

Saab – SF340A, VH-LPI Eildon Weir, Victoria



11 November 1998



Department of Transport and Regional Services

Australian Transport Safety Bureau

AIR SAFETY INVESTIGATION

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Saab – SF340A, VH-LPI
Eildon Weir, Victoria on 11 November 1998

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GLOSSARY OF TERMS AND ABBREVIATIONS

ACJ	Acceptable means of compliance (JAR)
AD	Airworthiness Directive
AGL	above ground level
AMA	Airworthiness Manual Advisories
AOM	Aircraft Operating Manual
ASI	airspeed indicator
ATC	Air Traffic Control
ATPL	Airline Transport Pilot Licence
ATSB	Australian Transport Safety Bureau
AVR	Aerodrome voice recorder
BASI	Bureau of Air Safety Investigation
CAR	Civil Aviation Regulation
CASA	Civil Aviation Safety Authority
DoA	Department of Aviation (Australia)
EADI	Electronic Attitude Director Indicator
ELW	Eildon Weir
FAR	Federal Aviation Regulation
FD/AP	Flight director/autopilot
HDG	heading
IAS	indicated airspeed
ICAO	International Civil Aviation Organisation
JAR	Joint Aviation Regulation
KIAS	Indicated airspeed measured in knots
LFV	Luffartsverket (Swedish Civil Aviation Administration)
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
NDB	Non directional Beacon
UTC	coordinated universal time
VOR	Very high frequency omni-directional radio range navigation aid

All time references in this report are made to UTC.

EXECUTIVE SUMMARY

On 11 November, 1998, VH-LPI, a Saab 340A turbo-propeller aircraft was enroute between Albury, NSW and Melbourne, Victoria on a scheduled public transport service. The aircraft was operating in instrument meteorological conditions and had accumulated a deposit of ice on the wings and windscreen wipers. The crew interpreted this ice deposit as being less than that required for them to activate the de-ice systems on the wing leading edges, in accordance with the aircraft flight manual procedures. As the aircraft approached Melbourne the crew were instructed to enter a holding pattern at Eildon Weir. The crew acknowledged this instruction and reduced power in order to slow the aircraft to the holding pattern airspeed. The crew subsequently allowed the airspeed to fall below the target speed of 154 knots, and despite remedial action, did not regain the target speed.

Shortly after the aircraft entered the holding pattern it suffered an aerodynamic stall and rolled approximately 126 degrees to the left and pitched nose down to approximately 35 degrees. The crew regained control after approximately 10 seconds. The aircraft lost 2,300 ft of altitude. The crew was not provided with a stall warning prior to the stall.

The investigation found that despite being certified to all required certification standards at the time, the Saab 340 aircraft can suffer from an aerodynamic stall whilst 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 aircraft operated in Canada. This modification was not fitted to other Saab 340 aircraft worldwide.

The investigation also found a number of other occurrences involving Saab 340 aircraft where little or no stall warning had been provided to the crew while operating in icing conditions. Deficiencies were found in the operator's manuals, procedures and training.

During the course of the investigation, a number of recommendations were made in 1998 and 1999 concerning flight in icing conditions and modifications to the Saab 340 stall warning system. The completion of the investigation and finalisation of the report were the result of extensive consultation with the aircraft manufacturer and certification authorities.

1.1 History of the flight

On 11 November 1998, a Saab SF-340A, VH-LPI, departed Albury NSW for Melbourne Vic., on a scheduled public transport service. The crew had earlier flown the aircraft from Melbourne to Albury and described the departure from Albury and following climb to cruising level as normal. The co-pilot was handling pilot for the sector and air traffic control (ATC) had cleared the aircraft to track via the Eildon Weir VHF omnidirectional radio range navigation aid (VOR) at flight level (FL) 150.

The aircraft was in cloud that extended from 10,000 ft to 20,000 ft. The outside air temperature was minus 6 degrees Celsius. The crew activated the engine anti-ice system and selected the propeller de-ice system to the NORM position, but had not activated the wing de-ice boots. They reported the only visible ice on the aircraft was a light rime deposit on the leading edge of the wings and a small build up of ice on the windscreen wiper arms. The crew's interpretation of this ice deposit was that it did not meet the requirements in the aircraft flight manual for the activation of de-ice boots and consequently they were not activated.

Flight conditions were reported as smooth with only light turbulence and the seatbelt signs had been turned off. The flight attendant had completed a normal cabin service.

As the aircraft approached Melbourne, the controller instructed the crew to enter the holding pattern at Eildon Weir (ELW) VOR at FL150. The controller further instructed the crew to hold over ELW until 0650 UTC and that they could extend the outbound leg of the holding pattern to enable them to leave ELW at time 0650. The aircraft arrived over ELW at 0638.

Before reaching ELW the co-pilot reduced the power on both engines to a torque setting of 47%. The aircraft speed reduced towards the holding pattern speed of 154 KIAS. It gradually decreased over the next 58 seconds to 149 KIAS, at which stage the pilot in command cautioned the co-pilot to check his airspeed. The co-pilot responded by increasing the power to approximately 62% torque. The airspeed stabilised at 144 KIAS and he then increased the power to 74% torque, at which stage the airspeed began to increase. As the aircraft passed overhead ELW he selected HDG/ALT (heading and altitude hold) mode and full rate bank angle of 28 degrees on the autopilot. He also selected the outbound heading and the recorded data showed the bank angle of the aircraft increased to 28 degrees left. The airspeed at the start of this turn was 149 KIAS.

During the next twenty-one seconds as the turn progressed the airspeed gradually decreased and the aircraft began to buffet at 141 KIAS. The crew assessed this buffet as a propeller ice imbalance. Six seconds later as the airspeed decreased to 136 KIAS, the autopilot disconnected. Less than one second later the aircraft rolled rapidly to the left and pitched nose down, consistent with an aerodynamic stall. The aircraft rolled to a recorded bank angle of 126.6 degrees to the left and pitched nose down to a recorded angle of 35.8 degrees.

The co-pilot initially started recovery action, however the pilot in command took control of the aircraft and recovered it to normal flight after a height loss of 2,300 ft. The crew advised the controller they had encountered some turbulence and ice and asked to be

recleared at FL 130. The controller recleared the aircraft to hold at FL 130, and there was no breakdown of separation between the aircraft and other traffic.

The crew reported that following the loss of control they observed a thin white line of rime ice on the leading edges. However, following activation of the wing de-ice boots, the ice broke away from the leading edges.

Neither crewmember recalled noticing either the stick shaker or stall warning clacker activating prior to the upset.

At about the time of the upset, the crew of another aircraft that was at FL 180 and approximately 5 minutes behind VH-LPI, requested a descent clearance to leave icing conditions.

The only person injured was the flight attendant, who suffered bruising to her back while trying to regain her seat.

The aircraft continued to Melbourne without further incident.

1.2 Injuries to persons

	<i>Crew</i>	<i>Passengers</i>	<i>Other</i>	<i>Total</i>
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	1	-	-	1
None	2	28	-	30

1.3 Damage to aircraft

After landing, the crew reported to the company that they had encountered turbulence. As a result the aircraft underwent a heavy turbulence inspection. Engineering staff carried out that inspection in accordance with the aircraft maintenance manual. No defect or damage was found.

1.4 Other damage

Not applicable.

1.5 Personnel

1.5.1 Pilot in command

Licence category	ATPL
Medical certificate	Class 1
Total hours	13,486.0
Total on type	3,109.0
Total last 90 days	167.0
Total on type last 90 days	167.0
Total last 30 days	48.4
Total on type last 30 days	48.4
Total last 24 hours	2.0
Last check	4 November 1998
Last check on type	4 November 1998

The pilot in command's medical certificate had a condition that vision correction was required. At the time of the occurrence he had complied with that condition.

