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AVIATION INVESTIGATION REPORT
A04O0103

AIRCRAFT STALL DURING INSTRUMENT APPROACH

GRANT EXECUTIVE JETS INC.
RAYTHEON B300 (SUPER KING AIR) C-GEJE
TIMMINS, ONTARIO
22 APRIL 2004

Canada

Aviation Investigation Report

Aircraft Stall During Instrument Approach

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Synopsis

The Raytheon B300 (Super King Air) aircraft (registration C-GEJE, serial number FL-385), operated by Grant Executive Jets Inc., was on a repositioning flight from Earlton to Timmins, Ontario, with only the flight crew and an engineer on board. At approximately 0650 eastern daylight time, the flight crew was conducting an instrument landing system (ILS) approach to Runway 03 at Timmins. The autopilot was on and had been in use for the entire flight.

The aircraft was in instrument meteorological conditions and icing conditions were encountered. The de-icing boots were being cycled and other anti-icing equipment had been selected ON. The aircraft was in level flight at 2700 feet above sea level in the vicinity of the final approach fix, with the landing gear down and flaps selected to the approach setting. The aircraft was above the glide slope and the airspeed was approximately 100 knots indicated airspeed (KIAS). The normal approach speed is approximately 125 KIAS. The pilot flying (PF) began to take corrective action just as the aircraft stalled. The PF initiated a stall recovery by applying maximum power and lowering the aircraft's nose. Approximately 850 feet was lost during the stall, and the aircraft reached a minimum height of approximately 800 feet above ground level. Once the aircraft recovered from the stall, the crew flew a missed approach. The crew conducted another ILS approach at an approach airspeed of approximately 140 KIAS and landed without further incident. After landing, the flight crew noted 1 to 1½ inches of ice on the aircraft's winglets and static wicks, and some ice on the engine nacelles and fuselage.

Ce rapport est également disponible en français.

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Appendices

1.0 Factual Information

1.1 History of the Flight

After take-off from Earlton, Ontario, the aircraft climbed to 10 000 feet above sea level (asl)[1] and after approximately 13 minutes in cruise flight, the crew began a descent for the approach into Timmins, Ontario. The aircraft entered cloud at about 5000 to 6000 feet asl and began to encounter light rime icing[2] conditions. The remainder of the descent and approach, including the stall and stall recovery, were conducted in instrument meteorological conditions (IMC). Icing conditions intensified to moderate[3] during the descent and approach. The flaps were selected to the approach setting in descent through approximately 4700 feet asl. The aircraft proceeded directly to RIDIK, the global positioning system (GPS) initial fix for the instrument landing system (ILS) approach, approximately 10 miles from the Timmins Airport (see Appendix A). The autopilot was in flight management system (FMS) mode and navigating to the selected GPS waypoint.

After the aircraft started to accumulate ice during the descent, the captain, who was the pilot flying (PF), selected the wing and horizontal stabilizer de-ice boots ON approximately four times over a period of five minutes. The boots were functioning and were removing the ice from the leading edges of the wings. The flight crew could not determine if ice was being removed from the leading edges of the horizontal stabilizers because the horizontal stabilizers are not visible from the cockpit; however, the green annunciator lights were illuminating, indicating that those boots were inflating and deflating. There was no indication of ice accumulation on the upper surface of the wings. However, it was noted that ice was accumulating on the engine nacelles and on small sections of the inner leading edges of the wings not protected by de-ice boots.

The aircraft levelled at 2700 feet asl in the vicinity of RIDIK. The autopilot was in altitude mode and maintained the selected altitude of 2700 feet asl and in the FMS mode, steering the aircraft toward Sandy Falls, Ontario, the non-directional beacon (NDB) and next GPS waypoint. The ILS frequency was selected and the localizer and glide path were functioning, but the autopilot was not selected to "Approach" mode; therefore, it was not following ILS guidance. Just prior to Sandy Falls, four miles from the threshold of Runway 03, the landing gear was selected down. The aircraft did not capture the glide path, but remained at 2700 feet asl as commanded by the

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1 See Glossary at Appendix F for all abbreviations and acronyms.

2 *Aeronautical Information Publication* (A.I.P. Canada), MET 2.4, defines light icing as "the rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour)." Rime ice is defined as "rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets."

3 A.I.P. Canada, MET 2.4, defines moderate icing as "the rate of accumulation is such that even short encounters become potentially hazardous, and use of deicing/anti-icing equipment or diversion is necessary."

FMS and flown by the autopilot. The airspeed decreased to 98 knots indicated airspeed (KIAS), and, at about 0653 eastern daylight time,[4] the aircraft stalled without any pre-stall warning. The autopilot disengaged about two seconds after the stall. After completing a stall recovery and a missed approach, the flight crew conducted another ILS approach to Runway 03 and landed successfully at 0707.

1.2 Flight Recorders

The aircraft was equipped with an F1000 flight data recorder (FDR) manufactured by L3 Communications. The FDR was shipped to the Transportation Safety Board of Canada (TSB) Engineering Laboratory for download and analysis of the data.

Appendix B is a plot of the data at the time of the stall. The data show that the aircraft was level at 2700 feet asl for approximately two minutes prior to the stall. After level off, the airspeed slowly decreased to about 135 KIAS and then remained relatively constant for the next 30 seconds. The power was then reduced from 48 per cent torque to 20 per cent torque, resulting in a fairly rapid airspeed decrease to 98 KIAS over the next 14 seconds. Power was then increased to about 54 per cent torque and the aircraft began to roll left at a rate of about 5° per second. The airspeed held at 98 KIAS for several seconds, while the roll rate increased to 15° per second and the pitch control position[5] increased to +20° before the aircraft stalled. The autopilot remained engaged until the aircraft stalled.

During the stall, the aircraft rolled left to 85° of bank and pitched to 39° nose down during a 0.25 g pushover. Maximum power was applied and, as the airspeed increased rapidly above 125 KIAS, a 2.4 g pull-up was initiated. The back pressure was momentarily released while the aircraft was in a 30° nose-down attitude, allowing the aircraft to accelerate to 150 KIAS before pulling to 2.7 g. When the aircraft reached level flight, the back pressure was momentarily released before a 1.5 g to 2 g pull-up was initiated, with the aircraft reaching 30° nose up. The maximum allowable g load with flaps extended is 2.0 g. The 30° nose-up attitude was held momentarily before it was adjusted to a normal climb attitude of 10° to 15°.

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4 All times are eastern daylight time (Coordinated Universal Time minus four hours).

