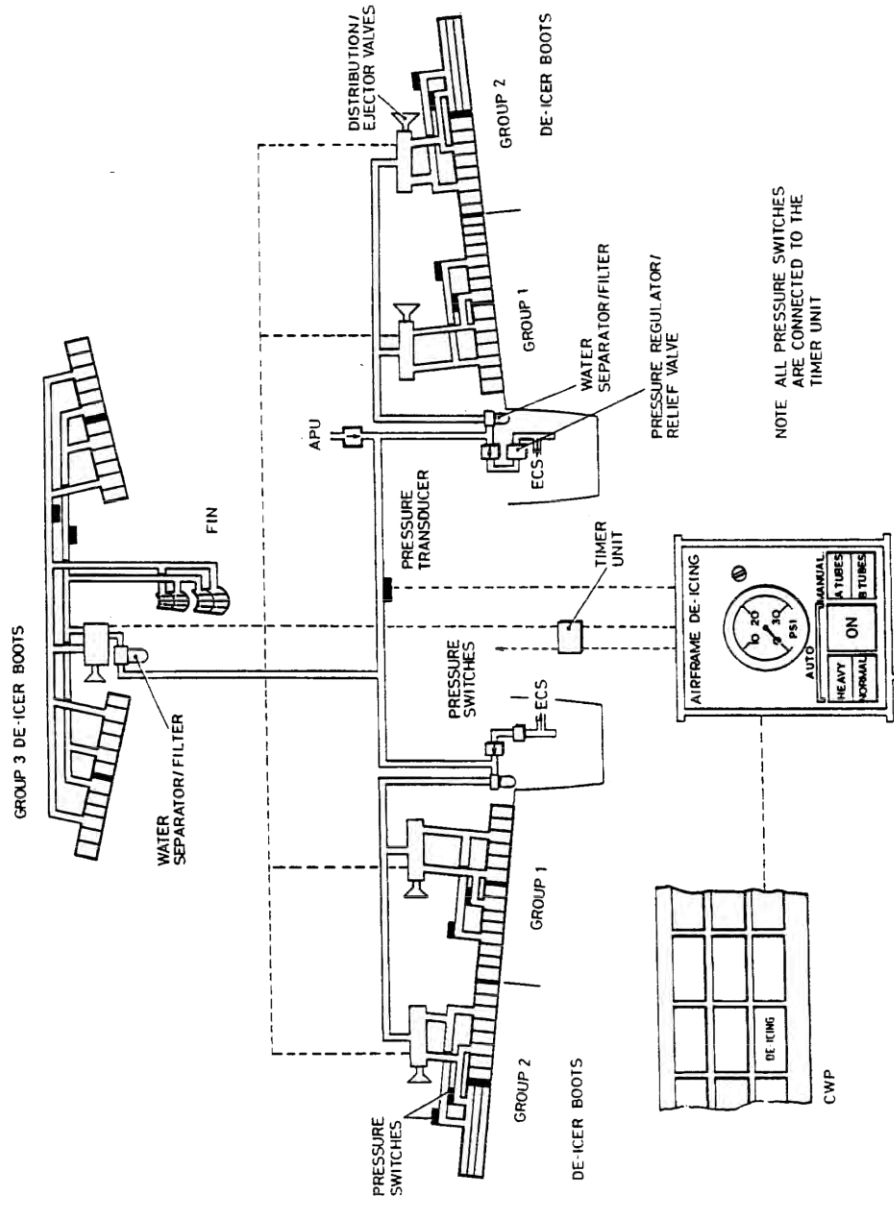


Figure 2: ATP systems for protection against icing, de-icing boots and inspection lights. Source: BAE Systems

BRITISH AEROSPACE

ATP Operations Manual

SYSTEMS DESCRIPTION AND PROCEDURES ICE AND RAIN PROTECTION



AIRFRAME DE-ICING SYSTEM SCHEMATIC
Figure 3

ATP272/01

005

14.20.13
Page 4
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Figure 3: Schematics of the de-icing system. Source: BAE Systems ATP Operations Manual, Systems description and procedures, Ice and rain protection 14.20.13

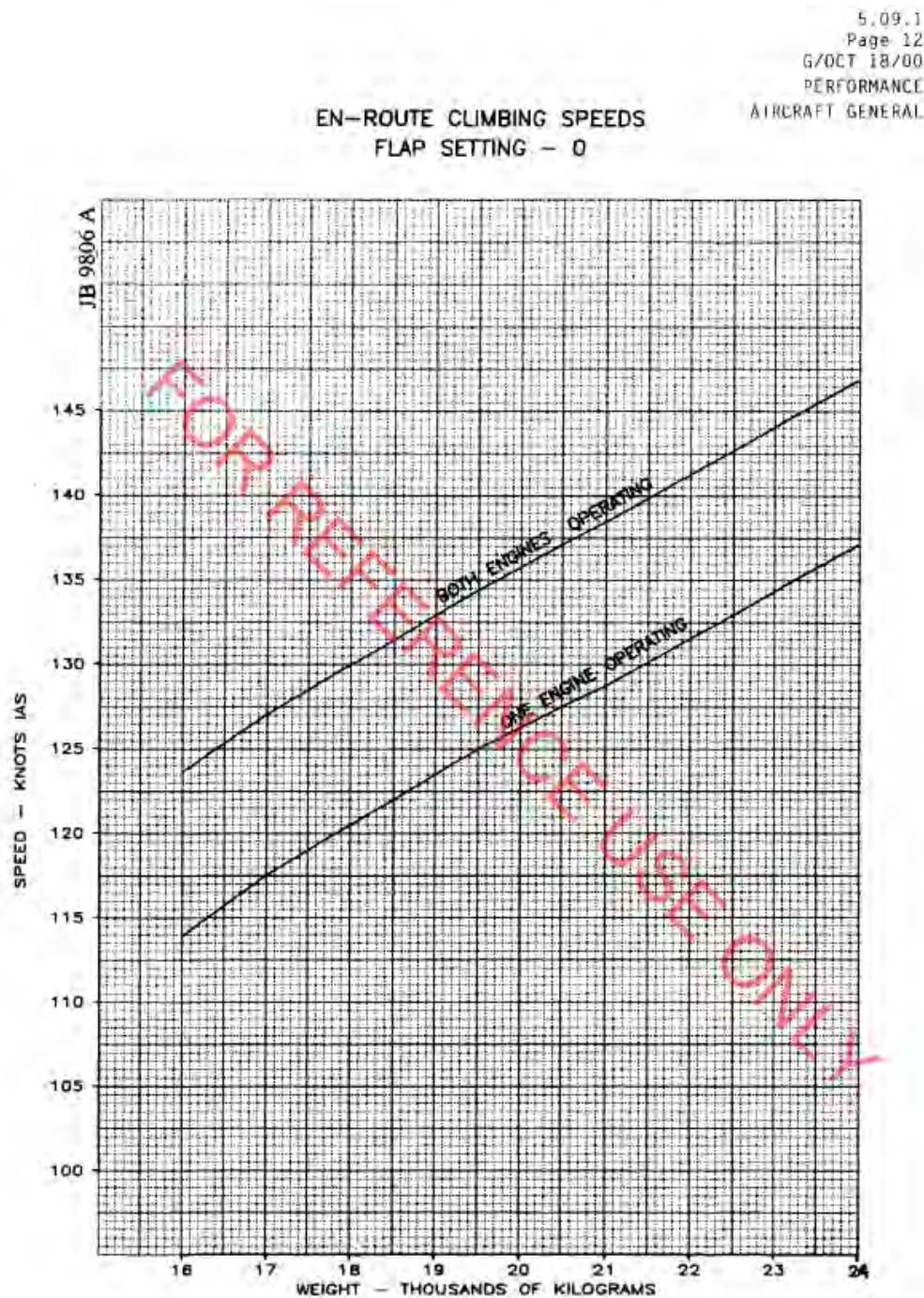
1.6.5 Winter season preparations

The annual winter preparation check had been performed on SE-MAF two weeks prior to the incident. The operator performs this check routinely in August-September to prevent known problems during winter operations. For instance, the system is inspected for leakage, boots are treated with ICEX to prevent adherence, condensation is removed from the system and the condition of the electrically heated elements and cockpit windows are checked.

1.6.6 Troubleshooting and technical findings

- 1.6.6.1 After the incident, the de-ice timer was found to have been replaced on SE-MAF only 35 flight hours previously. West Air Sweden's technical department therefore continued the troubleshooting, in case it was caused by another issue. The ejector distribution valve, relays controlling this valve and two pressure switches were thoroughly checked. One valve gasket was found in bad condition, but this was on the exhaust side, and West Air's technical organisation concluded that this was unlikely to have played a role in the problems experienced. The pressure switches were marginally outside the tolerance limits, but the error was "on the safe side" and did not explain the malfunctioning of the system. No other nonconformities were found.
- 1.6.6.2 West Air Sweden has stated that it has experienced frequent malfunctioning of the system's de-ice timer (P/N 42E13-17B/C). The company's reliability statistics show 43 unscheduled removals over 12 months, indicating only 650 flight hours between each replacement. This has unfortunate regularity consequences, as aircraft cannot take off and fly into areas with icing when this component is not working. In order to solve the problem, West Air Sweden has prepared, approved and implemented a new type of de-ice timer (solid state), which seems far more reliable. Such a timer had not yet been installed on SE-MAF at the time of the incident.
- ### 1.6.7 Procedures for flying in icing conditions
- 1.6.7.1 The effect of ice and how to deal with it is described in Chapter 4 of ATP AFM *Normal procedures ice and rain protection* (4.10.13 Page 3 G/NOV 08/10). A summary of the procedures in force at the time of the incident can be found in Appendix C.
- 1.6.7.2 In brief, BAE Systems describes how ice accretion on the windshield wipers should be seen as an indication of a need to inspect the wing leading edges. To avoid so-called bridging, where a shell of ice forms around the leading edge and is not broken off, it is recommended to let the ice accumulate to a thickness of about half an inch prior to operating the airframe de-icing system.
- 1.6.7.3 The manual says that the accumulation of ice can happen very quickly, that vibrations can be experienced at normal operating speeds, and that there is a particular risk, when flying in freezing precipitation, of ice accumulating in unprotected areas and thereby lowering the aircraft's performance and the crew's ability to control it. Flying at altitudes where the temperature is near freezing with visible precipitation on the windshield should be avoided. If the aircraft exhibits airframe buffet onset, unexpected loss of speed, uncommanded roll or unusual roll control wheel forces, the angle of attack must be reduced immediately and excessive manoeuvring avoided until the aircraft is free of ice. The autopilot must be deactivated and not activated again until the aircraft is free of ice.

1.6.7.4 The procedure states that the speed in icing conditions should not be less than "Both engines operating en-route climb speed plus 15 knots". The figure referenced, 5.09.6 (here shown in Figure 4) is titled *En-Route Climbing Speeds Flap setting – 0*, it does not mention icing, and it is not found in the procedure text. It is located 120 pages further back, in the AFM's performance chapter.



Doc. No. ATP 003

FIGURE 5.09.6

Figure 4: British Aerospace's figure, which forms the basis for the calculation of the lowest recommended speed in icing conditions. (See also Figure 11.) Source: BAE Systems

- 1.6.7.5 The operator's checklists for normal operations mentioned that the airframe de-icing system should be operated as required and turned off before landing. The procedure for various de-icing system faults and fault indications were described. It said that if the system generates fewer than six kicks, the boots must be activated manually. If this does not work, the aircraft must leave the icing conditions as soon as possible.
- 1.6.7.6 If suspecting that there is ice on the tail surface, the crew must also adhere to detailed instructions for use of flaps during approach and landing. The checklists had no references to minimum speeds in icing conditions.

1.6.8 Safety information from BAE Systems to operators

- 1.6.8.1 BAE Systems became aware of the incident with SE-MAF in connection with the troubleshooting initiated by the West Air (cf. 1.6.6). Following initial analyses of the flight recorder data, BAE Systems issued a Flight Operations Safety Letter (FOSIL) No. ATP/007/14 titled *Recommended Minimum Speed in Icing Conditions* (see Appendix D) on 25 November 2014. The main message was that crews on ATPs did not seem to be fully aware of the recommended minimum speeds in icing conditions described in the AFM. In addition to the incident with SE-MAF, BAE Systems referred to an incident in Cowley, England in 1991 (see 1.18.1).
- 1.6.8.2 The text from the AFM is quoted in FOSIL ATP/007/14. This means that it says that the speed in icing conditions should not be permitted to fall lower than "*the both engines operating en-route climb speed of figure 5.09.6 plus 15 knots*» (cf. 1.6.7.4). In addition, the following piece of information was added:

The both engines operating en-route climb speed is the single engine operating en-route climb speed plus 10 knots and Vser can be read from the speed cards.

- 1.6.8.3 FOSIL ATP/007/14 is concluded with the following recommendation:

BAE Systems recommend that Operators remind flight crews of the speeds given in the AFM and MOM.

1.6.9 General information about icing

BAE Systems has for several years published and updated an information folder titled "[Think Ice!](#)", *Icing Awareness for BAE Systems Regional Aircraft Operators*. The folder can be downloaded and serves as a supplement to official manuals. It covers meteorology, aerodynamics, aspects relating to de-icing on the ground, flight-operational procedures and systems for protection against icing on aircraft. The section on flying during the cruising phase mention that the speed during climbing must be increased in icing conditions:

The minimum en-route climb speed should be increased in icing conditions: see the AFM for details of this.

1.6.10 Training program

- 1.6.10.1 West Air Sweden uses Computer Based Training (CBT) for training in the aircraft's systems and their use. The training material for winter operations includes warnings that there is a risk in connection with icing, descriptions of meteorological conditions that

cause icing, different cloud types and recommended procedures if icing occurs. As regards de-icing systems and procedures, reference is made to the further developed aircraft type BAe Jetstream 61².

- 1.6.10.2 The section concerning icing in general and during the cruising phase focused on the use of anti-icing and de-icing systems. The fact that there are recommended minimum speeds for cruising altitude speed in icing conditions was not specifically mentioned. The following is quoted from this material:

When in icing conditions, monitor ice build-up and operate the airframe de-icing system in accordance with the AFM and MOM procedures.