The pilot in command began employment with the company in 1991 as a first officer on Metro 23 aircraft. He then moved to a first officer position on the Saab 340 aircraft in January 1992 and flew that aircraft type for two years before obtaining a command position on the Metro 23 aircraft in February 1994. He held that position until he gained his command endorsement on the Saab 340 aircraft in October 1995.

The pilot in command held a management position with the airline, and this required administrative duties in addition to flying duties. He commenced administrative duties at 1000 on the morning of the occurrence and signed on for flight duties at 1515 hours. He had spent the day prior to the occurrence on reserve duty, and had flown on each of the two preceding days. He reported that he had slept well in the three nights preceding the occurrence and that he was not suffering from any condition that may have affected his performance.

1.5.2 First officer

Licence category	ATPL
Medical certificate	Class 1
Total hours	5460.2
Total on type	365.0
Total last 90 days	177.0
Total on type last 90 days	177.0
Total last 30 days	66.4
Total on type last 30 days	66.4
Total last 24 hours	2.0
Last check	30 October 1998
Last check on type	30 October 1998

The first officer did not have any conditions on his medical certificate.

The first officer began employment with the company in 1998 as a first officer on the Saab 340 aircraft. He had previously been a flight instructor. After completing initial training, he began line-flying duties in the Saab 340 in May 1998.

He spent the day prior to the occurrence on reserve duty and reported for duty at 0300 on the day of the occurrence. Before this he had been on a day off and prior to the day off he had been rostered for flying duties where he had flown 4 sectors. He reported that he had slept normally during these days and was not suffering from any condition that may have affected his performance.

1.5.3 Crew training in stall recognition and recovery and unusual attitude recovery training

At the time the pilot in command completed his Saab 340 command endorsement training, the operator did not make use of flight simulators for training. His training in the aircraft had included stalls in several different configurations and the training captain commented that he had completed this sequence to a 'good' standard. He had also displayed competence in the normal and abnormal operation of the aircraft anti-ice and de-ice systems.

Examination of his training records revealed that he had passed all the required company checks satisfactorily.

The first officer had also undergone Saab 340 training in the aircraft and had also completed stall recognition and recovery during his initial endorsement on the aircraft

type. However, his training records did not contain any reference to the standard to which this training had been completed.

Prior to the occurrence the company had gained the use of a Saab 340 flight simulator for flight training. It conducted a cyclic training program that required crews to complete 12 different training exercises in the simulator over a 2-year period. Crews were required to undertake stall training as part of simulator exercise 2. There were no other exercises requiring training for stall recognition and recovery.

The pilot in command had completed simulator exercise 2 six months before the occurrence. His training records showed that he completed this and all other simulator exercises to a satisfactory standard.

The first officer completed simulator exercise 2 three months before the occurrence. His training records showed that he too completed the exercise to a satisfactory standard.

Prior to the company using the simulator for training, unusual attitude training was conducted in the aircraft. Attitudes were limited to between ten-to-twenty degrees nose up and down, and up to sixty degrees angle of bank. The company imposed these limits to prevent fluids being spilt from the aircraft toilet. When the simulator became available for training the limits for unusual attitude training remained the same as those that had been imposed on the aircraft during flight training.

Following the occurrence both crew members commented that during the occurrence the information provided to them by the electronic attitude director indicator was of little use to them to assist in the recovery. Both crew members described the electronic attitude director indicators as 'a mess of blue and brown'. The pilot in command reported that he had used the standby attitude indicator to aid in the recovery of the aircraft to straight and level flight (The electronic attitude director indicator is further discussed in section 1.6.9).

The company reported that training captains could use any time remaining at the end of scheduled simulator training for any exercise the crew suggested they wished to practise. The pilot in command reported that at the end of his first simulator session he had practised steep turns, stalls and some unusual attitude recovery. None of the twelve simulator exercises in the operator's 2 year cyclic program included unusual attitude recovery.

The aircraft operating manual and the aircraft flight manual did not contain any information on recovery from unusual attitudes. Subsequent to the occurrence the manufacturer changed the aircraft operating manual to include such information.

Following the occurrence, the operator changed its simulator training program to include unusual attitude recovery training.

1.5.4 Crew training in icing conditions

Apart from the training the crew received in their initial endorsement training, continuing competence in the use of de-ice and anti-ice systems revolved around normal use of the system as part of daily operations whenever icing conditions were encountered. Simulator training exercises included flight in icing conditions that required crews to activate anti-icing and de-icing systems. Non-normal operation of the anti-ice systems was covered in four of the 12 simulator training exercises.

The operator's policy and procedures manual contained very little guidance on flight in icing conditions.

1.6 Aircraft information

1.6.1 Significant particulars

Manufacturer	Saab Aircraft AB
Model	SF-340A
Serial Number	340A-151
Registration	VH-LPI
Country of manufacture	Sweden
Date of manufacture	1989
Engine	GE CT7-5A2
Propeller	Dowty R354/4-123-F/13
Certificate of registration	
Holder	Saab Aircraft Credit AB
No.	WG/10651/02
Issued	14 May 1997
Certificate of airworthiness	
No.	WG/10651
Issued	30 May 1997
Maintenance release	
No.	1288
Issued	26 October 1998
Total airframe hours	8501

1.6.2 Weight and balance

It was estimated that the aircraft weighed 12,500 kg at the time of the occurrence and that it was within certified weight and balance limits.

1.6.3 Saab 340A stall warning system

The stall warning system fitted to the Saab 340 consists of two independent dual channel stall warning computers, left and right angle-of-attack sensors, two stick shakers (one mounted on each control column) and a stick pusher actuator connected to the left control column. A mechanical linkage also transfers the stick push to the right control column. There are stall warning lights on each of the pilot's instrument panels, and three amber stall warning system failure lights on the centre warning panel. The crew can test the system using the test function in the overhead avionics panel.

The system provides five distinct warnings of an impending stall: autopilot disengage; stick shaker; aural clacker; a visual warning and finally a stick pusher.

The stall warning computers receive inputs from separate angle-of-attack sensors that are situated on the forward section of the fuselage. These sensors are electrically heated. The sensors measure the airflow relative to the fuselage, called vane angle-of-attack. This vane angle-of-attack is used as an input to the stall warning computers.

A weight-on-wheels sensor inhibits the stick pusher for seven seconds after takeoff to prevent inadvertent activation while the aircraft is in close proximity to the ground. A sensor detects the position of the flaps and increases the angle-of-attack signal provided to the stall warning computer between 0 and 1 degree, based on flap position. Activation of the wing de-ice system disables the flap compensation, and the angle-of-attack signal is

reduced by 0.4 of a degree to increase the stall margin by 1–2 knots when the de-ice boots are inflated.

The stall warning computer activates the stick shaker at 12.5 degrees angle-of-attack, and the stick pusher at 19 degrees angle-of-attack with the flaps in the retracted position. Initiation of this warning occurs when either of these sensors reaches the predetermined angle-of-attack. Both pilots receive the stick shaker warning through their respective control column. Activation of the stick shaker causes the autopilot to disengage.

Stick pusher activation is dependent on one angle-of-attack sensor reaching 19 degrees and the other being greater than 12.5 degrees. When the stick pusher is activated, one of the PUSH lights on each pilot's instrument panel will illuminate. If both angle-of-attack sensors reach 19 degrees, then both PUSH lights on each pilot's instrument panel will illuminate. Between the onset of stick shaker activation and stick push activation both the stick shaker and aural warning 'clacker' will operate continuously.

Stick pusher activation applies 80 lbs forward force on each control column which results in a 4 degrees elevator down position. The system is equipped with a gravity switch which operates at < 0.5 g to prevent the actuator from forcing the aircraft into an unacceptable nose down attitude.