5 The elevator position is to be measured as a function of column position. The angle recorded, even though it is derived from the column position, is a measurement of the elevator position.

1.3 Meteorological Information

Prior to departing Earlton, the flight crew checked the en route and destination weather. There was no icing forecast in the graphic area forecast or the terminal aerodrome forecast (TAF) for Timmins. The hourly aviation routine weather reports (METARs) for Timmins and other nearby airports were not reporting any freezing precipitation or icing conditions. No pilot reports had been issued advising of icing conditions.

The Graphic Area Forecasts for icing, turbulence and freezing level, issued at 0142 and valid for 0200 and 0800 on 22 April 2004, depicted freezing levels from the surface to 5000 feet. This indicated the possibility of warm air aloft, which when combined with below-freezing temperatures at the surface (as reported in the METARs), may be conducive to airborne icing conditions. Additional meteorological data are included in Appendix C.

1.4 Company Information

Grant Executive Jets Inc. has an approved Air Operator Certificate (AOC) to operate three aircraft, two Falcons and one Raytheon B300 Super King Air (also known as King Air 350). At the time of the occurrence, the company had recently acquired the King Air and it was being operated under Canadian Aviation Regulation (CAR) 604, with a Canadian Business Aircraft Association Private Operator Certificate. Grant Executive Jets Inc. had intended to operate the King Air under CAR 704 and applied to have the King Air added to its AOC as a 704 aircraft. On 24 June 2004, the aircraft was placed on the AOC under CAR 703 because the company did not have a qualified line indoctrination training captain, as required under CAR 704.

1.5 Personnel Information

The captain held a valid Airline Transport Pilot Licence (ATPL) and was certified and qualified for the flight in accordance with existing regulations. He had accumulated 3500 hours of multi-engine experience, 60 hours of which was on the King Air 350. On 15 December 2003, he completed a surface contamination and airborne icing course. He completed the BE-300 (King Air 350) initial pilot course at Flight Safety International (FSI) on 16 January 2004. This included 28.5 hours of flight simulator, 14.5 hours of which were as the pilot not flying (PNF). One item on the 38-hour ground-training curriculum was crew resource management (CRM). He also completed the BE-300 Collins Proline[6] Differences Course at FSI, including 4 hours of flight simulator on 31 March 2004.

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6 Proline refers to the "glass" cockpit avionics configuration of C-GEJE and other BE-300 and BE-350 aircraft.

The first officer also held a valid ATPL and was certified and qualified for the flight in accordance with existing regulations. Although he had almost 400 hours on type, he had not flown the BE-300 for about three years. He completed the BE-350 Proline pilot initial course at FSI on 14 April 2004. This included 14.3 hours of flight simulator, all of which was conducted as the PF. He also received limited CRM training as part of the ground-training curriculum at FSI. On 15 April 2004, he completed a surface contamination and airborne icing course. The occurrence flight was his first flight in C-GEJE since completing the training at FSI.

1.6 Flight Crew Preparation and Actions

Preparations by the flight crew for the flight to Timmins were in keeping with normal company practices. The anticipated weather was IMC, but the ceiling and visibility were not expected to pose a problem or cause any delay in landing at Timmins. The captain briefed the approach in accordance with standard operating procedures (SOPs)[7] but did not address issues such as minimum airspeed in icing conditions, the use of autopilot and flaps in icing conditions, or what to do in the event severe icing is encountered. He planned to fly a normal approach speed of 125 KIAS. Chapter 5, Section 5.4, of the SOPs details the approach briefing that must be completed before every approach. The format for the approach briefing is the commonly used AMORTS.[8] Under supplementary remarks, the SOPs list several items, including ice protection procedures and any special consideration or other relevant remarks.

During the descent and approach, the flight crew never perceived the icing conditions to be severe[9]; however, conditions were described as moderate mixed[10] icing. It was noted there was an abnormal accumulation of ice on certain parts of the engine nacelles, and toward the final approach segment, the icing was bordering on heavy.

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7 Grant Executive Jets Inc., King Air 350 SOPs, 04 January 2004.

8 AMORTS – Approach, Minima, Overshoot, Radios, Timing, Speeds and Supplementary Remarks

9 A.I.P. Canada, MET 2.4, defines severe icing as “the rate of accumulation is such that de-icing or anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.”

10 A.I.P. Canada, MET 2.4, defines clear ice as “glossy, clear, or translucent ice formed by the relatively slow freezing of large supercooled water droplets.” A.I.P. Canada does not define mixed ice; however, Transport Canada’s Commercial and Business Aviation Advisory Circular No. 0130R, “Airborne Icing Training Guidance Material,” 15 June 1999, describes mixed ice as “a mixture of clear and rime icing, as the term implies. It has the characteristics of both, can form rapidly and, since rime particles are embedded in clear ice, can build a very rough accumulation.”

1.7 *Aircraft Information*

1.7.1 *General*

Records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures. The weight and centre of gravity were within the prescribed limits, and the aircraft was certified for flight in known icing conditions. Compliance with ice protection was demonstrated in accordance with Federal Aviation Regulation 23.1419, when ice protection equipment is installed in accordance with the equipment list.

1.7.2 *Aircraft Ice Protection Systems*

The aircraft is equipped with electric windshield heat, an electric propeller de-ice system, and a pneumatic surface de-icing system that removes ice accumulation from the leading edges of the wings and horizontal stabilizers by alternately inflating and deflating the de-ice boots. All ice protection systems were serviceable and were functioning as designed. A three-position switch on the pilot's right subpanel, placarded Surface Deice – Single – Off – Manual, controls the pneumatic surface de-icing operation. The captain was operating the system in "Single," which, when selected, opens a distributor valve to inflate the wing boots. After approximately six seconds, the wing boots are deflated and the horizontal stabilizer boots are inflated for four seconds and then deflated, completing the cycle.

1.7.3 *Aircraft Stall Warning*

The stall warning system on the King Air 350 uses information from the lift transducer vane located on the leading edge of the left wing. The vane responds to the change in lift coefficient of the wing with a change in angle of attack and transmits a signal output to the lift computer. The computer processes signals from the lift transducer, flap position switch, landing gear squat switch and cockpit test switch. When the wing is not contaminated by ice accumulation, the system provides precise pre-stall warning by activating an aural warning when specific lift coefficients are reached. The system was not designed to account for aerodynamic degradation or adjust its warning to compensate for the reduced stall warning margin caused by ice accumulation. During certification trials with artificial ice shapes, it was determined that the aircraft demonstrated adequate pre-stall buffet. Ice protection for the stall warning lift transducer is provided by heating elements in the vane and mounting plate. The stall warning system was checked and found serviceable after the occurrence flight.