- 1.6.10.3 For icing during climb, the description was more comprehensive, and it was mentioned that the minimum speed must be increased. The method for finding the minimum speeds was not specified, however, and reference was again made to the AFM:

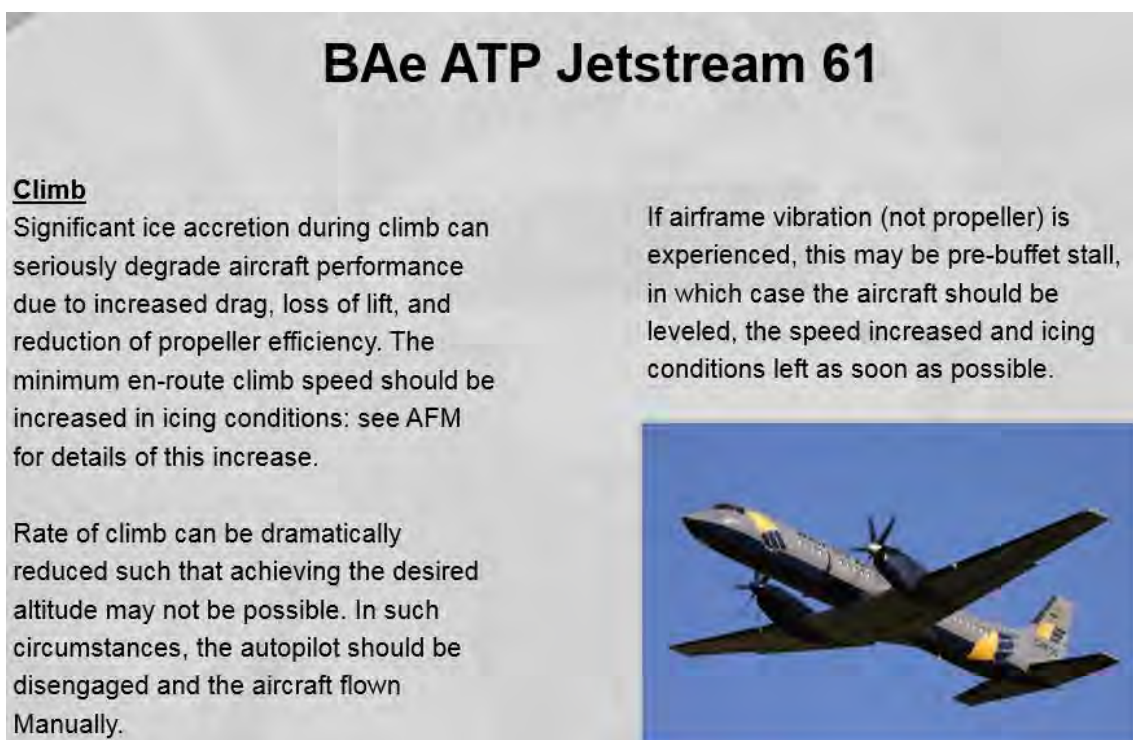


Figure 5: Summary from the operator's training material on winter operations for ATP crews. Source: West Air Sweden AB

1.7 Meteorological information

1.7.1 General information

- 1.7.1.1 The crew on SE-MAF had access to all relevant weather forecasts and observations, synoptic charts, SIGMET, etc., prior to departure. They also had a mobile app giving them access to updated information. As they had flown the same route both four and two hours earlier, they felt that they had a good overview of the situation. They had noted that

² BAE Systems has stated that the systems are identical for all practical purposes, although new certification provisions have been applied for BAe Jetstream 61

significant weather charts were showing a possibility of moderate icing in connection with a weather front coming in from the west.

1.7.2 Observed and forecast weather

1.7.2.1 The following METAR (routine weather observations for aviation purposes expressed in meteorological code) had been issued for Oslo Airport (ENGM) for the period 2020 – 2320 UTC³:

2020 UTC 20004KT CAVOK 07/04 Q1005 NOSIG=
 2050 UTC 23003KTC AVOK 08/04 Q1005 NOSIG=
 2120 UTC 00000KT CAVOK 08/04 Q1005=
 2150 UTC 00000KT CAVOK 08/04 Q1005=
 2220 UTC VRB01KT CAVOK 08/04 Q1005=
 2250 UTC 21003KT170V240 CAVOK 08/04 Q1006=
 2320 UTC 00000KT CAVOK 07/04 Q1006=

1.7.2.2 The following METAR was issued for Trondheim airport Værnes (ENVA) for the period 2050 – 2320 UTC:

2050UTC 11004KT 070V170 9999 FEW020 BKN040 10/07 Q1000 REUP REDZ RMK WIND 670FT 20012KT=
 2120 UTC 08004KT 050V110 9999 FEW020 BKN045 09/07 Q1000 RMK WIND 670FT 19015KT=
 2150 UTC 12004KT 040V180 9999 FEW040 BKN060 09/08 Q1000 RMK WIND 670FT 20015KT=
 2220 UTC 05004KT 010V070 9999 -DZ FEW030 SCT045 09/07 Q1000 RMK WIND 670FT 19015KT=
 2250 UTC 10005KT 9999 -DZ SCT030 BKN050 09/08 Q0999 RMK WIND 670FT 18008KT=
 2320 UTC 05003KT 010V100 9999 -DZ SCT035 BKN050 09/08 Q0999 RMK WIND 670FT 16010KT=

1.7.2.3 The following weather forecast (TAF, Terminal Aerodrome Forecast) was issued for Oslo and Værnes, respectively, at 2000 UTC:

ENGM 252000 UTC 2521/2621 20005KT CAVOK PROB40 2602/2607 2000 BCFG BKN003 BECMG 2607/2609 20015KT BECMG 2613/2615 26015KT TEMPO 2613/2617 27020G30KT=

ENVA 252000 UTC 2521/2621 VRB06KT 9999 -RA FEW015 BKN040 TEMPO 2600/2606 16015G25KT TEMPO 2606/2612 25012KT 4000 RADZ BKN012 BECMG 2609/2612 25018G30KT=

1.7.3 Aftercast

1.7.3.1 The Norwegian Meteorological Institute (MI) is the certified supplier of both aviation weather forecast services and observations in Norway⁴. Upon request from the Accident Investigation Board, MI prepared a report on the weather situation in the relevant area. MI wrote the following about observed and forecast weather in METAR and TAF:

An extensive weather front was above southern Norway. An occluded front was passing over Trøndelag and southward towards Hardangervidda, while a hot weather front was coming in towards the north-western part of southern Norway. The fronts were moving eastwards. CAVOK conditions were forecast for Oslo Airport that evening, with possible mist in the night. On Værnes, the forecast was for light rain and the cloud base at 4,000-7,000 ft in the evening and night. This correlated well with the observed weather.

³For decoding of meteorological abbreviations, see: https://www.ippc.no/ippc/help_met.jsp and https://www.ippc.no/ippc/help_metabbreviations.jsp

⁴ Avinor and Oslo Airport are certified as suppliers of observation services

1.7.3.2 The fronts and their movements are visible on surface analyses and significant weather charts. It emerges that moderate icing was forecast from FL060 and up to more than FL150 over Trøndelag, and that the area with icing spread southward towards the lake Mjøsa over the course of the evening.

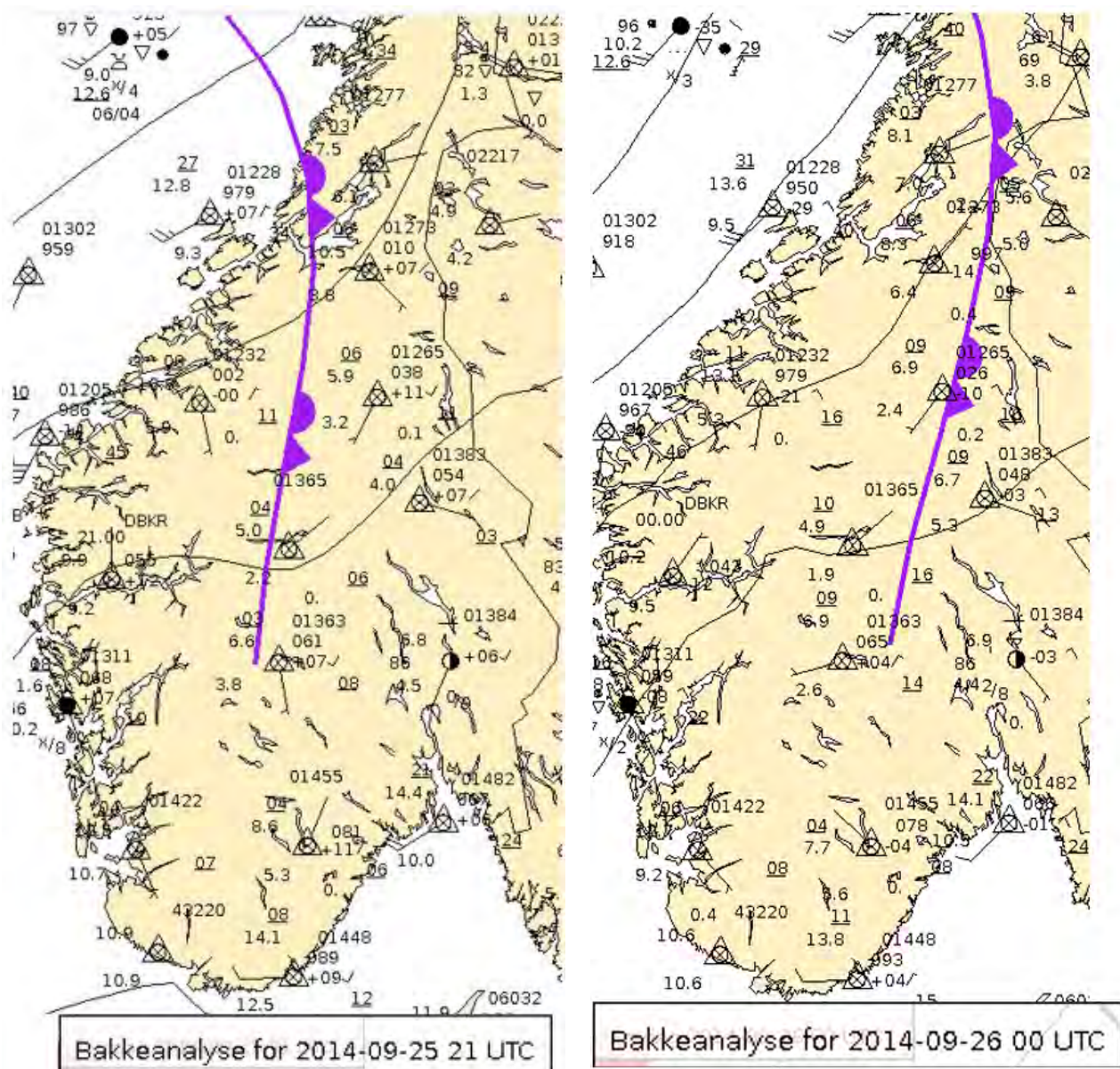


Figure 6: Surface analyses at 21 and 00 UTC. Source: The Norwegian Meteorological Institute

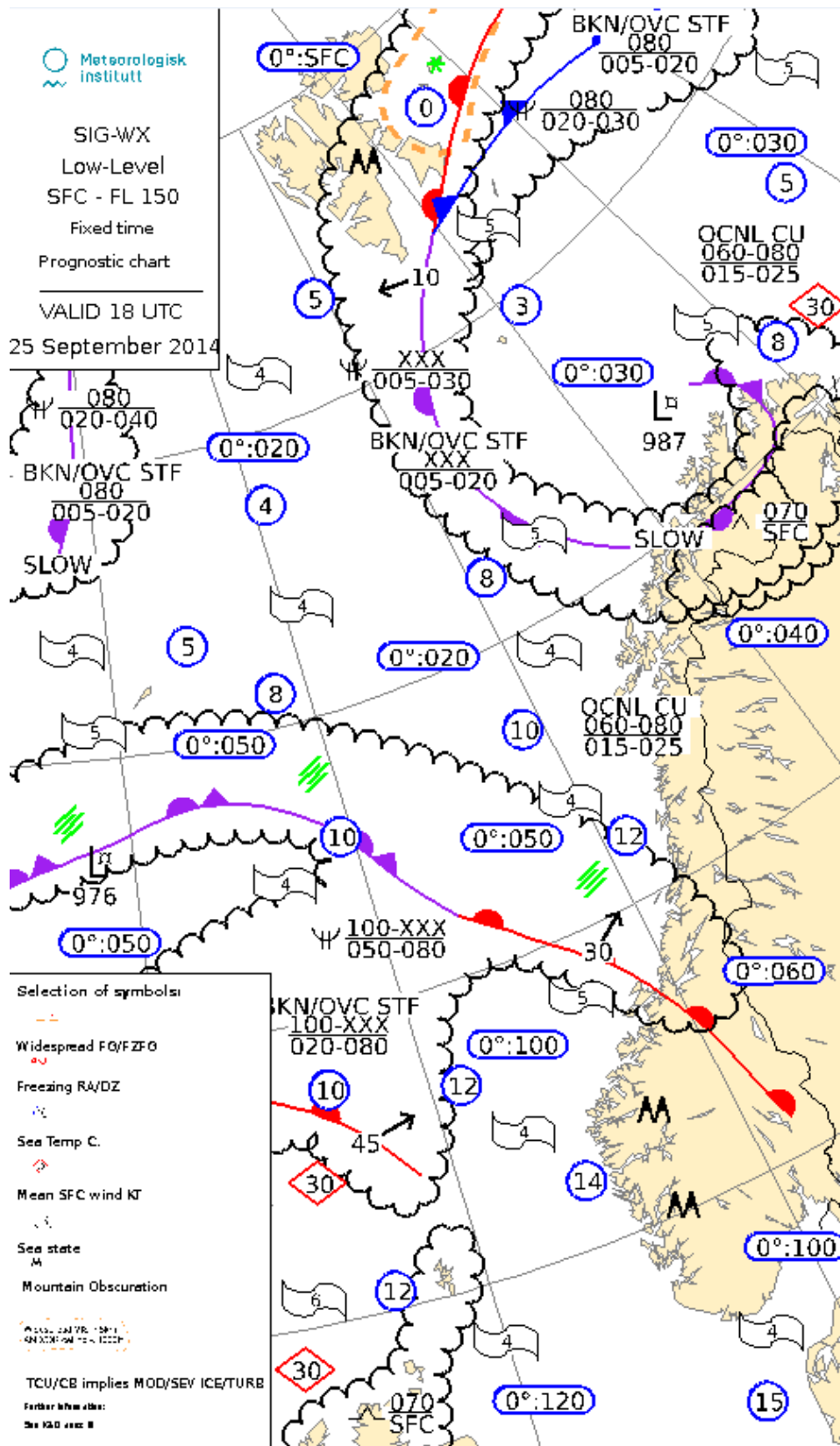


Figure 7: Significant weather chart at 18 UTC (legend in Appendix E). Source: The Norwegian Meteorological Institute

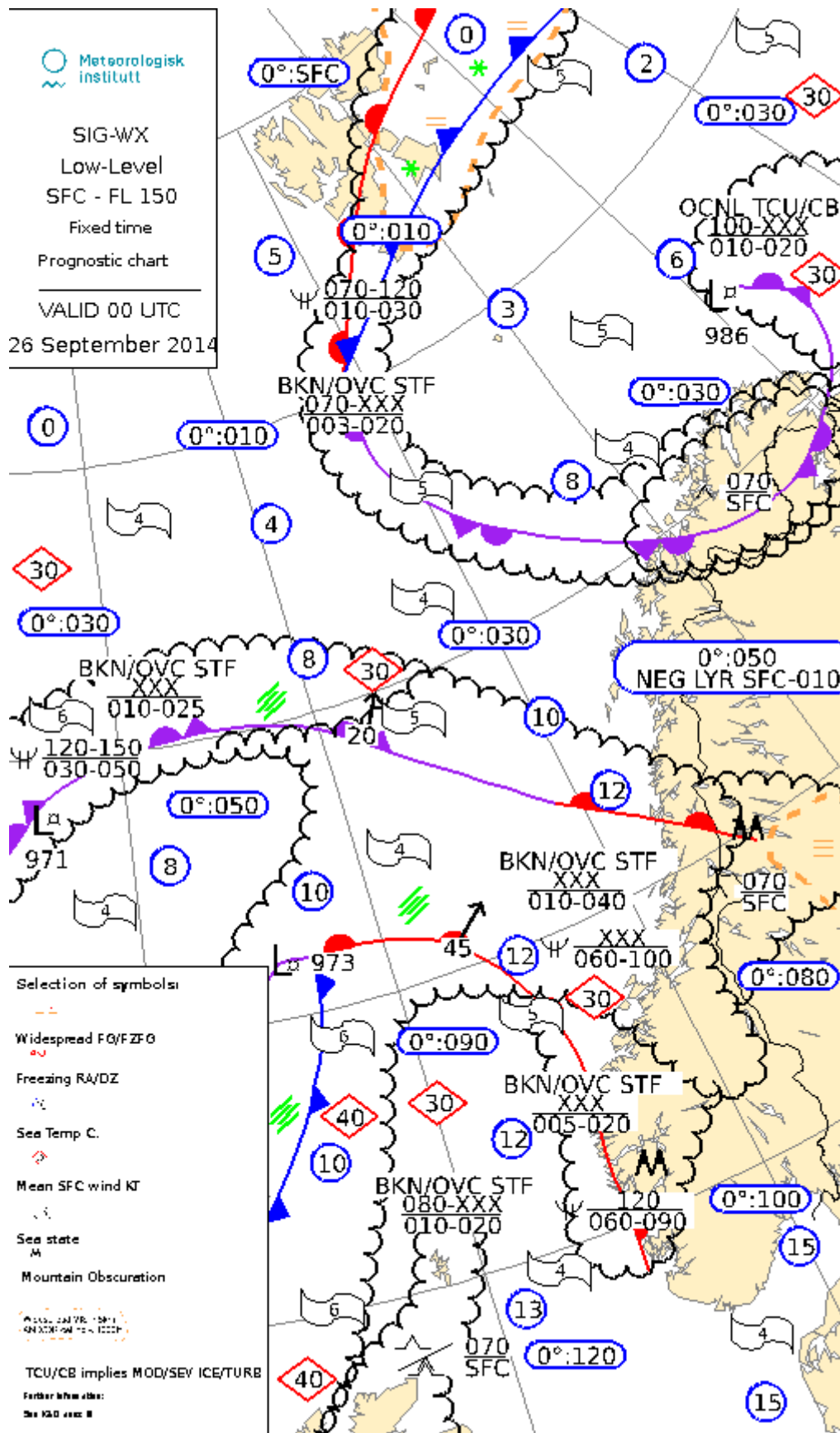


Figure 8: Significant weather chart at 00 UTC (legend in Appendix E). Source: The Norwegian Meteorological Institute

- 1.7.3.3 MI also used model data to support the preparation of a retrospective statement about the weather. These showed moderate to severe icing formed as some narrow bands in the north-south direction above Trøndelag and the northern part of south-eastern Norway, mainly west of the track and earlier in the evening than the relevant period. The scale ranges from 4-9, where green is 4, corresponding to light-moderate icing, and red is 9, corresponding to severe icing.