Failure of a stall warning computer causes a warning light to illuminate in the central warning panel located in the cockpit. If this warning light illuminates then the stick pusher is inoperative. However the stick shaker and the aural warning 'clacker' will still operate.

1.6.4 Stall warning system maintenance history

Examination of the maintenance records for the aircraft found that a routine inspection of the angle-of-attack system occurred on 22 October 1998.

The stall warning system was inspected and tested on a daily basis. The operator reported the system had tested normally during the daily inspection of the aircraft on the morning of the occurrence.

The pilot in command reported that as part of his aircraft acceptance he routinely inspected and tested the stall warning system, regardless of when the daily inspection occurred. He reported the system tested normally before the departure from Melbourne to Albury.

There were no defects recorded in the maintenance log of the aircraft to indicate that the stall warning system was not capable of normal operation.

1.6.5 Saab 340 ice and rain protection

The Saab 340 aircraft is certified for operations in known icing conditions in accordance with FAR/JAR Part 25, appendix C.

The aircraft ice and rain protection systems are divided into anti-ice systems and de-ice systems.

Anti-ice systems are fitted to the engine, pitot tubes, temperature probe, angle-of-attack sensors and windshield. De-ice systems are fitted to the wing, vertical and horizontal stabilisers and propellers.

The pitot tubes, temperature probe and angle-of-attack sensors are automatically heated as soon as one alternating current (AC) generator is on line following engine start.

The wing, vertical and horizontal stabiliser de-icing systems consist of conventional inflatable boots located on the leading edges of the wing and vertical and horizontal stabiliser. The boots are inflated by using precooled engine bleed air that is controlled by a pressure regulator and supply valve. De-icing occurs when accumulated ice is cracked by rapid inflation of the boots. A timer control unit regulates boot inflation cycles. The unit is selectable to either one cycle or continuous operation. In the one-cycle mode, the boots are inflated in a predetermined order and then deflated. In the continuous mode inflation of the boots will be repeated every three minutes. Each boot can be manually inflated using a push button for each zone.

Boot operation is monitored and a fault light will illuminate if a fault is detected in either the operation of the valves or the boots. If a boot remains inflated after normal operation of the system, the fault light will also illuminate. The crew can monitor inflation of the boots by observing the boot indication lights located on the overhead panel.

The propeller is equipped with de-icing boots that are electrically heated. A three-position switch for each propeller controls operation of the system. The system can be operated in either the NORM mode or the MAX mode. In NORM mode the power to the boots is on for 11 seconds and off for 79 seconds. In MAX mode the system operates for 90 seconds on then 90 seconds off. MAX mode is recommended when temperatures are colder than minus 12 degrees Celsius. The aircraft operating manual notes that use of MAX mode at temperatures warmer than minus 12 degrees Celsius, or NORM mode at temperatures warmer than minus 5 degrees Celsius, may cause accumulated ice to melt and refreeze behind the boots.

The front windshields and the forward part of the side windshields are electrically heated. All systems are monitored and provide a warning to the crew whenever power is lost to those systems. However, the operator's policy and procedures manual noted that 'as windscreen heat is not normally used, once clear of icing conditions consider leaving heat off to avoid thermal shock and risk of cracking'. The manufacturer's aircraft operating manual contained advice on the system operation and noted that windshield heating was part of the ice and rain protection system to permit the aircraft to operate in all weather conditions. The aircraft operating manual further noted that when set to ON, power would be gradually applied by the windshield heating controller to reduce thermal stresses in the windshields.

1.6.6 Flight guidance and autopilot system

The aircraft is equipped with a flight control computer that includes the flight director/autopilot, elevator and rudder auto-trim functions, and a yaw damper that provides directional stability augmentation.

The autopilot operates in a number of different modes in both the vertical and lateral planes. There are 11 modes that can be selected by the flight crew. Only one of these modes – IAS mode – will provide protection against penetrating the required stall speed margins.

The autopilot is also fitted with a half-bank mode. When activated this reduces the angle of bank from the normal bank limit of 27 degrees to 13.5 degrees. The aircraft flight manual Normal Procedures section – Operations in Icing Conditions, recommended that half-bank mode be used whenever possible in icing conditions. The manufacturer advised this would provide extra margins above the stall whenever possible, particularly in icing conditions.

The operator had previously used half-bank mode in all operations to provide a better ride for all passengers. However, following a routine surveillance inspection, the Civil Aviation Safety Authority (CASA) had directed the company to use full bank mode in holding patterns thereby reducing the radius of turn to keep the aircraft within the protected airspace of the holding pattern.

The autopilot can be disconnected by any of the following:

- the pilot deliberately disconnecting the autopilot; or
- the stall warning system, triggering the stall warning; or
- use of the manual trim by the crew; or
- faults in the system; or
- rapid roll rates (greater than 10 deg/sec).

Any excessive control force will not cause the autopilot to disconnect. However, it will cause that particular part of the system to disengage, with a matching warning on the centre warning panel.

1.6.7 Limits on the use of autopilot

The operator's policy and procedures manual section titled – Autopilot/Flight Director Operation – noted that it was company policy to use autopilot when above 5,000 ft only. The manual noted this would lead to significant gains in autopilot serviceability. There was no mention in this section about not using the autopilot in icing conditions. The aircraft flight manual noted that autopilot use was prohibited below 600 ft above ground level (AGL) during cruise, 200 ft AGL during takeoff or go around, 100 ft AGL for non-coupled approaches or 50 ft during approach.

The aircraft flight manual also noted:

Autopilot operations not authorised:

- speeds below 1.3 x stall speed – in HDG mode
- In icing conditions, FD/AP IAS MODE IS THE ONLY VERTICAL MODE TO BE USED DURING CLIMB WHEN ICE ACCUMULATION IS OBSERVED OR IF IT IS NOT CERTAIN THERE IS NO ICE ACCUMULATION ON THE AIRCRAFT.

This limitation is repeated in the FLIGHT PROCEDURES – GENERAL section of the aircraft operating manual. There are no other limits published in the manuals on the use of the autopilot in icing conditions. The manufacturer has subsequently advised that the use of IAS mode is not recommended in level flight.

Following an accident to an ATR-72 aircraft at Roselawn, Indiana, USA, in 1994, the Federal Aviation Administration (FAA) issued airworthiness directives as a result of that occurrence. Airworthiness directive 96-09-21 applied to Saab 340 aircraft and required a flight manual amendment covering operations of the aircraft in severe icing conditions. The airworthiness directive stated (in part):

Since the autopilot 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.

The Swedish airworthiness authority, Luftfartsverket (LFV), did not consider that these issues applied to the Saab 340 and therefore they did not issue a corresponding