The manufacturer's aircraft flight manual (AFM),[11] Section 5, Performance, indicates that the stall speed at the maximum weight with approach flaps and idle power is 88 KIAS. The aircraft weight at the time of the occurrence was estimated at 13 000 pounds, or approximately 2000 pounds below maximum gross weight. The AFM–calculated stall speed at this weight with flaps approach and idle power is 84 KIAS. Due to the distortion of the wing airfoil, stalling airspeeds increase as a result of ice accumulation. A note accompanying the stall speed charts in the AFM states that, for operations with ice accumulation present, stall speeds may increase by nine knots. Stall warning devices may not be accurate with ice on the aircraft; therefore, when ice is present, the devices cannot be relied on.

1.7.4 Aircraft Operation in Icing Conditions

When there is ice accumulation on the aircraft, it is necessary to maintain a comfortable margin of airspeed above the normal stall speed. Section 2 of the AFM describes icing limitations. It states that the minimum airspeed for sustained icing flight is 140 KIAS. Section 2 also describes limitations when encountering severe icing conditions. Airworthiness Directive (AD) 98-04-24,[12] *Operating in Severe Icing Conditions,* required that specific text be incorporated into the AFM. Details of this text are provided in Appendix D.

1.8 Flight Crew Training

1.8.1 Flight Simulator Training

The flight crew's simulator training at FSI included approach to the stall and stall recovery after the first indication of a stall. In-flight icing training at FSI consisted of limited exposure to icing conditions in the simulator during a normal departure sequence.

1.8.2 Crew Resource Management Training

CRM training is a mandatory requirement for air operators under the *Canadian Aviation Regulations* (CARs), Part VII, Standard 725[13] (Airline Operations), but not for Standard 724 (Commuter Operations). Commuter operations often involve the use of a two-person flight crew. Grant Executive Jets Inc. operates the Raytheon B300 using a crew concept, although the aircraft is certified for single-pilot operation.

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11 Raytheon Aircraft Beech Super King Air 350 and 350C (models B300 and B300C), Pilot's Operating Handbook, and the Federal Aviation Administration (FAA)–approved aircraft flight manual.

12 FAA, AD 98-04-24, *Operating in Severe Icing Conditions*, applicable to various Raytheon Aircraft Company models, including B300 Series Airplanes, effective 13 March 1998.

13 CARs, Part VII, Commercial Air Services, Standard 725.124 (39).

1.8.3 Training in the Duties of Pilot Not Flying

The initial pilot course at FSI does not include PNF roles and responsibilities in either the ground-training curriculum or the flight simulator sessions. Normally, trainees get bonus time in the right seat of the simulator, acting as the PNF for other trainees. When the first officer completed the BE-350 Proline pilot initial course, he did not act as the PNF during any of the simulator training because he was the only person on the course. The occurrence flight, his first flight in the aircraft, was the first time he acted as a PNF in the BE-350. He was familiar with PNF duties but had no previous opportunity to practise those duties. PNF duties are addressed throughout the company SOPs. Chapter 5 provides detailed guidance on the arrival phase of flight and includes specific duties for both the PF and the PNF. For example, Section 5.4, Approach Briefing, states (in part):

> During the actual approach, the flight crew is to compare the procedure as it is flown to what was briefed. Should a deviation become apparent to the PNF, it shall be brought to the attention of the PF.

Section 5.10, Approach – General, contains specific instructions regarding standard approach calls and clearly describes both PNF and PF responsibilities. For example, to reduce the likelihood of overshooting a desired track or vertical path during the intermediate/final approach phase, the PNF is instructed to warn the PF when approaching a track or ILS glide path.

1.9 Regulatory Guidance

1.9.1 Aircraft Stall Characteristics

CARs, Part V, Airworthiness Standards 523.207, Stall Warning, applicable to commuter category aeroplanes, states that there must be a clear and distinctive stall warning, with flaps and landing gear in any normal position, in straight and turning flight. The warning must be provided to the pilot with sufficient margin to prevent inadvertent stalling. Airworthiness Manual Advisory (AMA) 523/4A, dated 29 October 1999, provides guidance material for acceptable means of demonstrating compliance with the flight characteristics requirements of Chapter 523, for the approval of commuter category aeroplanes for flight in icing conditions. The AMA states “this advisory material is presently the subject of international harmonization, and this AMA is issued for use during type approval programs. When harmonization is completed, this AMA will be amended or revoked and the corresponding harmonized advisory material adopted.” The procedures section of the AMA notes that approval of flight in icing conditions requires compliance with the following (in part):

> Flight characteristics with ice accumulations appropriate to 45 minutes in Chapter 525, Appendix C, conditions (3-inch maximum) on the unprotected surfaces and normally expected ice on the protected surfaces prior to anti-icing system operation or during system operation.

The procedures section also lists items that have been found to be significant in past certification programs. Some of the items on the list include the following:

- the demonstration of adequate stall warning before stall characteristics; and
- the establishment of any systems limitations/procedures when operating in icing conditions (e.g. autopilot).

While certification trials with artificial ice shapes determined that the aircraft demonstrated adequate pre-stall buffet, the flight crew of C-GEJE received no pre-stall warning horn and no noticeable buffet until in the stall. The aircraft stalled at 98 KIAS, well above the calculated stall speed of 84 KIAS with flaps approach and idle power, and significantly above 93 KIAS, the estimated stall speed after adding the incremental 9 knots for ice accumulation.

1.9.2 Pneumatic De-ice Boot Operating Procedures

The Raytheon B300 AFM recommended procedure for the most effective de-icing operation is to allow at least 0.5 inch of ice to form before boot activation. This procedure is aimed at maximizing the effectiveness of the pneumatic de-icing equipment by reducing the amount of residual ice and the possibility of ice bridging. Ice bridging, in which ice forms above the furthest extension of the boot tubes, occurred in older generation boots that were not powerful enough to completely shed ice. Modern de-ice boots, such as those installed on C-GEJE, are characterized by short-segmented, small-diameter tubes, which are operated at relatively high pressures and have relatively fast inflation and deflation cycles. Research since the mid-1990s found that modern de-icing boots are effective in both shedding ice and completely preventing ice bridging. Ice bridging is prevented because residual ice that is not shed after the initial boot cycle continues to increase in thickness and sheds during subsequent cycles.