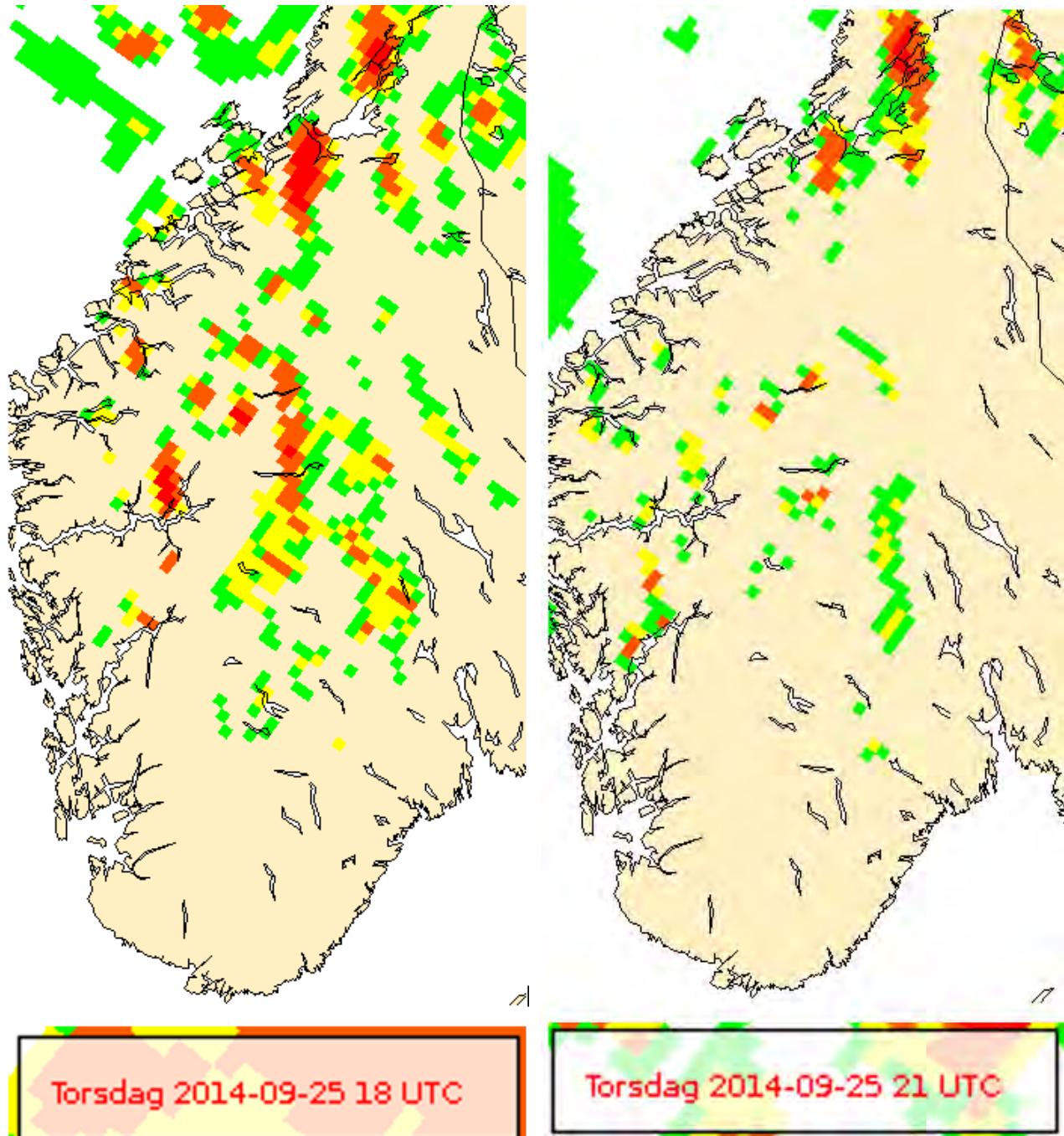


Figure 9: Icing conditions (Model data) at 18 and 21 UTC. Source: The Norwegian Meteorological Institute

- 1.7.3.4 Any mountain wave activity could not be revealed by satellite images, as the relevant area was covered in clouds. However, there are visible stripes on the lee side of mountains in Scotland, indicating mountain waves.

- 1.7.3.5 Prognostic rising air data for the relevant period show there may have been mountain wave activity on the relevant evening. Prognostic rising air data from Værnes at 00 UTC show moderate to severe icing at FL110-150.
- 1.7.3.6 There was no SIGMET/AIRMET for Trøndelag or south-eastern Norway for the relevant period. Nor were there recorded reports from aircraft about icing in the area.
- 1.7.3.7 Wind and temperature conditions at FL100-180 (model data):
- FL100 18UTC: 270-300/20-30kt, temp -6 to -2 °C.
FL100 00UTC: 270/30-50kt, temp -2 to 1 °C.
FL180 18UTC: 300-330/65kt, temp -18 to -15 °C.
FL180 00UTC: 270-290/40-45kt, temp -16 to -15 °C.
- 1.7.3.8 The Norwegian Meteorological Institute has concluded as follows:

The aircraft may have experienced varying degrees of icing during the flight. It is likely that the aircraft experienced severe icing within a minor horizontal area and within a limited vertical band. Icing in connection with lee clouds can be local and short-term and is therefore not necessarily detected by the model at the relevant location and at the relevant time. [...]

The mountain wave activity over Scotland may indicate that similar conditions may have been in force over southern Norway if the conditions were otherwise conducive to this.

It is likely that the aircraft may have experienced 270/50kt at FL150 30 minutes after take-off from ENGM en-route north. [...]

Based on the available information, it is likely that there were mountain waves over the area in question during that evening. Lee clouds will form in connection with mountain waves, and icing may be encountered in these lee clouds in rising and humid air. The icing can often be concentrated to small areas horizontally and thin bands vertically. It is not unlikely that the aircraft experienced severe icing at approx. 15,000ft.

1.7.4 Assessment of the intensity of any mountain waves

Upon request from the Accident Investigation Board concerning whether it was possible to say anything more detailed about the intensity and extent of any mountain waves, the Norwegian Meteorological Institute (MI) made a more detailed study of the situation. MI stresses that there are no observations to support this, and that the model used has inherent uncertainties. The following is quoted from the supplementary report:

In the model, we see clear mountain waves, and we expect that there were such waves in the relevant area. [...]. In the model, there are waves with a vertical speed of about 0.5 m/s in the area. There does not seem to have been conditions conducive to interrupting mountain waves. [...] The mountain waves in the model have peaks and troughs along roughly north-south lines, almost exactly across the course of the aircraft. [...] The uncertainty in the difference between the model and the relevant weather results in the vertical speed being maximum estimated to 1 m/s [under 200 ft/min].

1.8 Aids to navigation

Not relevant.

1.9 Communications

The communication functioned normally.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

1.11.1 Introduction

SE-MAF was equipped with a Plessey PV1584F flight recorder. West Air Sweden had downloaded the data from the recorder, and made them available to BAE Systems and the AIBN. A plot of selected parameters during the period from about 3 minutes before to about 3 minutes after the incident can be found in Figure 10. More parameters and a longer time period can be found in Appendix F. Data from the voice recorder (storage capacity 30 minutes) was automatically overwritten during the flight and was not available for investigation.

1.11.2 Recorded FDR data

1.11.2.1 FDR data in Appendix F shows that the aircraft used approx. 17 minutes to reach cruising altitude. The climb was steady and even. Airspeed⁵ at cruising altitude rose as expected for the first 2-3 minutes. Thereafter, from approx. 2212 (count⁶ 36300 on FDR), a gradual loss of speed can be observed. The speed fell by 3 kt for the first minute, then another 3 kt the next minute, and 6, 5, 11, 5, 7 and 18 kt in the subsequent minutes. This means that the speed fell by 58 kt over a period of approx. 8 minutes, reaching a minimum of 136 kt.

1.11.2.2 While the speed was falling, the pitch gradually increased. When the speed of SE-MAF had come down to the lowest recorded level, the pitch had increased from 0 to more than 7 degrees. The last two degrees were quickest, and uncontrolled bank occurred at this time.

1.11.2.3 The following can be seen from the plots in Figure 10:

- The speed fell as the pitch increased
- The incident lasted approx. 30 seconds (from FDR Counter 36780 – 36810)
- The minimum speed was 136 kt
- The extremes of the pitch was 7.1° nose up and 6.2° nose down
- The altitude loss was approx. 1,000 ft. during the period when the aircraft was completely or partially out of control
- The rolling reversed direction quickly and reached a maximum at 32.3° to the left.

⁵ Calibrated Air Speed, CAS, i.e. IAS corrected for position and compressibility error

⁶ 1 count equals 1 second

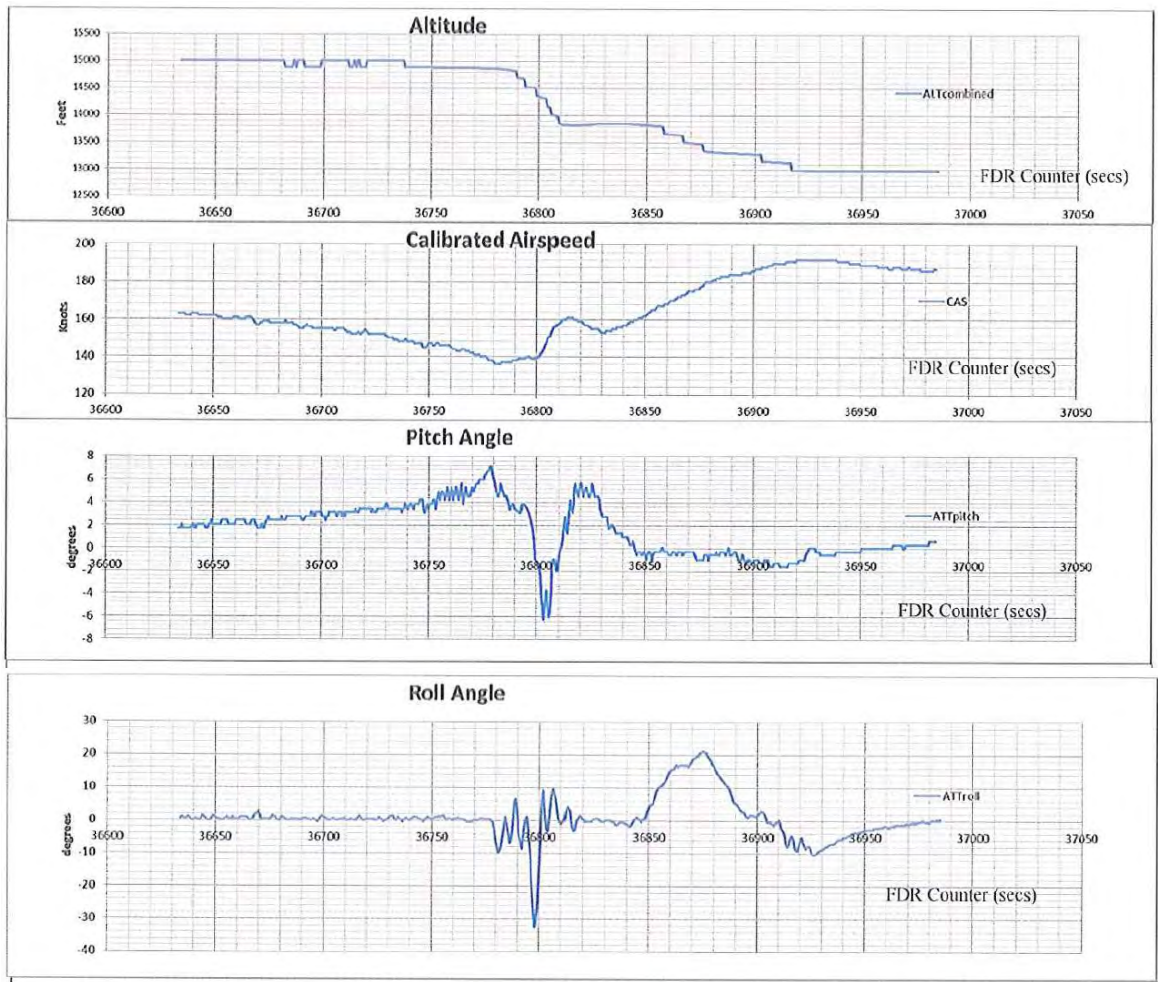


Figure 10: Recorded parameters for altitude, speed, pitch and roll angle during the period from approx. 3 minutes before to approx. 3 minutes after the incident

1.11.2.4 At the time of the most extreme roll angle, the vertical speed (loss of altitude) was 2,500-3,000 ft/min, with the following recorded values for speed, flight control surfaces⁷ and flight attitude:

Table 4: Snapshot from the FDR

| Count | Combined Altitude | CAS | Left elevator | Right elevator | Pitch trim angle | Aircraft pitch angle | Aircraft roll angle | Left aileron angle | Right aileron angle | Rudder angle |
|-------|-------------------|-----|---------------|----------------|------------------|----------------------|---------------------|--------------------|---------------------|--------------|
| 36798 | 14501 | 139 | 11.1 | 26.8 | -9.1 | 2 | -32.3 | 18.5 | -17.9 | 2.7 |

1.11.2.5 This means that the roll was 32.3° to the left while the airspeed was 19 kt below the recommended speed in icing conditions, while the pitch was still above the horizon. Maximum flight control input were not made by the crew at any time during the incident.