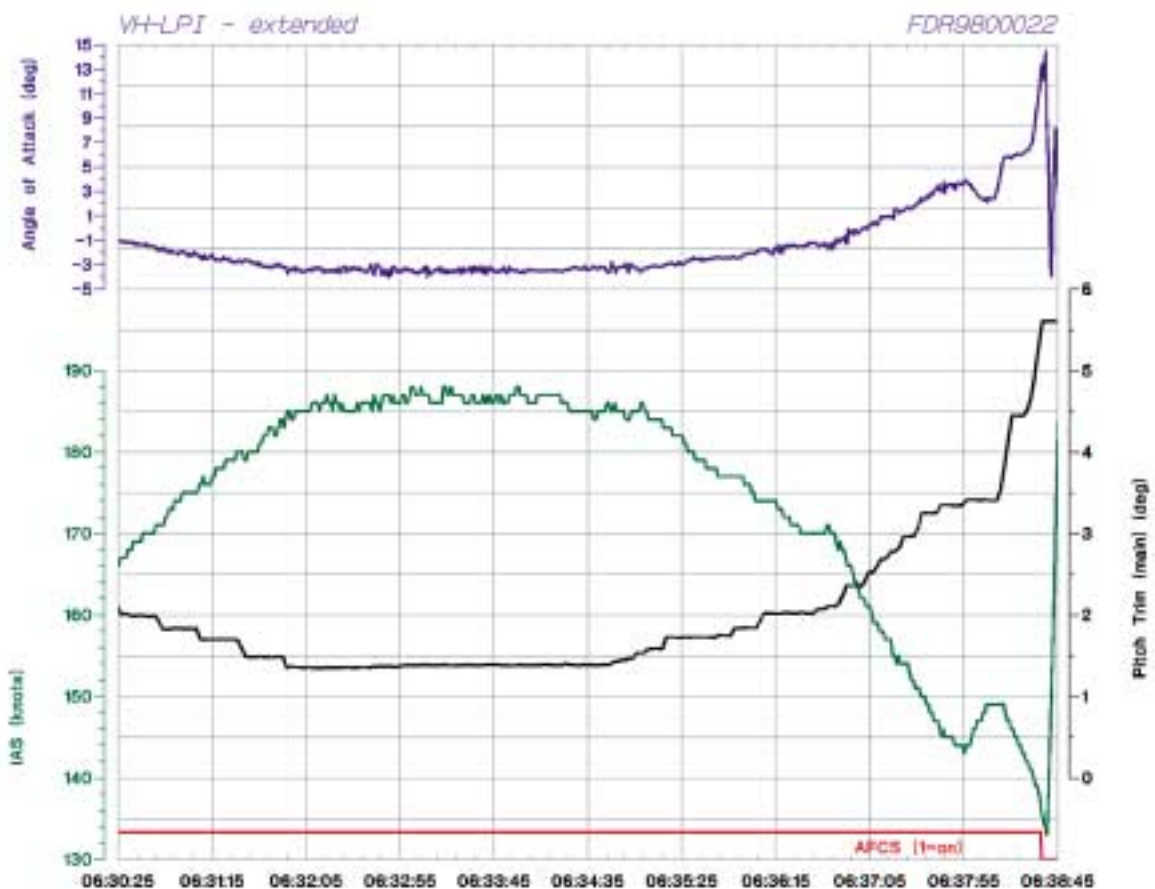
airworthiness directive for the type. As the airworthiness directive dealt with operations in severe icing conditions LFV did agree however, to insert certain sections of the airworthiness directive into the Saab 340 aircraft operating manual. Section 2.11 of the aircraft operating manual was modified to contain instructions on the use of the autopilot in freezing rain or drizzle. Neither of these icing conditions was encountered by the aircraft at Eildon Weir.

The manufacturer indicated that the airworthiness directive was not incorporated into the Saab 340 manuals due to disagreements concerning the applicability of the information to the Saab 340. They also indicated the airworthiness directive was applicable to US operators only.

CASA did not impose the requirements of airworthiness directive 96-09-21 to flight manuals of the Saab 340 because the state of manufacture did not issue it. CASA stated this was in accordance with the standards and recommended practices of ICAO Annex 8 – Airworthiness of Aircraft. The investigation team found however, that the airworthiness directive had been implemented in the flight manuals of other turboprop aircraft, either by a manufacturer’s amendment or a flight manual amendment issued by CASA.

In this occurrence, analysis of the recorded data showed that as the aircraft speed decreased, the autopilot commanded an increasing amount of nose up elevator to maintain altitude. Commensurate with this, the trim was also progressively increased nose up by the autopilot. For further information on recorded data refer to section 1.11 of this report.

FIGURE 1:
Shows the movement of the pitch trim in the time leading up to the occurrence.



1.6.8 Flight controls

The primary flight controls of the Saab 340, the ailerons, elevator and rudder, are conventional, manually operated rod and cable assemblies. All control surfaces are mass balanced. There is no hydraulic assistance to the flight controls.

Pitch trim on the Saab 340 is activated by the operation of trim switches on either control wheel to actuate elevator trim tabs. There is no trim wheel.

A common trim tab position indicator is located on the lower right corner of the centre instrument panel. It provides the only indication to the crew of the position of the various trim tabs.

The yaw damper, elevator and rudder auto-trim systems activate whenever the autopilot is engaged. The auto-trim systems continuously retrim the aircraft to minimise torque applied to the autopilot servos and to keep the control forces to zero.

The elevator trim systems do not provide any aural indication to alert the crew whenever they are operated. The only visual indication to the crew that the elevator trim system has re-trimmed the elevator, is movement of the elevator trim index on the common trim tab position indicator.

1.6.9 Electronic attitude director indicator

There were no recorded defects affecting the electronic attitude director indicators fitted to the aircraft at the time of the occurrence.

The electronic attitude director indicator is an electronic instrument that represents the artificial horizon for the pilots when flying with reference to instruments.

It consists of a display that depicts the sky as a blue section of the instrument and the ground as a brown section. Superimposed on this is a pitch scale that is displayed in white. The bank angle scale and roll index is depicted at the top of the instrument and is also displayed in white.

Section 1.15/8 of the aircraft operating manual contains information on the limits imposed on the instrument. At extreme attitudes (defined by the manufacturer as pitch more than 30 degrees up and 20 degrees down; roll more than 65 degree) with the exception of the attitude warning flag, attitude presentation and FD/AP command bars, all unnecessary information is removed from the electronic attitude director indicator.

During the investigation the occurrence sequence was replicated in the operator's CASA-approved Saab 340 flight simulator. At extreme attitudes, information presented on the pilot-in-command's electronic attitude director indicator did not agree with the description contained in section 1.15/8 of the Saab 340 aircraft operating manual.

On 25 October 1999, Saab issued an amendment to section 25/12 of the Saab 340 aircraft operating manual. This section, titled Flight Procedures - Training, contained information about recovery from unusual attitudes, recovery from stall warning (stick shaker), and recovery from stall. It included pictorial information on the information crews could expect to observe on the electronic attitude director indicator during these manoeuvres. This information differed from that contained in section 1.15/8 of the aircraft operating manual. However, it coincided with the pictorial displays observed in the operator's Saab 340 flight simulator during the replication of the occurrence sequence.

1.6.10 **Airspeed indicator**

The Saab 340 is equipped with three airspeed indicators. One is located on each of the pilot's instrument panels and a standby airspeed indicator is located on the centre instrument panel.

The allowable tolerance limits for the instrument are +/- 3 KIAS in the speed range 40 – 180 KIAS, at a temperature of 20 degrees Celsius (+/- 5 deg).

On 2 November 1998, a defect was entered in the maintenance log that the left ASI was indicating up to 5 KIAS higher than both the standby and right ASI. This was particularly obvious at low airspeeds. The ASI was recalibrated to ensure that it was within its permitted limits on 3 November 1998, and released for normal service.

There were no recorded defects affecting the airspeed indicators fitted to the aircraft on the date of the occurrence.

1.6.11 **Ice detection**

An ice detection system is not fitted as standard equipment on the Saab 340 but is available as an optional item of equipment. The aircraft involved in this occurrence did not have the optional ice detection system installed.

The manufacturer subsequently advised that the ice detection system was for engine anti-ice only. It alerted the crew to the fact that they had not switched on the engine anti-ice system. Furthermore, any warnings from the system were suppressed when the engine anti-ice system was selected on.

The aircraft flight manual included the following in the normal procedures section:

Monitor the accumulation of ice. The windshield wiper arms give a visual cue of icing, although airframe ice can be present without any build up on the wiper arms.

1.6.12 **FAA and European Joint Aviation Authorities (JAA) certification guidance for transport category aircraft**

In 1971 the FAA published Advisory Circular (AC) 20-73 titled 'Aircraft Ice Protection'. The document was produced using the then currently available data and knowledge on icing prediction and formation. It has not been updated since that time. The document contained little information about practical operations for flight testing in icing conditions. Transport Canada assessed the relevance of the document for icing certification, and determined it did not adequately define how to operate aircraft safely in icing conditions.