Transport Canada (TC) Commercial and Business Aviation issued Advisory Circular No. 0130R on 15 June 1999 to inform recipients of revisions to the airborne icing training guidance material. The guidance material was revised to include new information resulting from investigations into recent accidents in which airborne icing was determined to be a contributing factor. Air operators were informed that they were required to amend their training programs to include the new information before 01 October 1999. The section "Operational Use of Pneumatic De-Icing Boots" states:

> Pilots of aeroplanes fitted with pneumatic de-icing boots will find direction on operational use of the boots in the AFM. In most cases the AFM will direct pilots to delay operation of the boots, either in the manual mode or automatic mode (if fitted), until ¼ to 1 inch of ice has built up on the leading edge. As mentioned above, this guidance is almost universally included to prevent the occurrence of ice bridging. In its report on the fatal accident of a Comair EMB120 in January 1997, the National Transportation Safety Board (NTSB) of the United States concluded that a small amount of rough ice had built up on the wing as the aircraft slowed to configure for an approach, but this small amount was, however, sufficient to cause the aircraft to stall without warning as airspeed decreased. As a result, the NTSB recommends that, for modern turboprop aeroplanes:
>
> "… leading edge deicing boots should be activated as soon as the aeroplane enters icing conditions because ice bridging is not a concern in such aeroplanes and thin amounts of rough ice can be extremely hazardous."
>
> Unless specifically prohibited by the AFM, it is recommended that pilots of turbine-powered aeroplanes equipped with pneumatic de-icing boots with an automatic cycle, select the boots on automatic as soon as the aeroplane enters icing conditions. The boots should be left on until the aeroplane has departed the icing conditions. If the automatic boots have a FAST/SLOW option, the FAST option should be selected for moderate and severe icing conditions.

The TC Advisory Circular made no mention of the operation of pneumatic de-ice boots on aircraft that do not have an automatic cycle, such as C-GEJE.

1.9.3 Use of Autopilot in Icing Conditions

Autopilot use in icing conditions can mask the effects of airframe icing and possibly contribute to a loss of control. The autopilot may mask heavy control forces or trim the aircraft up to the point of stall and then disconnect unexpectedly with the aircraft on the brink of the stall. TC Advisory Circular 0130R discusses monitoring the autopilot in icing conditions and states (in part) the following:

> It is highly recommended that pilots disengage the autopilot and hand fly the aircraft when operating in icing conditions. If this is not desirable for safety reasons, such as cockpit workload or single-pilot operations, pilots should monitor the autopilot closely. This can be accomplished by frequently disengaging the autopilot while holding the control wheel

> firmly. The pilot should then be able to feel any trim changes and be better able to assess the effect of any ice accumulation on the performance of the aeroplane.

Section 1.21 of the company SOPs, on the use of the autopilot, states the following:

> Use of Autopilot: Crews are encouraged to make the maximum use of the aircraft autopilots. Whenever possible 'Coupled' approaches should be carried out subject to any restrictions in the AFM. An "Autopilot ON/OFF" call will be made by the PF and acknowledged by the PNF.

1.10 Additional Information

1.10.1 Aircraft Low Airspeed Warning

Numerous accidents and incidents have occurred in which commercial flight crews failed to maintain adequate airspeed. The TSB and its predecessor, the Canadian Aviation Safety Board, have investigated at least eight accidents involving flight in icing conditions. In some cases, the failure to maintain airspeed resulted in catastrophic events such as loss of control and impact with terrain. The NTSB and other national accident investigation agencies have also investigated numerous events in which stall or failure to maintain airspeed was cited as a causal or contributing factor. Three such occurrences, in which safety issues similar to those involved in this occurrence were identified, are described in Appendix E.

Past studies[14] have noted that, when flight crews are monitoring automated systems, they may not be aware of the aircraft's energy state, particularly when approaching or trending toward a low-energy state. The studies indicate that flight crews need to be alerted before the aircraft reaches a potentially hazardous low-energy state.

Advanced avionics capabilities may make it possible to develop and install low airspeed alert systems in many modern aircraft types. A low airspeed alert system has been developed for Embraer 120 aircraft, and installation of the system was mandated by FAA AD 2001-20-17. The system is designed to alert flight crews to low airspeed conditions in certain configurations and in icing conditions. Several avionics manufacturers offer low airspeed alert devices associated with approach and manoeuvring speeds, for use in less sophisticated general aviation aircraft. It may be feasible to develop low airspeed alert systems for most aeroplane types.

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14 Human Factors Team, FAA, *The Interfaces Between Flight Crews and Modern Flight Deck Systems*, 1996.

2.0 Analysis

2.1 General

Although the flight crew members were certified and qualified for the flight, they lacked training in specific areas. Similarly, although the aircraft was certified for flight in known icing conditions, inadequate stall warning and low speed warning contributed to the occurrence. This analysis discusses flight crew actions and decision making, the need for more comprehensive flight crew training, and the need for more effective aircraft stall warning and low speed warning.

2.2 Flight Crew Actions and Decision Making

When the flight entered cloud during the descent into Timmins and began to pick up light rime ice, which increased to moderate mixed ice, the flight crew was entering a critical, high-workload phase of flight. The aircraft was approximately 2½ minutes from the initial fix for the approach, and ice was accumulating in unusual areas, such as on the engine nacelles. Despite the ice accumulation, no consideration was given to altering the approach airspeed or aircraft configuration, or the use of autopilot. The crew was aware that the minimum airspeed in sustained icing conditions is 140 KIAS, but did not consider that airspeed restriction applicable during the final approach phase of flight and, therefore, planned to fly the approach at a normal approach speed of 125 KIAS.

The crew's focus was on the ice accumulating on the airframe and wing leading edges, rather than on monitoring the approach and aircraft performance. As a result, the crew members did not select the autopilot approach mode to "On," and the autopilot remained in FMS and altitude-hold mode. Although the ILS frequency was selected, and localizer and glide slope guidance was available, the crew did not notice that the autopilot was not selected to follow that guidance. When the landing gear was lowered just prior to the Sandy Falls NDB, engine power was reduced in anticipation of the aircraft descending on the glide slope. Neither the PF nor the PNF was monitoring the flight instruments, and neither noted that the aircraft remained level at 2700 feet asl and the airspeed decreased. A lack of CRM and division of cockpit duties during this high-workload portion of the flight resulted in critical flight parameters not being monitored.

Although neither flight crew member characterized the icing conditions as severe, it was noted that ice was accumulating in unusual areas, such as on the engine nacelles. According to the limitations section of the AFM, this is one of several visual cues that indicates severe icing. The AFM also states that use of the autopilot is prohibited when any of the specified visual cues exist. Both pilots, having recently completed surface-contamination and airborne-icing courses, should have been aware of the material in TC Advisory Circular No. 0130R, that states in part, "it is highly recommended that pilots disengage the autopilot and hand fly the aircraft when operating in icing conditions."