1.12 Wreckage and impact information

Not relevant.

⁷ The recorded deviation between L/H and R/H elevator is assumed to be a glitch in the FDR-calibration. A difference cannot be real as long as the systems are not operated mechanically disconnected.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

Not relevant.

1.15 Survival aspects

Not relevant.

1.16 Tests and research**1.16.1 Speed loss and reference speeds**

1.16.1.1 BAE Systems analysed the FDR data and prepared a figure to illustrate the speed loss during the incident. The figure compares the recorded minimum speed with both the manufacturer's recommended speed in icing conditions, the speed for activation of the stick shaker and the lowest stalling speed (see Figure 11). The figure also shows data from a previous icing incident with an similar aircraft (the Cowley incident, see 1.18.1.2) and experience values from the test flight program for icing conditions on the further developed aircraft type (BAe ATP Jetstream 61, Flight 163 min speed).

1.16.1.2 It emerges that the lowest speed during the incident with SE-MAF was 30 kt higher than the "clean" stalling speed and 16 kt higher than the "clean" stick shaker onset speed, but 22 kt lower than the recommended minimum speed in icing conditions:

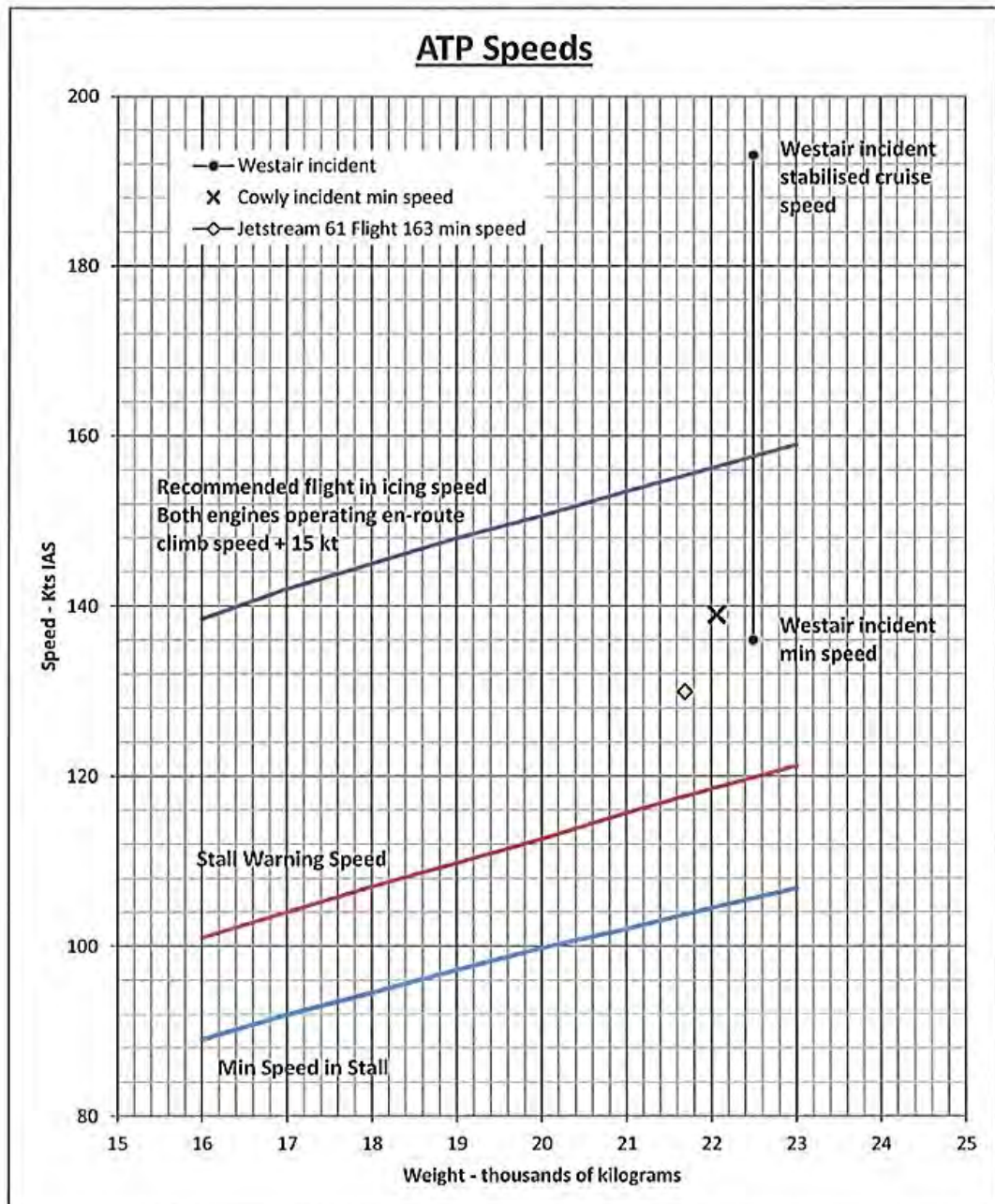


Figure 11: Speed loss for SE-MAF and the recorded minimum speed compared to the recommended minimum speed in icing conditions, stall warning speed and stall speed. The figure also shows minimum speed for the Cowley incident and values from the Jetstream 61 test flight. Source: BAE Systems

1.16.2 Aerodynamic assessment

- 1.16.2.1 BAE Systems analysed data from the flight recorder in SE-MAF extensively to assess whether the aircraft reached a stall condition. The angle of attack was estimated as the difference between the measured pitch attitude and the estimated flight path angle⁸. It was found that the lift coefficient (C_L) and therefore the lift, deviated substantially from normal (cf. Figure 12). Maximum C_L was approximately 1.05 at around 4° and remained

⁸ With reservations in regard to error resulting from interpolation

close to this value up to an angle of attack of around 12°. (The angle of attack was gradually increased from 4° to 12° while maintaining horizontal flight).

- 1.16.2.2 In these analyses, BAE Systems also compared the lift coefficient for SE-MAF with data from the test flight program that was implemented to document Jetstream 61 *Stall and Pushover Handling Characteristics in Icing*. Figure 12 shows BAE Systems' analysis, together with the Jetstream 61 effect of ice accretion; 'J61 Flt163 1st' and 'J61 Flt 150'⁹:

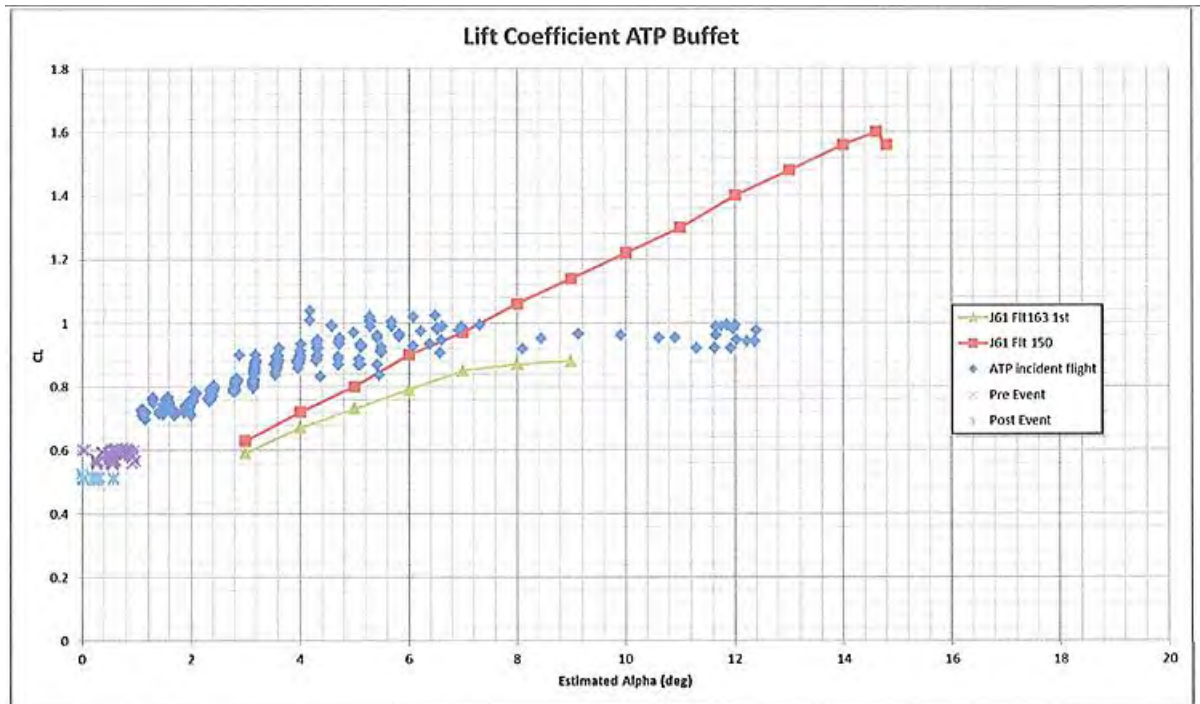


Figure 1: ATP Comparison of incident C_L vs α with flight test data from Ref.1

Figure 12: The lift coefficient for estimated angles of attack for the relevant flight (blue symbols) compared with Jetstream 61 with a clean wing (red graph) and a wing artificially contaminated with ice (green graph). Source: BAE Systems

- 1.16.2.3 The conclusions from BAE Systems for the lift calculations were as follows:

- Analysis of the FDR data for the incident flight indicates a maximum C_L value significantly below that for the clean aircraft at higher angles of attack.
- The minimum speed achieved during the incident was significantly higher than the clean wing (i.e. ice free) aircraft stall warning and minimum speed in the stall speeds.
- The minimum speed during the incident was substantially below the Both Engine Operation En-route + 15kt speed advised by BAE Systems for flight in icing conditions.

- 1.16.2.4 One reason for the reducing airspeed may have been drag caused by ice accreted on the airframe. BAE Systems considered how the drag developed (drag coefficient, C_D). A performance analysis shows that the airframe drag increased significantly; about as much and as quickly as in the Cowley incident, although this assumed that deceleration would

⁹ Not directly comparable, as J61 had vortex generators and presumably a higher C_{Lmax}

be entirely due to a drag increment caused by ice accretion. Subsequent to this analysis, BAE Systems suggest that the effect of the estimated mountain waves may have caused half the observed deceleration seen on the FDR data, which would reduce the contribution of drag to overall deceleration by a proportional amount.

1.17 Organisational and management information

1.17.1 West Air Sweden

1.17.1.1 *General information*

West Air Sweden AB has a Swedish Air Operator Certificate (AOC). The operator is part of the West Atlantic Group, also comprising the British airline Atlantic Airlines Ltd and the leasing company European Turboprop Management AB. The maintenance organisation European Aircraft Maintenance Ltd, domiciled in the Isle of Man, is also part of the group. The total size of the fleet was, according the 2013 annual report, 51 aircraft, of which 41 were ATPs. West Atlantic Group is the by far largest operator of ATPs.

In autumn 2014, West Air Sweden stated that they had a fleet of 32 ATPs, and that 21 of them were operating under a Swedish AOC. Eight of them were in daily use in Norway. West Air Sweden increased its capacity by 50% when they entered into a contract with Posten Norge in 2006. The operator had approx. 100 pilots at the time of the incident. While the pilots flying in Norway formerly were mostly Norwegian, there is now a sizeable contingent from Sweden and other countries such as France, Spain and the Netherlands.

Regular mail routes were flown from the base in Oslo to Stavanger, Bergen, Molde, Trondheim and Bodø. There were also flights to Harstad/Narvik, Tromsø and Longyearbyen. The northernmost routes are operated by Bombardier CRJ200 aircraft.

1.17.1.2 *Notification, reporting, internal investigation and follow-up of the incident with SE-MAF*

The commander wrote a report about the incident the following day. The report described the events in detail, and her precaution of maintaining a speed of at least 140 kt was mentioned (cf. 1.1.4). The AIBN was not notified by phone, and the reporting to Norwegian authorities was delayed¹⁰.

The operator initiated both a technical and an operational investigation only days after the incident. When the AIBN started its investigation approx. seven weeks later, the main focus of the operator's investigation was aimed at the malfunctioning of the de-icing system and the resulting accumulation of ice on the tail. Aspects relating to the minimum recommended speed in icing conditions were not mentioned until the manufacturer issued Flight Operations Safety Information Letter (FOSIL) No. ATP/007/14, titled *Recommended Minimum Speed in Icing Conditions* 25. November 2014 (cf. 1.6.8 and Appendix D).

FOSIL ATP/007/14 was included in its entirety in the operator's weekly information bulletin Flight Operations Information – FOI Week 48-2014. The information bulletin

¹⁰ National regulations at time required serious incidents to be notified immediately (by phone), followed by a written report to CAA-N within 72 hours.

totalled 13 A4 pages and covered ten different topics, with the mentioned FOSIL being the eighth. The heading was FOSIL ATP. The ATP chief pilot concluded the weekly bulletin with the following introduction about the icing incident:

BAE Systems has released a new FOSIL (Flight Operation Support Information Leaflet) due to our icing incident with possible tail ice over Norway. Please read the attached FOSIL below.

West Air Sweden was given access to the results of the aerodynamic analyses prepared by BAE Systems as soon as they had been completed (cf. 1.11). Based on their content, the chief pilot issued new information to the crews in FOI Week 2-2015. This time, the message was clear as regards the importance of adhering to the minimum speed in icing conditions. The relevant text from OM-B and AFM was quoted, and the graph showing the speed loss and the lowest recorded speed for SE-MAF in relation to the recommended minimum speed in icing conditions etc., was shown (cf. Figure 11).

In addition to existing relevant material quoted, West Air printed the following table in FOI Week 2-2015:

| Weight Kg | 16000 | 17000 | 18000 | 19000 | 20000 | 21000 | 22000 | 23000 | 24000 |
|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Min en- route Climb Speed kts | 124 | 127 | 130 | 133 | 136 | 139 | 141 | 144 | 147 |
| Min icing Speed kts | 139 | 142 | 145 | 148 | 151 | 154 | 156 | 159 | 162 |

Figure 13: Reference table for minimum speed in icing conditions. Source: West Air Sweden AB

1.17.1.3 The operator's handling of weather conditions as a risk factor

The weather conditions were an identified risk factor for the operator's flights over the mountains between Oslo and Bergen. For those flights, there were special climb procedures to avoid icing conditions. The route between Oslo and Værnes was not known to be equally exposed to adverse weather, and no special measures had been implemented.

Upon request from the Accident Investigation Board, the senior operational personnel with the operator stated that moderate icing was a common occurrence, but that they had not received reports in recent years about incidents causing serious problems during flights.

West Air Sweden AB had not implemented routine analysis of flight recorder data (flight data monitoring, FDM) in its flight safety programme when the incident took place, nor was this an authority requirement.

1.18 Additional information

1.18.1 Previous incidents

1.18.1.1 *Database search*

The Accident Investigation Board asked the Swedish transport authority Transportstyrelsen and the Civil Aviation Authority in Norway (Luftfartstilsynet) to search their databases for incidents where icing or mountain waves had been listed as a factor.