Advisory circular 25-7 is the flight test guide for certification of transport category aircraft under FAR part 25. It contains both interpretive and guidance material on how to achieve compliance with the FAR's. Section 6 of this document deals with stalling. Part of the purpose of stall testing is defined as:

...to determine that there is adequate pre-stall warning (either aerodynamic or artificial) to allow the pilot time to recover from any probable high angle of attack condition without inadvertently stalling the airplane.

The same section deals with aircraft requiring certification for flight in known icing conditions. It states that:

for airplanes that are certificated for flight in known icing conditions, stall characteristics should be demonstrated with simulated ice shapes symmetrically attached to all surfaces that are not protected by anti-ice or de-ice systems. (For further guidance on

approval for flight in known icing conditions, see paragraphs 231 and 232 of this advisory circular).

There is no other information in section 6 dealing with stall certification under ice conditions.

Paragraphs 231 and 232 deal with performance requirements and flying qualities in natural icing conditions. There is only general information contained in this section on the conduct of flight testing in icing conditions. Paragraph 232 requires that one full stall should be carried out in natural icing conditions in the landing configuration only.

On 18 August 1999, advisory circular 25-1419 –1 was issued. It is titled ‘Certification of Transport Category Airplanes for Flight in Icing Conditions’, and concerns certification of aircraft under FAR part 25. Specifically, it deals with certifying aircraft for flight in known icing conditions under FAR part 25.1419 and FAR part 25 Appendix C. Advisory circular 25-1419 – 1 requires that stalls be carried out in several different configurations.

Section 7 (e) of advisory circular 25-1419-1 is as follows:

e. Stall Warning.

Ice could form on stall warning and angle-of-attack sensors if these devices are not protected. Therefore, the sensors’ functions should be evaluated for operation in the icing conditions of Appendix C. Adequate stall warning (aerodynamic or artificial) should be provided with ice accumulations on the airplane. Ice accumulations that should be considered are those on unprotected surfaces, those that occur prior to the initial activation of the ice protection system, those that occur between the ice protection activation cycles, and those that remain after one cycle of the ice protection system. The activation points of artificial stall warning and stall identification systems, if installed, may need to be reset for operations in icing conditions to provide adequate stall warning margins and to prevent inadvertent stalling or loss of control, respectively.

The JAA have published Joint Aviation Regulation (JAR) 25 relating to certification of large (transport category) aeroplanes. Ice protection is covered under JAR 25.1419, which states:

If certification for flight in icing conditions is desired, an aeroplane must be able to safely operate in the continuous maximum and intermittent maximum icing conditions of Appendix C.

Appendix C of JAR 25 is identical to Appendix C of FAR part 25.

Compliance with JAR 25.1419 may be established by two methods. The first method is an arbitrary empirical method based on United Kingdom and French practice. The second method is a general approach based on US practice in applying FAR part 25, Appendix C. Both methods state that critical ice accretion will occur during the hold at 15,000 ft at –10 degree Celsius.

1.6.13 Saab 340A certification history

The Saab 340 is unique in that it was the first aircraft that was simultaneously certified to both FAR Part 25 and JAR 25. The aircraft was first certified in Australia in 1985.

Although the aircraft was certified to both FAR and JAR requirements the then Australian Department of Aviation (DoA) wrote to the company that was proposing to introduce the aircraft. Part of that letter stated:

It is now clear that, to avoid delays in the defining of Australian airworthiness certification requirements with design standards relating to JAR 25, it would be preferable to use ANO 101.6 and FAR 25 for the Saab-Fairchild 340 Airliner.

We therefore formally specify, as the design standard for Australian Certification of the Saab-Fairchild 340 Airliner, Air Navigation Orders Section 101.6 Issue 3 incorporating amendments 51, 52, 55, 57, 58, 62, 63, 65, 69.

At the time of introduction of the Saab 340A, DoA did not issue type certificate data sheets for imported aircraft but did issue its own certificates of airworthiness for those aircraft. This certificate of airworthiness was based on the Type Certificate issued by the then Board of Civil Aviation of Sweden (now LfV).

1.6.14 Aircraft operating limits

The Saab 340 aircraft flight manual was initially approved by the DoA and subsequently reapproved by CASA. The CASA authority approval status was A/340A/33. The limitations section of the aircraft flight manual defined that the aircraft was:

eligible for the following kinds of operations when the appropriate instruments and equipment required by airworthiness authorities and/or operating regulations are installed and approved, and are in operable condition.

- Atmospheric icing conditions
- Day and Night VFR
- IFR

At the time of the occurrence the aircraft met all of the CASA requirements outlined in the limitations section.

1.6.15 JAR/FAR Part 25 stall warning certification

JAR part 25.201 outlines the requirements that must be met when demonstrating the stall in the aircraft. Stalls must be demonstrated in straight and turning flight, with and without power. They must also be demonstrated in each configuration of flap, landing gear and deceleration devices that are likely to be used. The weights of the aircraft must also be within the allowable range for the aircraft. Deceleration of not greater than one knot per second is required for entry into the stall, and accelerated stalls must also be demonstrated in straight and turning flight.

JAR part 25.201(d) states:

Acceptable indications of a stall are:

- (1) a nose-down pitch that cannot be readily arrested and which may be accompanied simultaneously by a rolling motion which is not immediately controllable (provided that the rolling motion complies with JAR 25.203 (b) or (c) as appropriate);

JAR part 25.203 outlines the characteristics of the stall. It must be possible to produce and correct roll and yaw using unreversed use of ailerons and rudder up to the point the aircraft is stalled. In addition it must be possible to promptly prevent stalling and to recover from a stall using normal use of controls. Section [c] of this part states:

for turning flight stalls, the action of the aeroplane after the stall may not be so violent or extreme as to make it difficult, with normal piloting skill, to effect a prompt recovery and to regain control of the aeroplane. The maximum bank angle that occurs during the recovery may not exceed –

- (1) Approximately 60 degree in the original direction of the turn, or 30 degrees in the opposite direction, for deceleration rates up to 1 knot per second; and
- (2) Approximately 90 degrees in the original direction of the turn, or 60 degrees in the opposite direction, for deceleration rates in excess of 1 knot per second.

JAR part 25.207 requires that the crew be provided with a clear and distinctive stall warning with sufficient margin to prevent an inadvertent stall. This warning must be available in both straight and turning flight. It may be provided through the inherent aerodynamic qualities of the aeroplane (e.g., pre-stall buffet) or by a device that will give clearly distinguishable indications under expected conditions of flight. The use of a visual stall warning that requires the attention of the crew is not acceptable by itself.

During flight testing it became evident to the manufacturer that the Saab 340 would not demonstrate compliance with JAR/FAR 25.201 (d) (1). This was because the aircraft displayed an inadequate nose-down pitch. As a result, a stall identification system (stick pusher) was introduced to the aircraft design.

When the speed of the aircraft is reduced at rates not exceeding 1 knot per second the stall warning must begin in each configuration at a speed exceeding the stalling speed by not less than the greater of 5% or 5 knots of calibrated airspeed. The stall warning must continue until the angle of attack is reduced to approximately that at which the stall warning is initiated.

JAR 25 contains a section by which an acceptable means of compliance with the requirements can be demonstrated and provides added interpretative material on selected sections. ACJ 25.203 provides information on stall characteristics. In the section that deals with rolling motions at the stall the following is included:

...for stalls from a 30 degrees banked turn with an entry rate of 1 knot per second, the maximum bank angle which occurs during the recovery should not exceed approximately 60 degrees in the original direction of the turn, or 30 degrees in the opposite direction.