In this occurrence, the autopilot functioned as designed; it maintained the selected altitude and trimmed the aircraft to full nose up as the airspeed decreased to 98 KIAS. With the autopilot engaged, the increasing angle of attack and nose-up trim were not noticed by the flight crew until it was too late to avoid the stall. Hand flying the aircraft likely would have contributed to the pilots' ability to understand their situation and detect the decreasing airspeed situation early enough to take corrective action. Since the flight crew did not characterize the icing conditions as severe, the decision to fly the approach with autopilot engaged was not contrary to the AFM. In fact, the use of the autopilot was in accordance with company SOPs.

2.3 Flight Crew Training

2.3.1 Flight Simulator Training

Training in stall recognition and recovery, often conducted exclusively in the simulator, generally involves initiating recovery at the first indication of stall. The first indication is normally the artificial stall warning, which activates at least five knots above the stall. During this type of stall training, pilots do not see the full stall characteristics of the aircraft, such as any noticeable buffet or wing rock, or a tendency for a wing to drop. With this type of training, pilots may never have an opportunity to practise recovery from a full stall.

Although flight crews receive mandatory ground training in "airborne icing," the ability to train in a simulator for flight in actual icing conditions is limited. The changes to stall characteristics with ice accumulation typically are not duplicated in training, including the increase in stall speed and the onset of the stall before the activation of the artificial stall warning. Also, it is difficult to account for changes to normal stall symptoms such as buffet or an increased tendency for a wing drop. Without the benefit of having experienced these stall symptoms, pilots can be ill-prepared to recognize contaminated wing stall symptoms. Also, they may not be aware that an ice-induced stall will require a more aggressive recovery technique in which the nose is lowered more aggressively (altitude permitting) to reduce the angle of attack and trade altitude for airspeed.

The stall warning horn in C-GEJE did not activate either prior to or during the stall. The flight crew did not notice any buffet or other symptoms of an approaching stall. When the stall occurred, the PF was aggressive in lowering the aircraft's nose to reduce the angle of attack and rapidly gain airspeed. The resulting altitude loss of 850 feet was not uncommon for a recovery from a full stall; however, the altitude loss would have been lessened if the PF had not momentarily released back pressure when the aircraft was in a 30° nose-down attitude. Comprehensive stall training in a controlled environment may help the flight crew to recognize stall symptoms such as buffet.

Most advanced simulators can be programmed with available flight test data to simulate aircraft pre-stall and post-stall behaviour. The TSB recognizes that simulator training is expensive and that course designers must balance training exercises with the probability that flight crews may need to employ the techniques learned in the simulator. Simulation of in-flight icing scenarios that have resulted in accidents or serious stall/upset events could help prepare flight crews to deal with actual icing conditions and give them a better understanding of the risks involved with flight in icing conditions. Emphasis on operational changes, such as cycling pneumatic de-ice boots early and often, manually flying the aircraft when in icing conditions, keeping airspeed at or above ice-penetration speeds, and exiting icing conditions as quickly as possible could mitigate stalls in icing conditions.

2.3.2 Crew Resource Management Training

Effective CRM is essential to ensure a safe flight operation. Other than the CRM training the crew members received during their aircraft type training at FSI, neither pilot had any recent, formal CRM course. The CRM training provided by FSI was only one of many subjects covered in the ground school portion of the course. This non-exclusive type of CRM training can be a worthwhile refresher, but it does not serve as a substitute for a comprehensive, dedicated CRM course. Although some aspects of CRM may be covered under CARs, Part VII, Standard 724.115, Training Programs, a dedicated CRM course is not mandatory. Unless 704 operators voluntarily include formal CRM training in their training plans, flight crews will only be incidental to CRM training.

The flight crew did not discuss appropriate procedures for conducting the approach in icing conditions, either prior to or during the approach. There was no discussion about aircraft limitations, the use of the autopilot in icing conditions, or the possible visual signs of severe icing. There was ineffective workload management during a heavy workload phase of flight, which resulted in critical flight parameters not being monitored by either crew member. Overall, the flight crew did not employ effective CRM during the approach.

2.3.3 Training in the Duties of Pilot Not Flying

The PNF is an integral part of a two-person flight crew with important cockpit duties. Specific training in the role of PNF is important to prepare the PNF to successfully carry out those duties. However, there is no regulatory requirement to provide training in PNF duties, or to evaluate a pilot’s performance in the PNF role. The PNF had no opportunity to act as PNF during his initial type training at FSI. This likely contributed to an ineffective division of duties during the approach. Rather than monitoring the primary flight instruments and advising the

PF of deviations from the intended airspeed and flight path as soon as they occurred, the PNF likely assumed that the PF was monitoring the primary flight instruments and the autopilot's performance. He then became distracted with other PNF duties such as lowering the landing gear, checking that it was down and locked, and checking the ice accumulation on the airframe and wing leading edges.

2.4 *Aircraft Stall Warning*

The stall warning systems required by CARs, Part V, Airworthiness Standards 523.207, are intended to provide flight crews with adequate warning of proximity to a stall. However, when an aircraft is operating in icing conditions in which the stall angle of attack may be markedly reduced, the systems often do not provide adequate warning. In this occurrence, the aircraft stalled without any pre-stall warning and at a higher airspeed than would be expected with an uncontaminated wing. The stall warning system did not provide a warning to the pilots because it was not designed to account for aerodynamic degradation with ice contamination on the wings, or to adjust its warning to compensate for the reduced stall angle of attack. This unsafe condition is not unique to the King Air 350 and exists on numerous other turboprop aircraft.

2.5 *Aircraft Low Airspeed Warning*

This occurrence, and others, indicate that reliance on flight crew vigilance and existing stall warnings is not always sufficient in preventing hazardous low airspeed situations. Furthermore, the onset of flight at unsafe low airspeeds is not unique to flights using an autopilot, or operations in icing conditions. Low airspeed alert systems are designed to alert the flight crew members to the aircraft's decaying airspeed in time for them to take corrective action and avoid the stall. A low airspeed alert, associated with the minimum operationally acceptable airspeed for a particular phase of flight, would help flight crews maintain airspeed awareness in much the same way that altitude alert systems help flight crews maintain altitude awareness. The number of accidents and incidents involving flight crew failure to maintain adequate airspeed would be substantially reduced if low airspeed alert systems were developed and made mandatory.

The following TSB Engineering Laboratory report was completed:

LP 055/2004 – FDR Analysis

This report is available from the Transportation Safety Board of Canada upon request.