No relevant icing incidents were found in Sweden. The Norwegian Civil Aviation Authority submitted a list of 70 incidents going back to 2001 to the AIBN. Most of the incidents were related to temporarily frozen rudders, insufficient de-icing, pitot heat or other de-icing or anti-icing systems failures forcing aircraft to turn back to avoid icing conditions. Ten of the reports covered loss or incipient loss of control, and these have been listed in the overview below. Five of the incidents were classified as serious incidents or accidents and have been investigated by the AIBN:

| Location | Local date | AC reg. | make/model/series | AIBN report |
|-----------------------|------------|---------|---------------------|--------------------------------|
| Værnes 50 NM S of | 26.02.2015 | LN-PBO | CESSNA - 208 - B | --- Incident --- |
| Gardermoen - Værnes | 26.09.2014 | SE-MAF | BAe - ATP | --- Incident in question --- |
| Sola | 29.11.2011 | UNKNOWN | SAAB - 340 | --- Incident --- |
| Flesland - Gardermoen | 11.11.2010 | SE-LNX | BAe - ATP | --- Incident --- |
| Gardermoen 20NM S of | 17.12.2008 | LN-PBO | CESSNA - 208 | --- Incident --- |
| Gardermoen - Flesland | 07.08.2008 | LN-PBK | CESSNA - 208 | --- Incident --- |
| Flesland CTR | 09.11.2007 | OY-JRY | ATR - ATR42 - 300 | SL REP 2013/03 |
| Florø 14 NM E of | 19.01.2006 | LN-PBF | CESSNA - 208 - B | SL REP 2006/31 |
| Stord 50 NM E of | 14.09.2005 | LN-FAO | ATR - ATR42 - 300 | SL RAP 2009/02 |
| Skien Geiteryggen | 30.11.2001 | SE-LGA | BAe - JETSTREAM3100 | SL RAP 2005/11 |

The case with SE-LNX in 2010 (shaded grey) involved an aircraft from West Air Sweden which had to turn back to Flesland after encountering severe turbulence and severe icing out of Flesland. At FL130, the speed dropped to approx. 145 kt and they got buffeting. The crew lowered the nose to avoid stalling. When the speed started increasing again, they resumed climbing to FL150, and the same happened again. After this, they left the area where icing occurred. The crew believed that super cooled large droplets had caused ice to accumulate under the wings. The operator's follow-up of the incident included a comment by the chief pilot to the effect that the crew handled the situation as they were trained to do in the course "Flying in Norway", namely to return to an airspace where the temperature was above zero. No mention was made about staying above the minimum speed in icing conditions.

1.18.1.2 *The Cowley incident*

The UK accident investigation authority AAIB has issued a report about an icing incident at Cowley¹¹ near Oxford on 11 August 1991 ([Aircraft Accident Report 4/92](#)). During the climb to FL160, the aircraft suffered a significant degradation of performance with the autopilot engaged in pitch mode. The warning of an incipient stall did not activate, and the crew believed the vibrations they felt were from ice on the propellers. The aircraft

¹¹ Cowley was by mistake spelled "Cowly" in the AAIB-report.

stalled and lost 3,500 ft. of altitude before control was regained. The boots were only activated after control was lost.

The main conclusion in the AAIB report was that glaze ice had accumulated rapidly on the aircraft without the crew noticing. It was dark when the incident occurred, and the inspection lights that were meant to illuminate the leading wing edge were not correctly adjusted. The report contained a total of 14 safety recommendations, of which two were for the manufacturer to consider whether icing speeds were sufficiently highlighted in the aircraft flight manual. Other topics were related to the operator's self-imposed limitations on maximum intermediate turbine temperature, the choice of autopilot mode in icing conditions, prevention of propeller icing, stall warning logic, activation of boots, training of crew members, certification requirements in relation to icing, adjustment of wing inspection lights and vibration issues in connection with EFIS and flight data recorders.

1.18.1.3 *Other examples of icing incidents and accidents*

Historically, there have been several accidents and serious aircraft incidents in which turboprop transport aircraft (Large Aeroplanes) have lost control and where icing or the stall warning during icing have been factors (cf. e.g. [ATR 72-212 Roselawn 1994](#), [Embraer EMB-120RT Michigan 1997](#), [Saab SF340A Australia 1998](#), [Saab340A Argentina 2011](#), [Colgan Air Bombardier DHC-8-400 New York 2009](#)).

A common factor in several of these accidents has been the failure of the crew to recognise the symptoms of a beginning stall. Some aircraft types have been modified or designed to activate the stick shaker at lower angles of attack in icing conditions, but this is not the case for ATP (cf. 1.6.2.2).

1.18.2 Measures initiated – BAE Systems

- 1.18.2.1 In addition to the immediate measure of distributing safety information to operators a few weeks after the incident (cf. 1.6.8), in February 2015 BAE Systems chose to take the necessary steps to add supplementary information relating to stalling in icing conditions to the authority-approved Aircraft Manual (AFM) and Manufacturers Operations Manual (MOM) for ATP.
- 1.18.2.2 MOM contains the most exhaustive description. The revised text about the effect of ice on stalling and stall warning gives several warnings obviously inspired by the scenario from the relevant incident with SE-MAF:

Effect of ice on stall and stall warning

Small amounts of ice on the aerodynamic surfaces can adversely affect the lifting capability of the wings and cause the aircraft to stall at higher speeds than when they are clear of ice. Depending on the icing conditions encountered, the stall warning system may not function and in these cases pre-stall warning is provided to the crew by airframe buffet. This pre stall buffet is more severe and different to that experienced during a clean wing stall or that experienced with propeller ice induced vibration.

Ice can also increase drag thus leading to reduction in IAS. If the IAS is seen to reduce ensure that the minimum airspeed quoted in the AFM is maintained. If the airspeed is allowed to reduce below this stall warning buffet may be encountered before the stick shaker operates. Recovery is achieved by immediately reducing

the angle of attack (AoA). Avoid excessive manoeuvring until the aircraft is clear of ice. If the autopilot was in use up to initiation of recovery anticipate that a higher than normal force may be required to move the control column as the pitch trim might have trimmed nos up to maintain the autopilot selection.

- 1.18.2.3 Then follows a section which deals specifically with adhering to the minimum speed during flights in icing conditions up to beginning the approach regime. In this section, the manufacturer directs pilots to calculate the minimum speed based on a speed already available to the crew on the speed cards in front of them:

Minimum airspeed for flight in icing conditions until on approach

In icing conditions (or with airframe accreted ice) the speed should not be allowed to fall below the both engines operating en-route climb speed of Figure 5.09.6 plus 15 knots. As this figure is not usually available on the flight deck the same speed can be found by adding 25 knots to the V_{SER} (as displayed on the Speed Cards) for the appropriate mass.

1.18.3 Measures planned and implemented – West Air Sweden

- 1.18.3.1 West Air Sweden concluded its internal investigation at year-end 2014. It was considered that all significant conditions had been clarified, both technical and operational. The new de-ice timer was an improvement (cf. 1.6.6.2), and all pilots had been thoroughly informed about the importance of adhering to the minimum speed in icing conditions (cf. 1.17.1.2). As regards the operational side, the operator wrote that all that remained was to improve the training program:

The web based “Winter training” module will also be revised, to include important recommendations and procedures directly from the AFM.

- 1.18.3.2 West Air Sweden has announced that they will act as recommended by the AIBN in this report (see Chapter 4).

1.18.4 EASA Annual Safety Conference 2013

Icing is a continuing concern also for the competent authorities, amongst others in relation to certification standards. *Icing conditions on ground and in flight* was the topic for the EASA Annual Safety Conference in 2013. The program and presentations are accessible at the [EASA website](#).

1.19 Useful or effective investigation techniques

No methods qualifying for special mention have been used in this investigation.

2. ANALYSIS

2.1 Introduction and delineation

- 2.1.1 This analysis covers the findings of the investigation in an attempt to explain why the aircraft lost speed and came out of control during cruise. The analysis discusses atmospheric and aerodynamic factors, technical aspects of the aircraft and flight-operational conditions. The analysis results in conclusions where the most important lessons learned are given special emphasis, followed by recommendations that the AIBN believes can contribute to improve air safety.
- 2.1.2 The AIBN believes the investigation has shown that the vibrations and loss of control that occurred most likely was due to a stall or incipient stall. This is discussed in more detail in Item 2.3 of the analysis. It was initially natural to think that this "inexplicable" incident was due to a specific technical malfunction. It seemed likely that the control problems were due to ice on the tail surface, as the airframe de-icing system on the tail probably did not work. However, BAE Systems directed attention to the real problem, which was related to the minimum speed in icing conditions. The investigation uncovered a knowledge gap with the operator, a gap which the AIBN believes can be partly traced back to the aircraft's approved documentation. This is discussed in more detail in Item 2.6 of the analysis.
- 2.1.3 The analyses performed by BAE Systems show that the lift coefficient was significantly reduced in relation to what one would expect from a clean wing (cf. 1.16). Airframe buffeting indicated an incipient stall, even though the speed was higher than the stick shaker onset speed. The fact that buffeting can occur this early when the aircraft is in icing conditions is a known fact and was taken into account when the aircraft was certified. The certification requirements in this area are complex and have later been made stricter.
- 2.1.4 Unexpected stalling is a serious safety issue, and stalling without adequate forewarning can be considered an unsafe condition, sowing doubts about the airworthiness of an aircraft. It was not obvious to the crew of SE-MAF that a stall was imminent. The first officer experienced the vibrations and the aircraft's response as very different from what he experienced in the simulator (cf. 1.1.14). The AIBN nevertheless believes that this incident does not provide a basis for putting forward far-reaching airworthiness recommendations. There exist recommended minimum speeds in icing conditions that give higher safety margins, provided that they are known and adhered to. The significant safety problems uncovered in this investigation can be solved with simple measures. The AIBN will therefore not look closer into matters relating to construction and certification.
- 2.1.5 The investigation has not uncovered conditions associated with the loading of the aircraft or other aspects of the technical condition that can explain why the speed dropped or control was lost. Aircraft mass and center of gravity was within limits at takeoff, and it is unlikely that ice accretion on the airframe would be at such a magnitude that it would cause problems on the flight in question.

2.2 Atmospheric conditions

2.2.1 Icing

- 2.2.1.1 Weather information presented in connection with the investigation of the incident indicates that the aircraft was in an area where the altitude band in question may have been locally subjected to mountain waves with lee clouds and severe icing (cf. 1.7.3.8). This correlates well with the crew's statement that they did not experience icing during the climb, and that there was a strong westerly wind at altitude.
- 2.2.1.2 The crew also describes that there was no visible precipitation and that the observed ice was white and porous, and that it accumulated to a significant thickness over the course of a few minutes (cf. 1.1.5). This indicates that the icing was relatively strong, but the AIBN nevertheless got the impression that the icing was less intense than in the Cowley incident and several of the incidents previously investigated by the AIBN or mentioned in the list of accidents and incidents in 1.18.1. For SE-MAF, there were obviously no super cooled large droplets or super cooled rain involved, which is known to create hazardous conditions.
- 2.2.1.3 In AIBN's opinion, rime ice probably formed on large parts of the unprotected areas of the aircraft, and that this increased the drag. It is known that small droplets of freezing drizzle that from the pilots viewpoint may not even be discernible, can form rime ice with very severe aerodynamic effects. Thin rough ice generally cannot be removed by deicing boots. FAA Advisory Circular AC 20-73A – *Aircraft Ice Protection* issued in 2006, has a table that shows the effect as speed decrease independent from the well-known categories of icing intensity. The table could be informative for pilots and a useful reference when sending pilot reports (PIREPS/AIREPS). The table is shown in appendix G to this report.
- 2.2.1.4 Increasing pitch will expose more areas under the airframe and wings for ice accretion. Cause and further effect of increased pitch on SE-MAF is discussed in more detail in Item 2.3, *The loss of control*.

2.2.2 Mountain waves

- 2.2.2.1 Whether mountain waves may have created conditions that worsened the situation, has also been considered. According to the aviation meteorology text book *Flymeteorologi* (Dannevig, P. 1969), vertical speed in mountain waves over Scandinavia is usually 3-6 m/s [600-1,200 ft/min], rarely up to 10 m/s [2,000 ft/min]. They are often strongest at 2,000-5,000 m [6,500-16,000 ft] altitude, and do not in themselves create much turbulence. The largest disadvantage is the vertical movement of the aircraft, making it hard to maintain altitude. (The situation can be compared with being on an escalator heading down, forcing you to run upwards to stay in place).
- 2.2.2.2 The Norwegian Meteorological Institute estimated that the wave movement was maximum 1 m/s (approx. 200 ft/min). For instance, the aircraft may have flown north along a downwards wave. This would force the autopilot to compensate by increasing the angle of attack somewhat to maintain altitude. Assuming that the MI's estimate is correct, the aircraft would have to climb almost 200 ft/min to stay at FL150 in a worst-case scenario. This would reduce the aircraft's airspeed and may, according to BAE Systems, explain up to half of the observed speed loss (cf. 1.16.2.4).

2.2.3 Weather forecast and use of warnings

- 2.2.3.1 The Norwegian Meteorological Institute has concluded that mainly correlated well with the observed weather (cf. 1.7.3). The AIBN shares this view, but has noted that no warnings of any kind were issued (cf. 1.7.3.6).
- 2.2.3.2 The Regulations relating to aeronautical meteorological services (BSL G 7-1) article 21 describes how advisory information¹² (SIGMET, alt. AIRMET¹³) shall be issued if the weather conditions so require. In retrospect, it can seem that the weather situation shown on the charts, with the relevant front and the prevailing temperatures (cf. 1.7.3.2), indicated that there was a risk of icing and warnings should have reflected this. The AIBN has confronted MI with this view, and their comment was as follows:

“The weather situation [...] indicated local icing conditions, but not to such an extent that it qualified for issuing AIRMET on MOD ICE or SIGMET on SEV ICE. If model data had shown more extensive icing, correctly positioned in time and space, and this in addition had been supported by pilot reports, it is likely that the danger messages (SIGMET/AIRMET) further into the evening and night had reflected this.”

- 2.2.3.3 The AIBN has not gone more in depth to map and assess the services that was delivered in the period in question, and has not investigated for possible system weaknesses in the aeronautical meteorological services. SHT would, however, recall that although the Pilot Report (PIREP/AIREP) is a valuable supplement to meteorologists and useful for gaining experience about local variations, they are sporadic and often unreliable. This partly because aircraft with turbojet engines normally passes through the problematic levels quickly and without problems, while turboprop aircraft, that there is a lot lower number of, often has its cruising altitude at the top of the clouds. An important effect of the flight crew being notified through SIGMET etc., is increased awareness. When warned one will be quicker to recognize a potentially hazardous situation and take necessary action.

2.3 **The loss of control**

- 2.3.1 The Accident Investigation Board believes that it is likely that icing in combination with mountain waves caused the airspeed to decrease. Additional engine power was not applied to compensate for the speed loss. Countermeasures like reduction of angle of attack and initiation of descend were implemented too late, and control was lost. The level of control loss or alternative scenarios with different handling is not evaluated in this investigation.
- 2.3.2 When ice accumulates on the airframe the lift coefficient decreases. If the autopilot is engaged and the Flight Director Controller selected to ‘Altitude Hold’¹⁴, the autopilot will increase the nose up pitch to try to maintain the selected altitude. As the pitch attitude is increased, the force on the control column will also increase and the auto pilot pitch trim will trim nose up to alleviate this. If the pilot takes control at this stage, the applied nose

¹² Information issued by a meteorological office or surveillance office concerning observed or anticipated weather phenomenon that may impact aircraft safety during flight and on the ground, as well as the infrastructure and operation of a landing site.

¹³ Information issued by a meteorological surveillance office concerning observed or expected presence of hazardous weather conditions that do not require issuing a SIGMET

¹⁴ Assuming that engine power is constant.

up trim requires a large push force to move the control column forward and achieve a nose down pitching moment. An increased pitch attitude will also add to the drag. The aircraft being heavily loaded was also a factor, as this would require a higher angle of attack to maintain a given lift.