On 19 April 1996 ACJ 25.203 was amended to read:

Where the stall is indicated by a nose-down pitch, this may be accompanied by a rolling motion that is not immediately controllable, provided that the rolling motion complies with JAR 25.203 [b] or [c] as appropriate.

ACJ 25.207 (b) provides information on stall warning. This section outlines the warning as one which is:

...clear and distinctive to the pilot is one which cannot be misinterpreted or mistaken for any other warning, and which, without being unduly alarming, impresses itself upon the pilot and captures his attention regardless of what other tasks and activities are occupying his attention and commanding his concentration. Where a stall warning is to be provided by artificial means, a stick shaker device producing both a tactile and an audible warning is an Acceptable Means of Compliance.

FAR parts 25.201, 25.203 and 25.207 contain substantially similar material to that contained in the corresponding JAR sections. The only major difference is in FAR part 25.207 where the stall warning margin is 7%.

1.6.16 Saab 340A stall characteristics

The stall characteristics of the Saab 340 are that the inner section of the right wing will stall first. The left outer wing then begins to stall. This results in the pronounced left-wing drop at the point of stall. This motion is consistent with that of the aircraft at ELW.

The aircraft operating manual contained a section titled FLIGHT PROCEDURES – FLIGHT CHARACTERISTICS. This section described (in part) the characteristics of the stall in the Saab 340A as follows:

Stall onset in this aircraft is recognized by a light buffeting just prior to actual stall, followed by a sharp left roll in excess of 15 degrees bank angle and nose down movement. The roll cannot be controlled until angle-of-attack is decreased below the stall point.

Due to these stall characteristics, the aircraft has been provided with a stall warning and stick pusher system to minimise the risk of entering the stall onset regime.

1.6.17 Saab 340A icing certification tests

The Saab 340A aircraft underwent certification testing for flight in icing conditions in February and March 1984. The aircraft was subjected to a number of flights in natural icing conditions, all of which fell within the requirements of FAR/JAR 25 Appendix C.

The aircraft was initially configured for flight in icing conditions with the installation of rubber boots on the outer section of the wings, and the leading edges of the tailplane and vertical stabiliser. In that configuration Saab examined handling qualities with simulated ice shapes of half-inch double horn type on the protected parts of the aircraft, and 3-inch shapes on the unprotected parts. Flight testing revealed there was an adverse affect on the stall speed with this amount of ice on the aircraft, and added protection was provided on the inner wings and vertical stabiliser. Flight testing in that modified configuration revealed acceptable handling qualities, and that became the build standard for all aircraft as they left the production line.

Following the introduction of the aircraft into service it was restricted to a maximum flap extension of 20 degrees only for landing following flight in icing conditions. This resulted from an occurrence where a Saab 340 experienced tailplane stalling during a landing approach when 35 degrees of flap was extended. Investigations by the manufacturer revealed that a thin rough deposit of ice on the tailplane caused it to stall. The manufacturer modified the design of the tailplane to overcome this problem, and the aircraft was then cleared for operations with full flap. Although the manufacturer modified the tailplane as a result of the tailplane stall occurrence, it did not investigate the effect of thin rough deposits of ice on the wings of the Saab 340 aircraft at that time. The aircraft involved in this occurrence was equipped with the modified tailplane.

When the Saab 2000 aircraft was introduced the manufacturer carried out testing to examine the effect of a thin rough deposit of ice. The Saab 2000 wing was based on the same aerofoil section as that of the Saab 340. During certification testing of the Saab 2000, tests were conducted with #40 grit sandpaper on the leading edges of the wings to simulate a thin rough ice deposit. The testing revealed the performance degradation from this type of deposit was less than that from a 1 inch simulated double horn ice shape (Canadian requirements).

During the original certification of the Saab 340, the manufacturer produced a similar stall speed chart to that produced for the Canadian certification requirements. This chart provided stall speeds for the Saab 340 when it was flown with 3 inch ice shapes on unprotected and 1/2 inch ice shapes on protected parts of the wing and tail leading edges. These shapes were similar to those that were found in the NASA Lewis icing tunnel, and were used during the flying-qualities demonstration. The ice shapes were fitted to replicate ice accretion that could be reasonably expected to accumulate during flight into icing conditions without activation of the de-icing boots. However, the chart was not included

in the aircraft flight manual or aircraft operating manual to provide guidance to operators on increases to stalling speed when the aircraft was operated in icing conditions.

Analysis of the Saab stall speed chart that was produced by the manufacturer during the original certification process revealed that the wings-level¹ stall speed at a weight of 12,500 kg was 121 KIAS. This was equivalent to an increase in stall speed of 13 KIAS over that for an uncontaminated airframe, i.e., free of ice, which was 108 KIAS.

Analysis of the chart produced by the manufacturer for Canadian operations of the Saab 340 revealed that wings-level stall speed at a weight of 12,500 kg was 126 KIAS with ice accumulated on the airframe. This was equivalent to an increase in stall speed of 18 KIAS over that for an uncontaminated airframe.

During the occurrence sequence involving the aircraft, it reached 27 degrees angle of bank at the point of disconnection of the autopilot. The following table shows calculation of 'ice free' stall speed at that point:

<i>Angle of Bank Ø</i>	<i>Cos Ø</i>	<i>'G'</i>	<i>Stall Speed 12500 kgs</i>
0.0	1.00000	1.00000	104 KIAS
27.0	0.89101	1.12233	110 KIAS

The certification test report for the Saab 340 icing protection contained a summary of the stalling characteristics of the aircraft while flying in icing conditions. It stated:

The results from the stall tests show that the artificial stall warning is sometimes activated very late especially in the flaps down configuration. However, there is an adequate natural stall warning (vibration/buffet) in all flap conditions, which starts well in advance of the stall.

The stall tests were carried out with a number of different ice shape configurations. These configurations were:

- 3 inch shapes on the unprotected parts of the leading edges;
- 3 inch shapes with the addition of inflated wing boots; and
- 3 inch shapes on the unprotected parts of the wing with the addition of 1/2 inch horn-type shapes on all protected parts of the leading edges.

The report also stated the stick pusher was effective in all wings level stalls. However, in turning stalls, the aircraft would roll before the pusher was activated.

The icing certification tests revealed that ice on the propellers is shed unevenly which leads to a vibration within the aircraft. The report noted that this vibration did not increase to an uncomfortable or unacceptable level.

The function of the de-ice boots was demonstrated during flight testing. The flight test report concluded they had functioned correctly and that the efficacy of the boots was related to temperature. At cold temperatures (-5C to -10C) the ice deposits on the aircraft was normally shed at the first cycle of the boots. Following activation of the boots very little residual ice was seen to remain. At colder temperatures it was noted that the boots took several cycles to shed the ice and a significant amount of residual ice remained between cycling of the boots.

Activation of the boots took place at different thicknesses from a quarter of an inch to one inch. The report stated:

¹ Stall speed increases as angle of bank increases. As bank increases the aircraft experiences higher 'G' forces. 'G' is calculated as 1 / cosine Ø where Ø is the angle of bank. Stall speed increases proportional to the square root of 'G'.

Regardless of the ice thickness the boots have shed the ice in the expected way and ice thickness is not a critical parameter when to operate the boots. However, a minimum build-up of 1/4 inch of ice should be allowed before operating the boots to assure that the ice will crack and not form a bridge around the inflated boot and thereby make it impossible for the boots to remove the ice.

During the investigation the manufacturer advised BASI (now ATSB) it had received no reports of ice bridging around the de-ice boots on the Saab 340 aircraft.

Ice bridging is a phenomenon that has existed in folklore since the early days of aircraft operation when de-icing boots were first introduced to aircraft design. These early boots were characterised by long uninterrupted spanwise, large diameter tubes, which were inflated by low-pressure engine driven pneumatic pumps. This combination of low-pressure pump and long and large diameter tube for the de-ice boot resulted in a long inflation time. The subsequent deflation time was also lengthy, resulting in a long 'dwell time'. Dwell time is that time that the boot remains inflated between inflation and deflation.