3.0 Conclusions

3.1 Findings as to Causes and Contributing Factors

1. During the approach, the flight crew did not monitor the airspeed, and it decreased until the aircraft stalled.

2. The aircraft stalled at a higher-than-normal airspeed for the configuration because it had accumulated ice on critical flying surfaces during the approach.

3. The aircraft stall warning system did not activate because it was not designed to account for the aerodynamic degradation from the ice accumulation, or to adjust its warning to compensate for the reduced stall angle of attack caused by the ice.

4. During the approach, the autopilot was not changed from the altitude-hold mode to the approach mode; therefore, the aircraft did not intercept the glide slope. As a result, when the pilot flying decreased the engine power in anticipation of glide slope interception, the aircraft decelerated in level flight.

5. Because the aircraft was on autopilot, the flight crew members did not notice any indications of impending stall, nor did they notice any signs of decreasing airspeed such as increasing nose-up attitude, trim changes, increasing angle of attack, and less responsive controls.

6. The flight crew did not consider that the 140-knot minimum airspeed in sustained icing conditions applied to all phases of flight, including the approach. The crew, therefore, planned to fly the approach at a normal approach airspeed of 125 KIAS (knots indicated airspeed).

7. Because the flight crew members did not characterize the icing conditions as severe, they did not follow the precautions specified in the aircraft flight manual for flight in severe icing conditions, such as requesting priority handling from air traffic control to exit the icing conditions, or disengaging the autopilot.

8. The flight crew did not practise effective crew resource management (CRM) during the approach: there was no discussion of appropriate procedures for conducting the approach in icing conditions, and critical flight parameters were not effectively monitored by either crew member.

3.2 *Findings as to Risk*

1. Other than the CRM training both flight crew members received during their aircraft-type training at Flight Safety International (FSI), neither pilot had any recent, formal CRM training. Since the flight was conducted under Canadian Aviation Regulation (CAR) 604, specific CRM training was not required, nor is it required for CAR 704 operations.

2. The first officer, who was the pilot not flying (PNF), had no specific training in the role and duties of the PNF during his initial type training at FSI, and there is not a regulatory requirement to receive this type of training.

3. Typically, flight crews receive only limited training in stall recognition and recovery, where recovery is initiated at the first indication of a stall. Such training does not allow pilots to become familiar with natural stall symptoms, such as buffet, or allow for practise in recovering from a full aerodynamic stall.

4. Typically, the training of flight crews for flight in icing conditions is limited to familiarization with anti-icing and de-icing equipment and simulator training, while the opportunity to train for flight in actual icing conditions is limited.

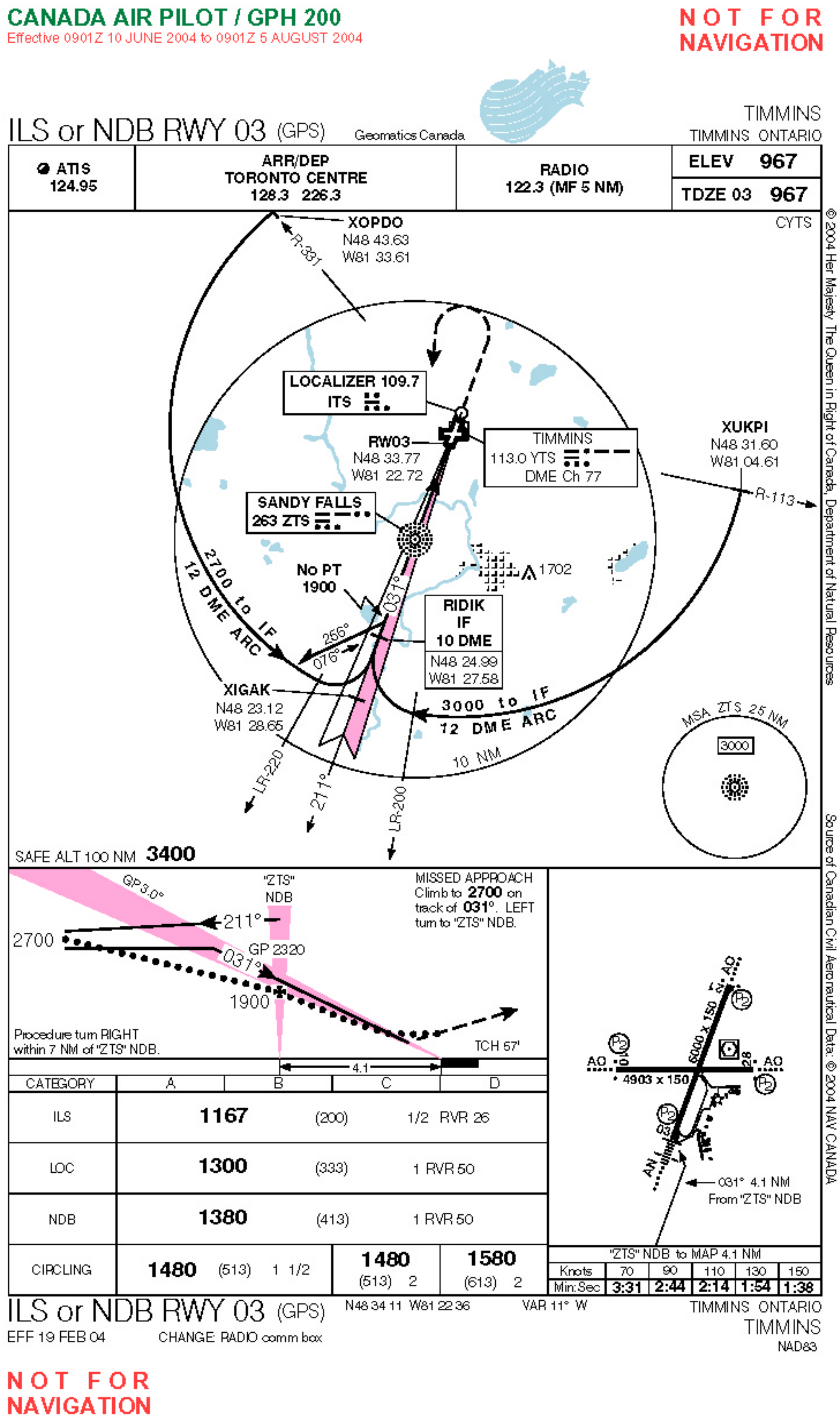
5. Inappropriate guidance on pneumatic de-ice boot operating procedures can lead to de-ice boots being used in a less-than-optimal manner.