- 2.3.3 It appears unlikely that this type of aircraft can experience such a critical speed loss when cruising at level FL150, unless the aircraft is exposed to an unexpected level of icing, perhaps caused by low levels of icing for an extended period or failure of the de-icing system. Both the AFM and the training programme referred to the need to increase speed when climbing, when the stall margin is much narrower than during horizontal flying (cf. 1.6.9 and 1.6.10). However, mountain waves can force the aircraft to climb to maintain altitude, without seeing the effect in the form of declining climbing ability. The relationship thereby corresponds to what happens if a constant climb rate is chosen that exceeds the aircraft's performance (such as in the Cowley incident, cf. 1.18.1.2).
- 2.3.4 The mountain wave effect and additional drag is camouflaged by the autopilot in Altitude Hold, and the Accident Investigation Board believes that mountain waves may have been an "unknown factor" in the speed loss in this case. The fact that the icing was not perceived to be extreme may have made it harder to assess the situation and may also have delayed the crew's decision to leave the problematic flight level range.
- 2.3.5 Wings with ice accretion are less effective and provide less lift than clean wings. The airflow is disturbed and can separate at lower angles of attack than normal. This means that the stall speed is higher, and this is why there is a recommended minimum speed in icing conditions.
- 2.3.6 In the case of SE-MAF, the speed fell to 136 kt, which is 22 kt lower than recommended for the mass involved in icing conditions (cf. 1.16.1). Calculations prepared by BAE Systems show that the wing did not produce more lift in spite of the increased angle of attack (cf. 1.16.2.3). Combined with the crew's description of the wing dropping out of control, the AIBN believes this provides a basis for claiming that the wings were contaminated with ice, and that the airflow separated over the entire or parts of the wing (aerodynamic stall).
- 2.3.7 The AIBN has estimated that the aircraft was completely or partially out of control for about 30 seconds. Thereafter, a few more seconds passed before the flight can be said to have stabilised (Appendix F, count 36820). The snapshot shown in Item 1.11.2.4, with a 32° roll while the aircraft was still falling at a descent rate of more than 2,500 ft/min and the pitch was above the horizon, illustrates the seriousness. Stalling can have catastrophic results if control is not regained in time. With ice-contaminated wings and tail surfaces, both the flying ability and the ability to regain control are impaired and unpredictable. The recovery phase, i.e. when control was regained, is discussed in more detail in Item 2.5.

2.4 De-icing system

2.4.1 Observations on the operation of the de-icing system

- 2.4.1.1 The Accident Investigation Board has previously pointed out that BAE Systems did not support the mandated change to operation of the aircraft recommended by the US Federal Aviation Administration (FAA) regarding activating the boots at the first sign of ice on the wings (cf. [SL REP 11/2005](#), accident with British Aerospace Jetstream 31). At the

time and in connection with this investigation, BAE Systems presented a letter with its comments to FAA NPRM 1999, where the boot manufacturer BFGoodrich refers to the results from its own experiments showing that waiting until there is a quarter to half an inch of ice before activating the boots yields the best effect. From the perspective of the Type Certificate Holder, change to these procedures would require re-certification of flight in icing for the aircraft type.

2.4.1.2 Pilots get no precise indication of the thickness of the ice layer on the leading wing edges (cf. 1.6.7.2). In addition, the thickness cannot be estimated from the fact that 3-4 cm of ice was observed on the window frame when the boots were activated. Activation of the de-icing system does not show up on the FDR, and according to BAE Systems, neither the time nor the effect of a successful de-icing of the wings and tail will be visible on other recorded parameters, e.g. speed and pitch or engine parameters. The AIBN assumes that the warning light came on when the second sequence started, i.e. around 5 minutes after the crew saw ice break loose from the leading wing edges (cf. 1.6.4.6).

2.4.1.3 The AIBN will desist from again raising the discussion on when the boots are best activated. If the crew suspects icing during the approach, the system must be activated regardless of ice thickness (cf. Appendix C). The incident shows that "correct" use of the boots alone is no guarantee against stalling. It is not sufficient to see that ice comes off the leading wing edges, the aircraft can still stall before the stick shaker is activated. We do not know whether the situation would have been different if the system had been operated in HEAVY or MANUAL mode. The Accident Investigation Board believes these observations emphasise how important it is to comply with the minimum speed in icing conditions.

2.4.2 The importance of the fault in the de-icing system

2.4.2.1 BAE Systems confirmed that the symptoms were compatible with a de-ice timer fault. This indicates that the boots on the tail surface probably did not inflate, and that there probably was a substantial accumulation of ice on the tail surface when control was lost.

2.4.2.2 The crew's experience of the speed trend suddenly going "all the way down" (cf. 1.1.6), made the AIBN ask BAE Systems whether the de-icing system may have failed in a manner that left the boots on the wing or tail inflated. This was considered highly improbable, and it was rejected that such a malfunction could explain why the drag increased and the speed dropped. The importance of the fault on the de-icing system was limited to a somewhat increased share of the total drag. The fault on the airframe de-ice timer therefore had no direct effect on the loss of control.

2.5 **The recovery phase**

2.5.1 Initially in the recovery phase, the correct order of priority would have been disconnecting the autopilot using the switch on the control column and then immediately lowering the nose to reduce the angle of attack. The first officer has explained that he had to use considerable force to push the control column forward, indicating that the autopilot was using maximum or close to maximum pitch trim (cf. 1.18.2.2 and 2.3). The flight recorder contained no parameter for the autopilot status, but the crew's statements indicate that it took some time before it was disconnected (cf. 1.1.7).

2.5.2 The AIBN assessed why the autopilot did not disconnect automatically during the incident. According to the autopilot documentation, a roll exceeding 35°, a pitch

exceeding 25° or a stick force of more than 50 lb on the elevator should cause the autopilot to disconnect. The flight attitude was not that extreme, and even though the first officer used considerable force on the control column, none of the mentioned or any other disconnection parameters were probably met in this case.

- 2.5.3 When the aircraft is approaching a stall, excessive manoeuvring is discouraged, as rudder and aileron movement can cause stalling. It was therefore the correct course of action to reduce the altitude and permit a course change while the incident was underway (cf. 1.1.8). A loss of altitude of barely 1,000 ft was not dramatic in relation to the terrain. The fact that it took some time for the flight to stabilise once the speed had risen again can be explained by the first officer being mentally shaken by the sudden and unexpected loss of control and the abnormal response from the aircraft's controls.
- 2.5.4 In connection with the investigation, BAE Systems has confirmed that they recommend maintaining cruise power unless there is an emergency. Speed loss as a result of icing is handled by leaving that altitude, as the crew was planning. The commander's observations on abstaining from the use of engine power in a recovery situation (cf. 1.1.15) is also in line with applicable procedures. In recent years, there has been a general tendency, regardless of aircraft type, to consider the best way to correct an incipient stall at a safe altitude to be reducing the angle of attack rather than increasing engine power and focus too much on minimising altitude loss.
- 2.5.5 When the aircraft came down to FL130, it maintained cruise speed as normal. The aircraft was then probably out of the altitude band where the combination of icing and mountain waves created problems.
- 2.5.6 Calculations from BAE Systems comparing drag and lift before and after the incident indicate that the wing's ability to produce lift remained somewhat reduced also after the incident (cf. Figure 12). It has not been possible to determine with certainty what caused the loss of lift, but it is likely that it was a result of ice accretion on unprotected sections of the wing leading edge. The weather charts and the FDR data indicate that the temperature at FL130 was also below freezing, and that the aircraft was flying in temperatures above freezing for only the last five minutes of the approach (cf. the 0 isotherm in Figure 8 and Saturated Air Temperature (SAT) in Appendix F, which show that the temperature rose above freezing when passing through FL090 during the descent).

2.6 Minimum speed in icing conditions

- 2.6.1 Losing control over a large aircraft during cruise is not a normal situation, and it can be complicated and time-consuming to determine what really happened. It was good that the operator secured flight recorder data from the incident, and that both a technical and an operational internal investigation were initiated. The AIBN can understand how the operator was unable to exclude tailplane icing as the probable cause during the first few weeks. Without going into details concerning the aerodynamic conditions, it can be mentioned that ice on the tail section is rarely a problem during flying in cruising altitude, as the tail surface generates little lift in this phase. If the tail surface stalls, it is typically during the approach, when flaps are extended and the trim changes are large. The aircraft can then pitch suddenly and uncontrolled downwards, creating serious problems. A characteristic of tailplane icing is that only the control column vibrates, not the entire aircraft.

- 2.6.2 However, the AIBN considers it worrying that the information concerning the aircraft's considerable speed loss was available to the senior operational personnel from the day after the incident, without anyone reacting. The commander's report shows that she thought the safety margin to be sufficient if they stayed above 140 kt (cf. 1.1.4), whereas the recommended minimum speed for the relevant mass in reality was as high as 158 kt (cf. 1.6.7 and 1.16.1). Knowledge about special procedures for approach in icing conditions seemed to be in place for all operational personnel the AIBN spoke to in connection with the investigation. However, there was an impression that knowledge, or at least awareness, was lacking as regards icing in other phases.
- 2.6.3 When BAE Systems had analysed the FDR data from the incident with SE-MAF, it took just a few weeks before they issued the Flight Operations Safety Information Letter where the main message was that ATP crews did not seem to be fully aware of the recommended minimum speed in icing conditions (cf. 1.6.8.1). The first time West Air Sweden communicated this information to its pilots, the focus was still mostly on the tailplane ice issue (1.17.1.2). It seemed as if the documentation from BAE Systems highlighted existing published material to which senior operational personnel were not yet familiar with. This reinforces the impression that there was a collective knowledge gap as regards minimum speeds in icing conditions.
- 2.6.4 As documented in the fact section's Item 1.6.7, the information about recommended minimum speed was not easily available in the aircraft's official manuals. It was necessary to look in multiple locations and perform calculations to find the relevant speed. The measures implemented to rectify this are discussed in more detail in Item 2.8.

2.7 Awareness of icing risk and mountain waves

- 2.7.1 Mountains near coasts and fjords far north make icing a risk factor that operators in Norway must take seriously. The fact that no examples of icing incidents were found in the Swedish incident database may be due to administrative issues, but also the fact that icing is more common in Norway than in Sweden (cf. 1.18.1.1). Although the statistical material is thin, the AIBN believes there is reason to note that half the aircraft in the list of icing incidents in 1.18.1.1 are registered abroad.
- 2.7.2 West Air Sweden operates frequently in Norway, all the way up to Svalbard, with a large percentage of pilots with the weight of their experience from flying further south. A significant portion of the flying takes place with mass near the maximum, and the flight levels normally used by turboprop aircraft are exposed to icing. Special procedures for flights out of Flesland are an example of West Air Sweden taking action in this area (cf. 1.17.1.3), but the AIBN believes that the incident with SE-MAF has highlighted a need for more attention to icing.
- 2.7.3 Seen in an aircraft safety perspective, the incident with SE-LNX in 2010 could have provided valuable lessons for the operator (cf. 1.18.1). Although much time had passed since the Cowley incident in 1991, an active search for comparable incidents would have singled it out, enabling the organisation to increase its knowledge and awareness about stalling and icing. These icing incidents have many shared characteristics with the serious aircraft incident ATR 42, LN-FAO, operated by Coast Air, investigated by the AIBN and the subject of a comprehensive report issued in 2009 (cf. SHT [2009/02](#)).

2.8 Assessment of implemented measures

2.8.1 The AIBN believes BAE Systems' final supplement and clarifications in the AFM concerning MOM are significant improvements (cf. 1.18.2), but that there is still reason to consider if enough has been done to prevent stalling in icing conditions. Knowledge and training are essential here, and it is positive that West Air Sweden has announced that they will improve their training program. The AIBN expects that the new content from BAE Systems will be included in the syllabus (cf. 1.6.10 and 1.18.3).

2.8.2 The new text in MOM refers, like the previous text, to a figure that is hard to find. In the figure, you are supposed to find a speed and add 15 kt (cf. 1.18.2.3). Then BAE Systems shows that they also have seen the need for pilots to have this information in front of them, and then refers to a different speed that can be used as the basis, provided that you remember to add 25 kt:

[...] As this figure is not usually available on the flight deck the same speed can be found by adding 25 knots to the V_{SER} (as displayed on the Speed Cards) for the appropriate mass.

2.8.3 The AIBN considers it not satisfactory that the formula for calculation is mentioned in manuals and basis training, but that pilots in operational service are expected to memorise the source of speed reference and calculate the values themselves. The prevalence of icing in Norway means that the minimum speed to avoid stalling in icing conditions during the cruise is not just of theoretical interest, and the AIBN believes pilots should have the values readily available while flying.

2.8.4 Speed cards are small booklets used by pilots in the cockpit to determine various speeds for different masses in different flying phases. The AIBN knows that other turboprop operators have included icing speeds in their speed booklets, and believes this should also be considered for ATP. There may also be other ways or means of communicating the information, e.g. making the table in FOI Week 2-2015 available in the cockpit (cf. 1.17.1.2). Two safety recommendations are made in this area.

3. CONCLUSION

3.1 Findings of particular importance for air safety

The vibrations and loss of control experienced by the crew was most likely a result of a stall or incipient stall. Ice that had accumulated on the aircraft increased the drag and reduced the lift, while mountain waves probably also contributed to lowering the speed. The crew was unfamiliar with the aircraft type's minimum speeds in icing conditions, and implemented countermeasures too late. The incident can to some degree be linked to deficiencies in the operator's training program and weaknesses in the aircraft's authority-approved documentation.

3.2 Findings

- a) The crew members had valid licenses and privileges for the aircraft type.
- b) The aircraft was registered in accordance with the regulations and had a valid environmental and airworthiness certificate.

- c) The mass and centre of gravity of the aircraft were within the prescribed limits.
- d) In spite the forecast for moderate icing on significant weather charts that afternoon, no warning (AIRMET, SIGMET) had been issued in connection with the expected passing weather front that evening.
- e) Ice protection system on the propellers and air intakes were on and functioned as intended.
- f) At cruising altitude FL150, ice accumulated on the aircraft, and the crew operated the Airframe De-icing system in normal mode to remove ice from the leading edges of the wings, fin and tailplane.
- g) The crew saw the ice breaking off from the wing leading edges.
- h) The cruising speed declined substantially over the course of a few minutes, and when the crew realise that this forced them do descend, violent shaking and buffeting suddenly occurred, while the nose pitched up and the aircraft banked out of control to the left.
- i) The speed loss was presumably the result of increased drag caused by the aircraft flying in a band of severe icing combined with downward vertical air currents in mountain waves.
- j) From the certification of the aircraft, it is known that the stall speed with ice contamination can be significantly higher than normal. Natural buffeting is then considered to be sufficient forewarning.
- k) The lowest speed during the incident was 16 kt higher than the value for activation of the aircraft's stick shaker, and 30 kt higher than the aircraft's scheduled clean stall speed.
- l) The lowest speed during the incident was 22 kt lower than the recommended minimum speed in icing conditions.
- m) The crew was late in disconnecting the autopilot, but otherwise adhered to the recommended procedure to regain control of the aircraft.
- n) Control was regained after around 30 seconds, and the loss of altitude of 1,000 ft was undramatic in relation to the underlying terrain.
- o) When control had been regained, the flight continued at FL130 without problems to land at the destination.
- p) Just after the incident, a warning light came on, signalling a problem with the Airframe De-icing system that removes ice from the leading edges of the wings, fin and horisontal stabilizers.
- q) The de-icing system fault probably resulted in the tail fin and stabilizers leading edges not being de-iced, but this is assumed to have had only a marginal or no impact on the loss of control.