Classic ice bridging occurred when ice accreted around the inflated tube and remained after the tube deflated. The resulting cavity beneath the ice allowed the tube to inflate and deflate beneath the 'ice bridge' resulting in no ice removal from the wing.

Modern turbo-propeller aircraft are equipped with a different form of de-ice boots. These boots are characterised by having short lengths of inflatable tubes that are segmented across the span and are of a much smaller diameter. They are inflated at much higher pressures by engine bleed air. This combination of high pressure air and shorter tube length and diameter results in very short dwell times, often less than 2 seconds in some configurations. This system results in a very effective system for ice removal.

Providing that the de-ice system (which includes the boots) are maintained correctly there is no documented evidence to date of de-icing boot ice bridging in modern turbo-propeller aircraft.

The certification test report also contained information on visible cues to detect ice build up on the aircraft. It stated:

the first sign of entering icing conditions is that ice starts to build-up on the windshield wipers. The wing leading edges also gives an early warning of entering icing conditions, especially when rime (white) ice starts forming on the black boots.

The report concluded that the first and best cue is ice accretion on the windscreen wipers.

1.6.18 Saab 340 aircraft flight manual definition of icing conditions

The limitations section of the aircraft flight manual defined icing conditions as:

Icing conditions exist when visible moisture in any form is present (such as clouds, fog with visibility of one mile or less, rain, snow, sleet, ice crystals) or standing water, slush or snow (hard packed snow excluded) is present on the ramps, taxiways or runways and the OAT or SAT is +5 degrees C and below during ground and flight operation.

1.6.19 Certification of Saab 340 aircraft in other countries

Both Luftfartsverket and the manufacturer advised that the Saab 340 has not been required to undergo any additional icing certification requirements in any country except Canada.

The flight certification testing in Canada resulted from analysis of the original flight test reports of the aircraft. Testing was carried out using a Saab 340B (WT)² aircraft and results analysed and then applied to the Saab 340A aircraft.

1.6.20 Introduction of the Saab 340 to Canadian operations

Transport Canada examined the Saab 340 before its introduction to operations in Canada in November 1994. Transport category aircraft in Canada are certified to FAR Part 25. Transport Canada followed the guidance of their own publications, Airworthiness Manual Advisories (AMA) 525/2X and 525/5X, to define the general requirement of FAR 25, that an aircraft could 'Safely Operate' in and after flight in icing conditions. In November 1994, Transport Canada concluded that there was no guidance material available to adequately describe compliance with the applicable section of FAR Part 25.1419 – Flight in Icing Conditions. Aircraft previously certificated for flight in icing conditions under FAR 25 used FAA advisory publication - advisory circular 20-73. Transport Canada did not consider that advisory circular 20-73 provided acceptable guidance on the flight testing of performance and flight characteristics in icing conditions, and therefore did not use this document when certifying the Saab 340.

During certification, Transport Canada reviewed many reports provided by the manufacturer when the aircraft was originally certified in 1985. As a result of that review, Transport Canada had significant concerns about the adequacy of stall warning and protection after flight in icing conditions, particularly in the flap 35 position. Subsequently, Transport Canada concluded that the Saab 340 aircraft had:

not been shown to comply with the Transport Canada requirements for approval of flight in icing conditions.

Transport Canada was specifically concerned the aircraft could stall after flight in icing conditions with no warning to the crew. The manufacturer included information in the Flight Procedures-Training section of the Saab 340 A aircraft operating manual, dated November 1996, which stated:

Do not perform training with iced up aircraft. Real stall might be encountered prior stall warning.

The manufacturer subsequently advised that this information was included in the manual as a result of a winter operations review.

To comply with the Canadian requirements, the manufacturer modified the stall warning system fitted to the Saab 340 aircraft by including the ICE SPEED modification.

1.6.21 Stall warning system fitted to Canadian operated Saab 340 aircraft

The stall warning systems fitted to Canadian registered Saab 340's are essentially the same as those fitted to Australian and other Saab 340 aircraft operated worldwide. However, to meet Transport Canada's requirements, an added input has been provided to the stall warning computers. This input is designated as ICE SPEED and is controlled by the activation of an ICE SPEED switch.

Activation of the ICE SPEED switch causes the stall warning computer to operate on lower triggering levels for the stall warning and the stall identification. The stall warning will

² This model of the Saab 340 is fitted with extended wing tips

operate at 5.9 degrees angle-of-attack with flaps at zero and at 2.1 degrees angle-of-attack with flaps in the 35 degree position. There is a linear movement of the triggering level between the flaps zero and flaps 35 position. The stall identification occurs at an angle-of-attack of 11.0 degrees regardless of flap setting.

Selection of ICE SPEED will inhibit the lower angle of attack triggering levels for 6 minutes after takeoff to prevent stick pusher activation if an engine failure occurs during this time.

Following certification flights in Canada, a supplement was included in the aircraft operating manual that related to Saab 340 Canadian operations. The supplement included a stall speed chart for operations with ice on the aircraft.

1.6.22 Operations manual – Australian regulatory requirements

Civil Aviation Regulation (CAR) 215 provides that an operator shall provide an operations manual for the use and guidance of its operations personnel. The manual must contain all relevant information, procedures and instructions concerning operations of the operator's aircraft that will assure the safe conduct of those operations. An operator may be 'directed' by CASA under CAR 215 (3) to include particular information in a manual or to revise or vary particular information in the manual.

Under CAR 215 (6) an operator is required to furnish CASA with a copy of the manual.

The operator used the manufacturer's aircraft operating manual to fulfil the requirements of CAR 215 for the operation of the Saab 340 aircraft.

1.6.23 Aircraft operations manual – Operations in icing conditions

The 'Normal Procedures' section of the Saab 340 aircraft operating manual contained a section dealing with aircraft operation in icing conditions. It directed the reader to section 5-5 of the aircraft flight manual.

Section 5-5 of the aircraft flight manual dealt with operation of the aircraft both before and after entering icing conditions. Before entering icing conditions the crew were required to activate the engine anti-ice systems. After entering icing conditions the crews were required to activate the propeller de-icing system only when ice accretion was observed on any part of the aircraft at temperatures of -5 degrees Celsius or colder. They were also directed to monitor ice build-up in accordance with the following information:

The windshield wiper arms give a visual clue of icing, although airframe ice can be present without any build up on the wiper arms. Wing ice will increase stalling speed. If it is not certain there is no ice accumulation on the aircraft, or if ice accumulation is observed on the aircraft, maintain an airspeed of not less than $V_{ref} + 10$ KIAS for landing and not less than 1.4 times the stall speed in any configuration. During climb, autopilot/flight director IAS mode is the only authorised mode. EN-ROUTE CLIMB SPEED WITH RESIDUAL AIRFRAME AND PROPELLER ICE gives the optimum climb gradient as well as the optimum rate-of-climb and is equal to 1.4 times the stall speed in the clean configuration. $1/2$ -bank mode is recommended to be used whenever possible.

The aircraft flight manual also contained the following section on the activation of the wing boot de-ice system:

Operate the BOOT DE-ICE system when ice has accumulated to approximately $1/2$ -inch (12 mm) thickness on the leading edges.

This information conflicted with the certification test flight report which indicated that de-icing boots should be operated when a minimum of 1/2 inch of ice had been accumulated on the leading edges.

The flight procedures section of the aircraft operating manual also advised that the boot de-ice system should not be activated until approximately 1/2 inch of ice had accumulated on the aircraft. The aircraft operating manual contained three separate supplements that provided information on icing and cold weather operations.³ Supplement number 4 recommended operation of the de-ice boots when between 1/4 and 1/2 half-inch (5 mm to 10 mm) was accumulated on the leading edges.