6. Inconsistent guidance on autopilot use in icing conditions can lead to its use in conditions where hand flying would provide an increased opportunity to recognize an imminent stall.

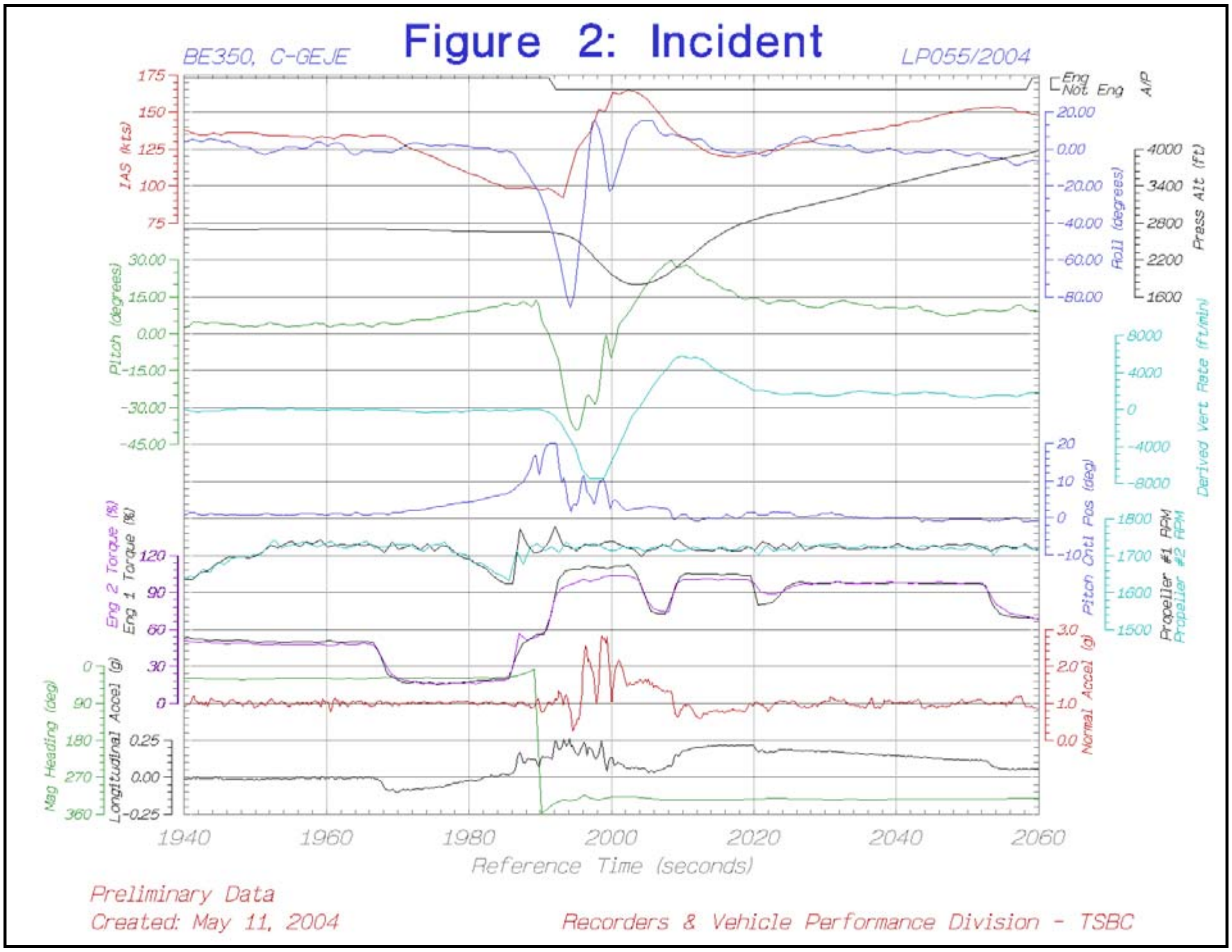
7. Typically, aircraft such as the Raytheon B300 are not equipped with a low airspeed alerting system.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 02 November 2005.

Appendix A – ILS or NDB Runway 03 (GPS) Timmins



Appendix B – Flight Data Recorder Plot



Appendix C – Meteorological Information

The 0600 Timmins aviation routine weather report (METAR), issued approximately 20 minutes prior to the flight's departure from Earlton, was as follows:

> Wind 330°T at 8 gusting to 18 knots, visibility 10 statute miles (sm) in light snow, a broken cloud layer at 500 feet agl, and an overcast layer at 1500 feet agl; the temperature was -4°C and the dew point was -7°C; the ceiling was described as ragged.

The terminal aerodrome forecast (TAF) for Timmins, issued on 22 April 2004 at 0129, and valid from 0200 to 1400, was as follows:

> Wind 330°T at 10 knots, visibility 6 sm, scattered clouds at 400 feet agl, an overcast cloud layer at 3000 feet agl; a temporary condition between 0200 and 0600 of 3 sm in light snow showers and an overcast cloud layer at 400 feet agl. After 0600, scattered clouds at 800 feet agl, a broken cloud layer at 2500 feet agl; a temporary condition between 0600 and 1100 of an overcast cloud layer at 800 feet agl.

An amended TAF issued at 0604 and valid for the period 0600 to 1400, was as follows:

> Wind 330°T at 12 gusting to 22 knots, visibility 6 sm, scattered clouds at 500 feet agl, an overcast cloud layer at 1500 feet agl; a temporary condition between 0600 and 1100 of overcast cloud at 500 feet agl.

Appendix D – Aircraft Operation in Icing Conditions

Airworthiness Directive (AD) 98-04-24, *Operating in Severe Icing Conditions,* required that text be added to the aircraft flight manual (AFM). The following are excerpts of text that was added to the AFM, Section 2, Limitations:

> WARNING Severe icing may result from environmental conditions outside of those for which the airplane is certificated. Flight in freezing rain, freezing drizzle, or mixed icing conditions (supercooled liquid water and ice crystals) may result in ice build-up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. This ice may not be shed using the ice protection systems, and may seriously degrade the performance and controllability of the airplane.
>
> 1. During flight, severe icing conditions that exceed those for which the airplane is certificated shall be determined by the following visual cues. If one or more of these visual cues exists, immediately request priority handling from Air Traffic Control to facilitate a route or an altitude change to exit the icing conditions.
>
>   a. Unusually extensive ice accumulation on the airframe and windshield in areas not normally observed to collect ice.
>
>   b. Accumulation of ice on the upper surface of the wing, aft of the protected area.
>
>   c. Accumulation of ice on the engine nacelles and propeller spinners farther aft than normally observed.
>
> 2. Since the autopilot, when installed and operating, may mask tactile cues that indicate adverse changes in handling characteristics, use of the autopilot is prohibited when any of the visual cues specified above exist, or when unusual lateral trim requirements or autopilot trim warnings are encountered while the airplane is in icing conditions.