- r) There was no other evidence of any defects or malfunctions in the aircraft that could have contributed to the incident.
- s) The crew members lacked knowledge about applicable minimum speeds for flying in icing conditions except from during approach, and senior operational personnel with the operator seem to have suffered from the same knowledge gap.
- t) The operator's computer-based training program did not mention minimum speeds during cruise.
- u) The type certificate holder's approved manuals for the aircraft provide all the necessary information for flight in icing conditions, including minimum speed. However, some of the information was not easily found.
- v) Following the incident, BAE Systems has initiated improvements in the aircraft documentation relating to minimum airspeed for flight in icing conditions until on approach.

4. SAFETY RECOMMENDATIONS

The investigation of this serious incident has identified one area where the Accident Investigation Board Norway considers there to be a need for making safety recommendations to improve aviation safety¹⁵:

Safety recommendation SL 2015/09T

Ice accretion on the wings can cause the ATP aircraft to stall prematurely, before the stick shaker warns the crew. Accidents have occurred on similar aircraft types when crew members have failed to recognise natural buffeting as a warning of an imminent stall. The AIBN believes safety margins can be strengthened by making ATP pilots aware of the applicable recommended minimum speeds in icing conditions. In addition to planned and initiated measures like improved descriptions in manuals and training programs, the AIBN believes that values for recommended minimum speeds in icing conditions should be easily available for pilots in the cockpit.

The Accident Investigation Board Norway (AIBN) recommends that BAE Systems consider including recommended minimum speeds in icing conditions in the official Speed Cards for ATP, or in another suitable manner that makes the information easily available for reference in the cockpit.

Safety recommendation SL 2015/10T

Ice accretion on the wings can cause the ATP aircraft to stall prematurely, before the stick shaker warns the crew. Accidents have occurred on similar aircraft types when crew members have failed to recognise natural buffeting as a warning of an imminent stall. The AIBN believes safety margins can be strengthened by making ATP pilots aware of the applicable recommended minimum speeds in icing conditions. In addition to planned and initiated measures like improved descriptions in manuals and training programs, the

¹⁵ Provisions concerning safety recommendations and their follow-up are provided in Regulation (EU) 996/2010 Art. 17-18.

AIBN believes that values for recommended minimum speeds in icing conditions should be easily available for pilots in the cockpit.

Should the type certificate holder BAE Systems not implement measures to comply with this recommendation above, (cf. AIBN's safety recommendation 2015/09T), the AIBN recommends that the operator does so on its own initiative.

The Accident Investigation Board Norway (AIBN) recommends that West Atlantic Group finds a suitable way to make minimum speeds in icing conditions for ATP easily available in the cockpit.

The Accident Investigation Board Norway

Lillestrøm, 29 October 2015

APPENDICES

- Appendix A: Glossary
- Appendix B: Loadsheet and balance chart
- Appendix C: ATP Operations Manual - Normal procedures ice and rain protection
- Appendix D: Flight Operations Safety Information Letter (FOSIL) no. ATP/007/14
- Appendix E: Legend significant weather chart
- Appendix F: Parameters from FDR
- Appendix G: FAA AC 20-73A Appendix P – Icing Rate

GLOSSARY

| | |
|------------------|--|
| AFM | Aircraft Flight Manual |
| AMM | Aircraft Maintenance Manual |
| AOA | Angle of Attack |
| AOC | Air Operator Certificate |
| CAA | Civil Aviation Authority |
| CBT | Computer Based Training |
| CAS | Calibrated Air Speed |
| CVR | Cockpit Voice Recorder |
| CWP | Central Warning Panel |
| EEC | Engine Electronic Control |
| EASA | European Aviation Safety Agency |
| FAA | Federal Aviation Authority |
| FDR | Flight Data Recorder |
| FOI | Flight Operations Information |
| FOSIL | Flight Operations Safety Information Leaflet |
| hPa | Hectopascal |
| IAS | Indicated Air Speed |
| IMC | Instrument Meteorological Conditions, |
| KIAS | Kt Indicated Air Speed |
| Kt/knot(s) | Nautical Mile (s) per hour |
| METAR | Aerodrome routine meteorological report (in meteorological code) |
| MOM | Manufacturers Operations Manual |
| NTSB | National Transportation Safety Board |
| OM | Operations Manual |
| OPC | Operator Proficiency Check |
| PC | Proficiency Check |
| PF | Pilot Flying |
| PM | Pilot Monitoring |
| QNH | Altimeter sub-scale setting to obtain elevation when on ground |
| SIGMET | Significant Meteorological Information |
| TAF | Terminal aerodrome forecast (in meteorological code) |
| UTC | Co-ordinated Universal Time |
| V _S | Stall speed |
| V _{SER} | Single engine operating en-route climb speed |

ATP Operations Manual – Normal procedures ice and rain protection

4.10.13
Page 2
G/NOV 08/10

**NORMAL PROCEDURES
ICE AND RAIN PROTECTION**

Airframe De-icing

The first indication of airframe icing will be ice accretion on the windscreen wipers. This should alert the flight crew to the need for wing leading edge inspection.

The ice on the wing leading edges should normally be allowed to build up to a thickness of approximately half an inch prior to operation of the airframe de-icing system. After one cycle of the airframe de-icing, and having cleared the initial ice, consider switching the system off to allow a further build up of half an inch. Such action will prevent ice bridging over the inflatable boots. The thickness of ice on the wing leading edges can be observed at night by using the ice inspection lights. The tailplane leading edge can be checked through the rear passenger cabin windows (except freighter aircraft).

In the event of severe airframe icing being experienced (i.e. 'NORMAL' selection fails to remove the ice) then put the mode selector to HEAVY.

If the descent has been made in icing conditions select the airframe de-icing system to ON and HEAVY for 3 minutes prior to landing. During the approach, a wing leading edge inspection should be carried out for accreted ice at approximately 1 000 ft AGL. If ice is seen or suspected on the airframe, the de-icing system should be operated irrespective of the thickness of ice. The airframe de-icing system should be switched off passing 500 ft AGL, but no later than 200 ft AGL on the approach to landing.

4.10.13
Page 3
G/NOV 08/10

NORMAL PROCEDURES
ICE AND RAIN PROTECTION

Operation at low power settings

During operation of the airframe de-icing system at low engine power settings, the pressure supply to the de-icing system may fall to less than 16 PSIG and may result in operation of the "DE-ICING" light on the CWP. If the "DE-ICING" light illuminates and the cause is identified using the Emergency and Abnormal drills as low pressure, the power levers can be either advanced (to increase LP pressure as shown on the airframe de-icing pressure gauge) or retarded (to initiate the switch to HP pressure as indicated by the "HP BLEED" legend on the overhead panel) and the airframe de-icing system selected off and reselected to "ON" to reset the warning legend.

ECS Malfunction

In the event of an ECS malfunction, with both HP air bleeds having been selected to OFF it may be necessary to increase engine power, so as to maintain the airframe de-icing system pressure at 16-20 PSIG.

EFFECTS OF ICE

General

When icing conditions are encountered, ice will build up on the aircraft. This build up can be very rapid. The engine/propeller and airframe de-icing systems will remove most of this ice but ice can remain on parts of the wing, tailplane and fin leading edges and on the fuselage.

The actual effects of ice on the aircraft performance are dependent upon the nature of ice on the aircraft. In addition, airframe buffet may be encountered at normal operating speeds. Propeller vibration may also be encountered.

Freezing rain, freezing drizzle and unusual icing conditions may cause heavy accretion which could exceed the capabilities of the ice protection systems. Such ice can also accrete on the unprotected surfaces. This ice cannot be shed and it may seriously degrade performance and control of the aircraft.

Prolonged operations in altitude bands where temperatures are near freezing and heavy moisture is visible on the windscreen, should be avoided.

If the aircraft exhibits airframe buffet onset, unexpected loss of speed, uncommanded roll or unusual roll control wheel forces, immediately reduce the angle of attack (AOA) and avoid excessive manoeuvring, until the airframe is clear of ice.

If ice is seen forming behind the unprotected surfaces, or unusual roll trim requirements or autopilot trim warnings are encountered, then:

- Leave icing conditions as soon as possible.
- If flap is extended, do not retract the flap until the airframe is clear of ice.

4.10.13
Page 4
G/NOV 08/10

NORMAL PROCEDURES
ICE AND RAIN PROTECTION

- Hold the control wheel firmly and disengage the autopilot (if in use).
- Increase the airspeed as much as configuration will allow, but not above V_{RA} .
- Do not engage the autopilot until the airframe is clear of ice.

Ice Effects - Climb, Cruise and Descent

The additional drag due to the presence of ice on the aircraft will reduce the performance. A careful check of the fuel state should be maintained. Where possible, cruising levels should be changed to avoid icing conditions.

In icing conditions the speed should not be allowed to fall below the both engines operating en-route climb speed of Figure 5.09.6 plus 15 knots.

NOTE: Both the icing speed increment and the ice accretion on the airframe have an effect on the aircraft performance. The aircraft should be operated in accordance with associated performance information, in the Operations Manual.

It is also recommended that for descent, the minimum fuel descent technique of 180 knots IAS be adopted.

BAE System Flight Operations Support Information Letter (FOSIL) nr. ATP/007/14
Recommended Minimum Speed in Icing Conditions**BAE SYSTEMS****ATP****FLIGHT OPERATIONS SUPPORT INFORMATION LEAFLET**
ATP/007/14**AIRCRAFT TYPE: ATP****SUBJECT : RECOMMENDED MINIMUM SPEED IN ICING CONDITIONS****Suggested Operator Distribution** Director of Operations Chief Pilot Head of Training**1. Introduction**

A recent incident has shown that crews may not be fully aware of the recommended minimum speeds in icing conditions provided in the Aircraft Flight Manual (AFM).

2. Discussion

In 1992 an ATP stalled when the crew were using the pitch mode of the autopilot to try and achieve their cleared flight level. The aircraft had accreted ice and approached the stall as the speed reduced to 142 knots. The aircraft subsequently stalled and lost about 4000 feet in altitude. As the aircraft slowed the autopilot had demanded more nose up trim and so when the pilot took control he found it difficult to pitch the nose down as nearly full nose up trim had been applied. Had the AFM recommended minimum speed been maintained there would not have been an incident. From the AFM the minimum speed recommended in icing is the both engines operating en-route climb speed plus 15 knots; as the estimated mass was 22065 kg this speed would have been 157 knots in this case. This report can be accessed on the UK Air Accident Investigation Branch's site as Formal Report 4/92.

A recent incident, currently under investigation, appears to have similar characteristics and, although the investigation is still underway BAE Systems wish to remind crews of the information contained in the AFM and the Manufacturers Operating Manual (MOM) regarding flight in icing conditions, and these are (copied from AFM 003 4.10.13):

It should be noted that the certification basis of the ATP for flight in icing conditions takes credit for both natural stall warning (buffet) and artificial stall warning (stick shake) as means to alert crews that the aircraft is approaching an aerodynamic stall.

DATE OF ORIGINAL ISSUE: 25/11/14**- 1 -**

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Climb, Cruise and Descent

In icing conditions the speed should not be allowed to fall below the both engines operating en-route climb speed of figure 5.09.6 plus 15 knots. It is also recommended that for descent the minimum fuel descent technique of 180 knots IAS be adopted.

Approach and landing

For the approach and landing phase, after experiencing airframe icing or descending to land in icing conditions, 15 knots should be added to the normal speeds and a visual icing check carried out at 1000 feet above runway level.

If no ice is present the approach and threshold speeds can be reduced to the normal values.

If ice is present the increased approach speed should be maintained. In the final stages of the approach the speed should be adjusted to cross the threshold at $V_{AT} (V_{REF})$ plus 15 knots.

If the aircraft crosses the threshold at V_{AT} plus 15 knots the hold off should not be prolonged and the power levers closed slowly so that the touchdown is made at V_{AT} . A nose down pitching moment may be encountered during touchdown, and the scheduled landing distance required should be increased by 25%.

In the event of a go-around in icing conditions 15 knots should be added to all go-around and initial climb speeds. The speed for en-route climbs in this condition should be the both engines operating climb speed of Figure 5.09.6 plus 15 knots.

The both engines operating en-route climb speed is the single engine operating en-route climb speed plus 10 knots and V_{ser} can be read from the speed cards.

3.Recommendation

BAE Systems recommend that Operators remind flight crews of the speeds given in the AFM and MOM. For any queries please contact us at raftops@baesystems.com.

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Tegnforklaring Low Level SIGWX kart Norge



For luftrommet fra SFC-FL150 iht. ICAO Annex 3. For turbulens, ising og skyer gis øverste og nederste grense

Generell informasjon

| | |
|----------|--|
| | Signifikant vær, ICE/TCU/CB (ising, towering cumulus, cumulonimbus) |
| | Signifikant vær, TURB/VA/RC (turbulens, vulkansk aske, radioaktiv sky) |
| | Sikt- og skybasereduksjon: skybase<1000ft og/el sikt<5km. |
| | Markerer trykksenteret |
| L | Markerer lavtrykk |
| H | Markerer høytrykk |
| | Varmfront |
| | Kaldfront |
| | Okklusjon |

Fare

| | |
|--|-------------------------------------|
| | Moderat turbulens (ikke CAT) |
| | Kraftig (SEV) turbulens (ikke CAT). |
| | Fjellbølger |
| | Moderat ising |
| | Kraftig(SEV) ising |
| | Underkjølt nedbør. FZRA/FZDZ |

Vær

| | | | |
|--|-----------------|--|----------------|
| | Hagl (GR) | | Torden |
| | Tåke (FG) | | Iståke (FZFG), |
| | Tåkedis/mist BR | | Snø |
| | Snø | | Regn |
| | Yr | | Regnbyger |
| | Snøbyger | | |

Tilleggsinformasjon

| | |
|--|----------------------------------|
| | Bakkevind ≥ 30 kt (i knop) |
| | 0-isoterm (i hektotof, se Skyer) |
| | Mountain Obscuration |
| | Sjøtemperatur |
| | Vulkansk aske |
| | Radioaktivt utslipp |

Bølger [seastate iht METAR-koden]:

| S' | Betegnelsen | Bølgehøyde i m |
|----|-------------|----------------|
| 3 | Slight | 0.5 - 1.25 |
| 4 | Moderate | 1.25 - 2.5 |
| 5 | Rough | 2.5 - 4 |
| 6 | Very rough | 4 - 6 |
| 7 | High | 6 - 9 |
| 8 | Very high | 9 - 14 |
| 9 | Phenomenal | Over 14 |

Skyer

Skyhøyde i hektotof, feks 010 tilsvarer 1000ft.

CB – Cumulonimbus og

TCU – Towering cumulus angis med:

ISOL(isolated)=Individual CB/TCU with a max spatial coverage less than 50% of the area concerned.

OCNL(occasional)=Well-separated CB/TCU with a max spatial coverage between 50 and 75 per cent of the area concerned.

FRQ(frequent)=Little or no separation between adjacent CB/TCU with a max spatial coverage greater than 75 per cent of the area concerned

EMBD= Embedded in layers of other clouds and cannot be readily recognized.