A portion of AD 98-04-24 is contained in the AFM, Section 3A, Abnormal Procedures, "Severe Icing Conditions." The text reads as follows (in part):

> The following weather conditions may be conducive to severe in-flight icing:
>
> - visible rain at temperatures below 0°C ambient air temperature; and,
> - droplets that splash or splatter on impact at temperatures below 0°C ambient air temperature.
>
> Procedures for exiting the severe icing environment:
>
> If the visual cues specified in the Limitations Section for identifying severe icing conditions are observed, accomplish the following:
>
> 1. Immediately request priority handling from ATC …
> 2. Avoid abrupt and excessive maneuvring that may exacerbate control difficulties.
> 3. Do not engage the autopilot.
> 4. If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.
> 5. If an unusual roll response or uncommanded roll movement is observed, reduce the angle of attack.
> 6. Do not extend flaps when holding in icing conditions. Operation with flaps extended can result in a reduced wing angle of attack with the possibility of ice forming on the upper surface further aft on the wing than normal, possibly aft of the protected area.
> 7. If the flaps are extended, do not retract them until the airframe is clear of ice.
> 8. Report these weather conditions to ATC.

Appendix E – Related Occurrences

King Air A100, Eveleth, Minnesota, U.S., 25 October 2002

On 25 October 2002, a Raytheon King Air A100 crashed while conducting an instrument approach in instrument meteorological conditions (IMC) at Eveleth, Minnesota, U.S. The National Transportation Safety Board (NTSB) investigation determined that the probable cause of the accident was the flight crew's failure to maintain adequate airspeed, which led to an aerodynamic stall from which they did not recover. The NTSB also concluded that the flight crew was not adhering to the company's approach procedures and was not effectively applying crew resource management techniques during the approach segment of the flight. Concerning stall warning, the NTSB noted that, although current airworthiness standards require that aircraft be equipped to provide a clear and distinctive stall warning at an airspeed at least five knots higher than the stall speed, stall warnings do not always provide flight crews with timely notification of developing hazardous low airspeed conditions.

Saab 340A, Eildon Weir, Australia, 11 November 1998

On 11 November 1998, a Saab 340A entering a holding pattern over Eildon Weir, Australia, stalled and descended 2300 feet before the crew regained control. The aircraft was operating in IMC and had accumulated ice. The Australian Transport Safety Bureau (ATSB) investigation determined that the crew allowed the aircraft's airspeed to slow below the published holding speed, and the stall warning system did not activate prior to the stall. Also, the crew interpreted the ice deposits as being less than that specified in the aircraft flight manual (AFM) for activation of the wing de-ice system. At the time of the incident, the AFM recommended activation of the de-ice boots when ice accumulated to about ½ inch on the wing leading edges. In October 1999, Saab Aircraft revised the AFM with a requirement to operate the de-ice boots in the continuous mode at the first sign of ice accumulation.

The ATSB investigation found that, despite being certified to all required certification standards at the time, the Saab 340 aircraft can suffer from an aerodynamic stall while operating in icing conditions, without the required warnings being provided to flight crew. This problem had been highlighted when the aircraft was introduced to operations in Canada, and as a result, a modified stall warning system was mandated for Saab 340 aircraft operated in Canada. Flight crew activation of an ice-speed switch causes the stall warning computer to operate at lower angles of attack. This ice-speed modification was not fitted to other Saab 340 aircraft worldwide. The ATSB determined that, if this system had been fitted and activated, the crew would have been provided with 10 to 18 seconds of warning of the impending stall.

Embraer EMB-120RT, Monroe, Michigan, U.S., 09 January 1997

On 09 January 1997, an Embraer EMB-120RT, operated by Comair Airlines with 3 crew members and 26 passengers on board, crashed near Monroe, Michigan, U.S., during a rapid descent after an uncommanded roll excursion. There were no survivors. IMC prevailed at the time of the accident. The NTSB investigation revealed that, prior to the rapid descent, the aircraft had descended into icing conditions. It was likely that the aircraft gradually accumulated a thin, rough glaze/mixed-ice coverage on the leading edge de-icing boot surfaces, possibly with ice-ridge formation on the leading edge upper surface. The ice accumulation may have been imperceptible to the pilots. Comair Airlines' guidance indicated that pilots should delay activation of the leading edge de-icing boots until they observed ¼ to ½ inch ice accumulation, despite Embraer's Federal Aviation Administration–approved EMB-120 AFM Revision 43, which indicated that pilots should activate the leading edge de-icing boots at the first sign of ice accumulation. The NTSB concluded that the pilots did not activate the leading edge de-icing boots during the descent, likely because they did not perceive that the aircraft was accreting significant (if any) structural ice. The pilots did, however, activate the windshield heat and propeller de-ice system, consistent with guidance to activate anti-ice systems before flying into known icing conditions.

The safety issues in the NTSB report focussed on the following: procedures for the use of ice protection systems; airspeed and flap-configuration information; stall warning/protection system capabilities; operation of the autopilot in icing conditions; aircraft icing certification requirements; and icing-related research.

Appendix F – Glossary

AD	Airworthiness Directive
AFM	aircraft flight manual
agl	above ground level
AMA	Airworthiness Manual Advisory
AMORTS	Approach, Minima, Overshoot, Radios, Timing, Speeds and Supplementary Remarks
AOC	Air Operator Certificate
asl	above sea level
ATPL	Airline Transport Pilot Licence
ATSB	Australian Transport Safety Bureau
CAR	Canadian Aviation Regulation
CARs	*Canadian Aviation Regulations*
CRM	crew resource management
FAA	Federal Aviation Administration (U.S.)
FDR	flight data recorder
FMS	flight management system
FSI	Flight Safety International
g	force of gravity
GPS	global positioning system
ILS	instrument landing system
IMC	instrument meteorological conditions
KIAS	knots indicated airspeed
METAR	aviation routine weather report
NDB	non-directional beacon
NTSB	National Transportation Safety Board (U.S.)
PF	pilot flying
PNF	pilot not flying
sm	statute miles
SOPs	standard operating procedures
T	True
TAF	terminal aerodrome forecast
TC	Transport Canada
TSB	Transportation Safety Board of Canada
°	degrees
°C	degrees Celsius