CU – Cumulus og

STF – Stratiform clouds angis med:

FEW = (few) skymengde 1 - 2 åttedeler

SCT = (scattered) skymengde 3 - 4 åttedeler

BKN = (broken) skymengde 5 - 7 åttedeler

OVC = (overcast) skymengde 8 åttedeler

NSC = Nil significant cloud



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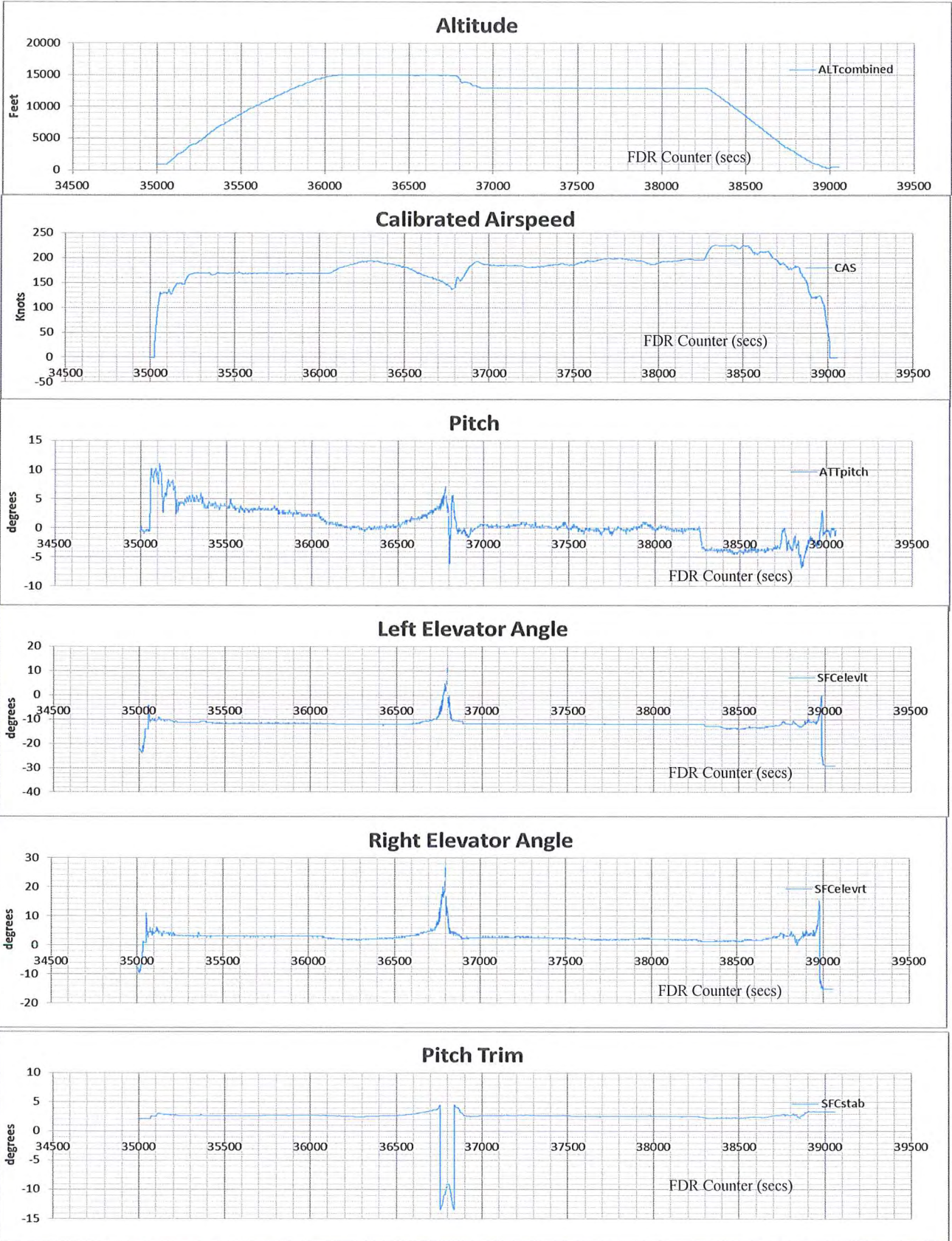
PAGE : 12 of 17

ISSUE DATE : 19/5/2015

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Appendix 2: Full Flight Plots from FDR



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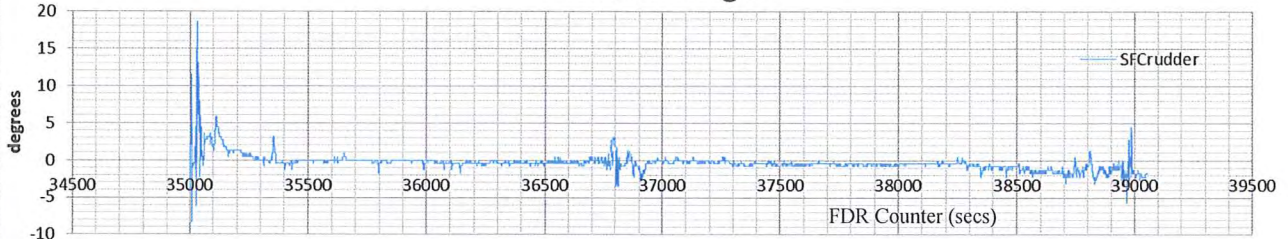
PAGE : 13 of 17

ISSUE DATE : 19/5/2015

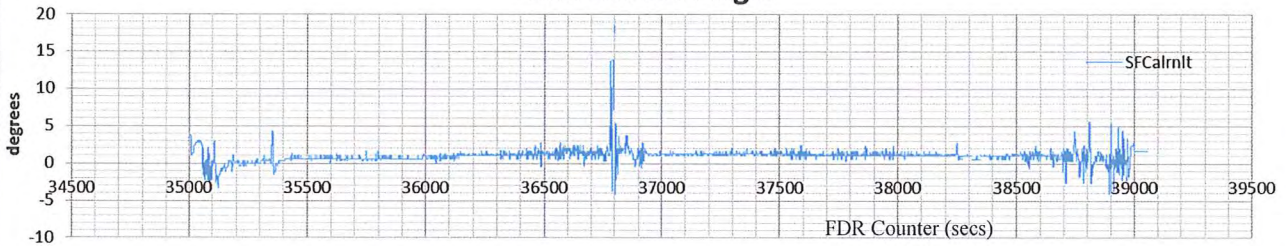
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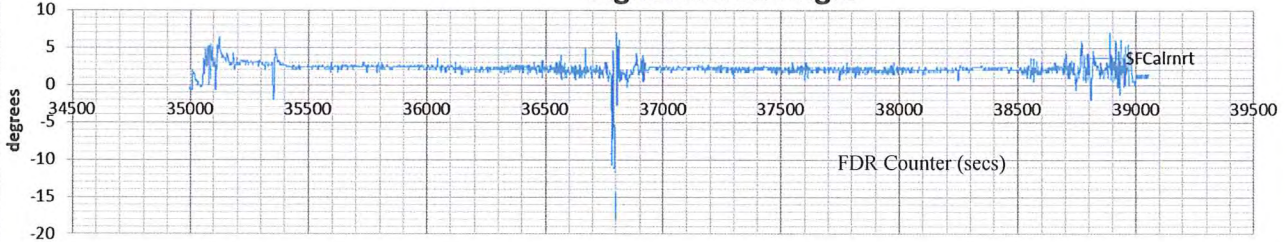
Rudder Angle



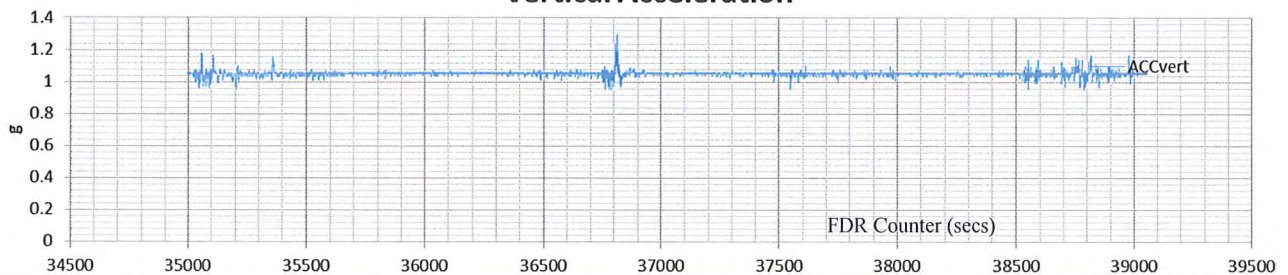
Left Aileron Angle



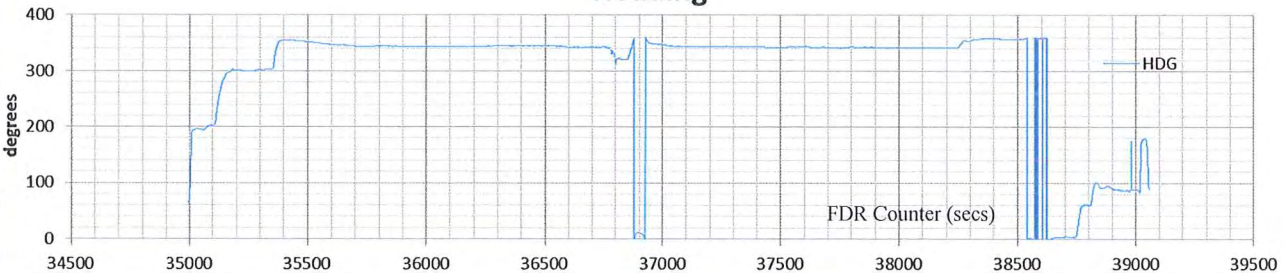
Right Aileron Angle



Vertical Acceleration



Heading





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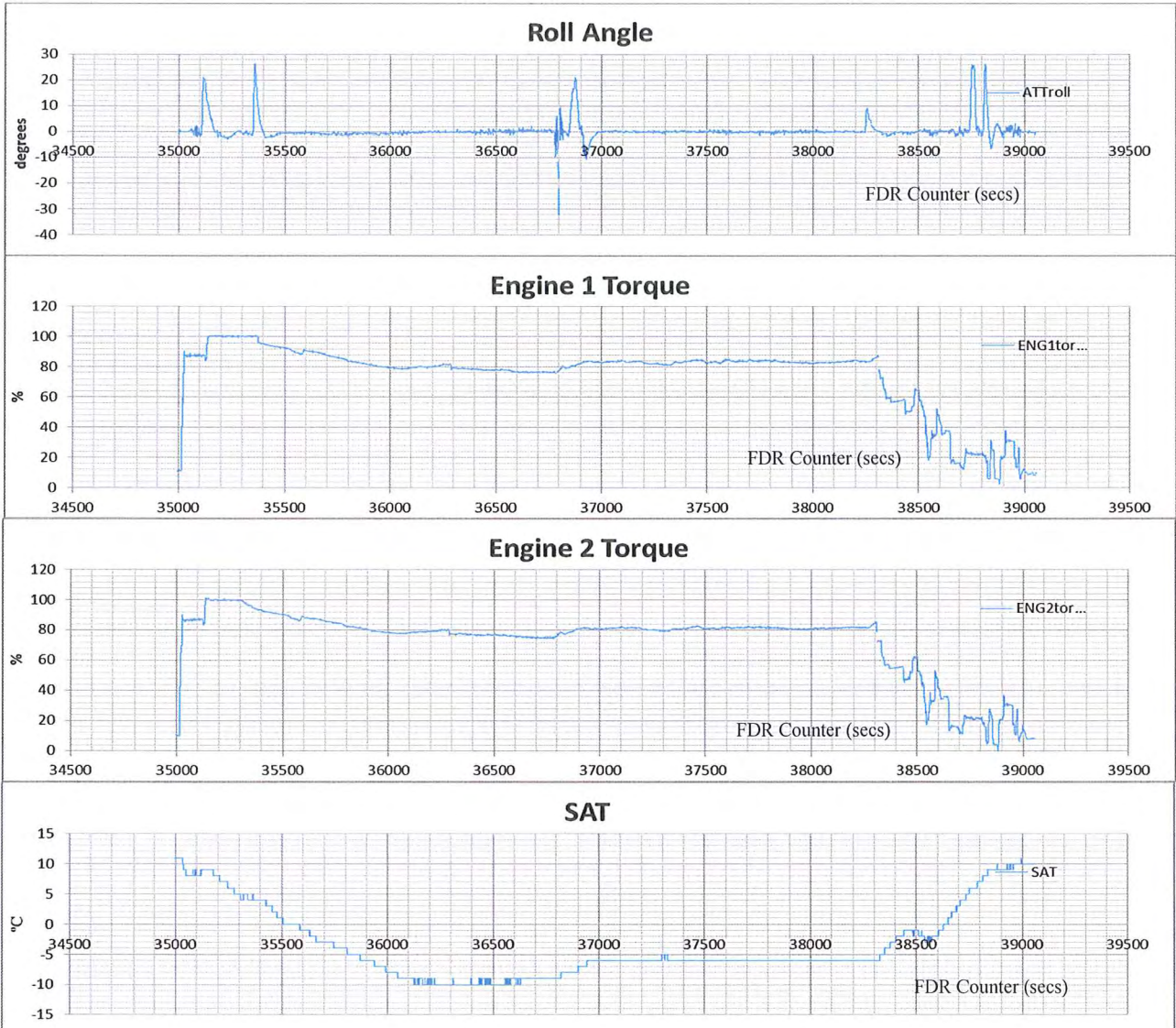
ISSUE : 4

PAGE : 14 of 17

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8/16/06

AC 20-73A

**APPENDIX P. USING ICING RATE TO DOCUMENT ICING EXPOSURES
(CONTINUED)**

Table P-3. Effects on Aircraft²

| Aircraft Effect (AE) | Speed (Note a) | Power (Note b) | Climb (Note c) | Control (Note d) | Vibration (Note e) |
|-----------------------------|------------------------|---------------------------------|---------------------------------|---|--|
| Level 1 | Less than 10 knot loss | Less than 10% increase required | No effect or less than 10% loss | No effect | No effect |
| Level 2 | 10-19 knot loss | 10%-19% increase required | 10%-19% loss rate of climb | No effect | No effect |
| Level 3 | 20-39 knot loss | 20%-39% increase required | 20% or more loss rate of climb | Unusually slow or sensitive response from control input | Controls may have slight vibration |
| Level 4 | 40 or more knot loss | Not able to maintain speed | Not able to climb | Little or no response to control input | May have intense buffet and/or vibration |

Notes:

- a. **SPEED:** Loss of speed because of aircraft icing. This is based on the airspeed before the buildup of ice on the aircraft. This is also before applying added power to keep original airspeed.
- b. **POWER:** Added power required to keep aircraft speed and performance that was being flown before the buildup of ice on the aircraft. Refers to primary power settings, that is, torque, rpm, or manifold pressure.
- c. **CLIMB:** Estimated decay in rate of climb (ROC) due to aircraft icing. For example, 10 percent loss in ROC, 20 percent loss in ROC, or not able to climb at normal climb speed with maximum climb power applied.
- d. **CONTROL:** Effect of icing on the aircraft's response to control inputs.

Levels 1 and 2. No noticeable effect on response to control input.

Level 3. Aircraft is slow to respond to control input. Aircraft may feel sluggish or very sensitive in one or more axes.

Level 4. Little or no response to control input. Controls may feel unusually heavy or unusually light.
- e. **VIBRATION/BUFFET:** May be felt as a general airframe buffet or sensed through the flight controls. It is not intended to refer to unusual propeller vibration (for airplanes so equipped) in icing conditions.

² The Task I-B working group devised this table under the 1997 FAA Aircraft Icing Plan. It was developed for use with pilot reports (PIREPs) for icing conditions, but it is also suitable as a checklist for icing test flights. The table lists four increasingly worsening levels of effects due to icing conditions on three performance factors (speed, power, and climb capability) and two handling aspects (control and vibration). See reference P2.