This information conflicted with the information provided in the aircraft flight manual and also with the certification test flight report.

There was no information in the manual on how to determine 1/2 inch thickness of ice accretion on the leading edge of the wing. There was also no device fitted to the wing to allow the crew to determine a 1/2 inch thickness of ice on the leading edges of the wings that are situated some 6.5 to 10 metres away from their flight deck stations.

1.6.24 Aircraft operating manual – Holding procedures

The aircraft operating manual contained section 25/6 titled FLIGHT PROCEDURES – DESCENT/HOLDING. The only information contained within this section dealing with holding was:

Use clean aircraft and V_{HOLD} (See sect. 27 SPEEDS)

1.6.25 Operator's operations manual – Holding procedures

The operator had included its own normal procedures section at the front of the manufacturer's aircraft operating manual. In this section (22/3) under the procedure titled INSTRUMENT APPROACH AND LAND – LLZ, ILS information was provided on crew duties to be undertaken in a holding pattern. The duties of the pilot flying were to:

If holding is necessary –
Set 30-40% TRQ,
Speed V_{CLEAN} (min)

The duty of the pilot not flying was to monitor the holding pattern entry.

Section 22/3 also contained information on INSTRUMENT APPROACH AND LAND-NDB, VOR. It advised crews that if holding was required, holding pattern entry was to be at VP (pattern speed). The section contained an additional reference to $V_{\text{P CLEAN}}$ (MIN) as a holding speed. These speeds were not defined by the manufacturer.

Neither the aircraft operating manual, aircraft flight manual or the operator's Policy and Procedures Manual contained any added information or guidance on holding procedures.

The pilot in command reported that as the aircraft began the holding pattern he may have checked his navigation charts for the holding procedure, and when the aircraft started to vibrate he checked that the propeller de-ice system was activated. Apart from those two

³ Supplement Number 1, Section 37/1 of the aircraft operating manual – Operation in Icing Conditions (issued December 23 1994)
Supplement Number 2, Section 37/2 of the aircraft operating manual – Cold Weather Operations (issued November 30 1996)
Supplement Number 4, Section 37/4 of the aircraft operating manual – Aspects of Operation in Icing Conditions (issued April 30 1997)

actions he reported that he could not be sure what he was doing after entry to the holding pattern was initiated.

1.6.26 Holding Speeds for the Saab 340

The aircraft operating manual section 27/1 referred to the various speeds applicable to the aircraft.

Holding Speed – V_{HOLD} was defined as follows:

The speed in a clean configuration for holding patterns. This speed is calculated to give a margin of 1.3 to V_S in a 25 degree banked turn and an additional 15 KIAS to compensate for turbulence, windshear etc. In icing conditions with residual ice on the wings, the speed will give at least a margin of 1.4 to V_S in a 25 degree banked turn. In icing conditions with severe turbulence or equivalent conditions a higher speed might be required. This speed shall not be considered as the minimum speed. If the above conditions do not exist, a lower speed may be used.

The section contained a chart to enable stall speed to be calculated. The chart showed aircraft weights in pounds. At the time of the occurrence, the stall speed (V_S) (wings level, uncontaminated wing) for the aircraft was calculated at 104 KIAS. The stall speed for 25 degrees angle of bank was calculated at 108 KIAS.

The section also contained a chart of holding speeds. From this chart the holding speed for the aircraft at ELW was extrapolated as 154 KIAS. However, calculated V_{HOLD} at the occurrence weight using 1.3 V_S 25 degrees angle of bank + 15 KIAS, was 156 KIAS, i.e., 2 KIAS greater than published V_{HOLD} . The prescribed V_{HOLD} for the icing conditions encountered at the time of the occurrence was 1.4 V_S in a 25 degree angle of bank turn. This was calculated to be 153 KIAS, i.e., 1 knot less than the published V_{HOLD} .

As a result of flight testing the manufacturer had obtained information concerning stall speeds applicable to operations in icing conditions ($1/2$ inch of ice on protected surfaces and 3 inches of ice on unprotected surfaces). However, this information was not published in the Saab 340 aircraft operating manual or aircraft flight manual that were current at the time of the occurrence. This information demonstrated that for a Saab 340 at the occurrence weight, V_S for flap zero, wings level⁴, would have been 121 KIAS. Based on this figure, the prescribed V_{HOLD} in icing conditions (1.4 V_S at 25 degrees angle of bank) would therefore have been 178 KIAS, i.e., 24 KIAS higher than the published V_{HOLD} .

The Canadian Saab 340 aircraft flight manual contained a chart for stall speeds with residual airframe ice (1 inch on protected surfaces, 3 inches on unprotected surfaces). This chart revealed that V_S would have been 126 KIAS. The prescribed V_{HOLD} in icing conditions would therefore have been 176 KIAS. The aircraft operating manual contained a supplement for Canadian operations. The supplement contained a definition of speeds similar to those contained in section 27/1. The definition for V_{HOLD} contained additional information that a speed of $V_{\text{HOLD}} + 20$ KIAS would give at least a margin of 1.3 to V_S .

This supplement also contained a chart of holding speeds. The speeds were identical to the chart published in section 27/1 of the aircraft operating manual. However, the chart carried a note stating:

if there is ice accretion or if it is not certain there is no ice accretion on the wing, add 20 KIAS to compensate for turbulence, windshear, etc.

There was no such note on the holding speed chart in section 27/1.

⁴ The chart did not contain an axis for calculation of V_S in a turn. Using the formula $V_S \times \sqrt{G}$, V_S in a 25 degree angle of bank turn was calculated to be 127 KIAS.

Based on the Canadian information the V_{HOLD} for the aircraft at ELW would have been 174 KIAS.

1.6.27 Unusual engine vibrations – Alert Bulletin No. 19.

On 4 June 1993, the manufacturer issued Alert Bulletin Number 19, which was incorporated into the aircraft operating manual. It contained the following information:

propeller vibrations are common, particularly in icing conditions. This may be caused by uneven ice accretions and ice shedding, and is often accompanied by the sound of ice particles hitting the airframe. The vibrations can be from low to high and are about similar from both propellers in this case.

1.7 Meteorological Information

ELW is located within forecast Area 30. At the time of the occurrence Area 30 was under the influence of a high-pressure ridge which was entering the Bass Strait area from the Great Australian Bight. A low-pressure centre was also located just to the north of Swan Hill, Vic., with a trough extending through eastern Victoria to the Tasman Sea. A moist east to south-east air stream extended across the state.

Middle level cloud, mainly altostratus, was widespread across the state and rain was reported at most observing sites throughout the day.

A radiosonde trace from Laverton, Vic. at 1000 UTC showed that moist atmospheric conditions extended to above 20,000 ft. The freezing level was reported to be at 10,000 ft. Moderate icing was forecast in the middle level cloud on the Area 30 forecast.

1.8 Aids to navigation

The ELW VOR was serviceable at the time of the occurrence.

1.9 Communications

The aircraft was in contact with air traffic control and recordings of the occurrence provided details of the holding instructions given to the aircraft. They also confirmed that the aircraft following VH-LPI requested descent because it encountered icing conditions at FL 180.

An investigation of this occurrence by Airservices Australia revealed that the controller first became aware of icing in the area when the aircraft following VH-LPI requested descent due to icing. The Airservices Australia investigation revealed that when the crew of VH-LPI requested descent over ELW, they did not disclose to the controller they had experienced a loss of control.

The first indication that the controller had that operations were not normal was when the crew of VH-LPI requested to hold at FL 130 due to icing and that they had lost altitude. At that stage the aircraft was at FL 133. The crew of the aircraft did not request clearance nor did the controller clear the aircraft to descend from FL 150.

1.10 Aerodrome information

Not relevant to the investigation.

1.11 Recorded information

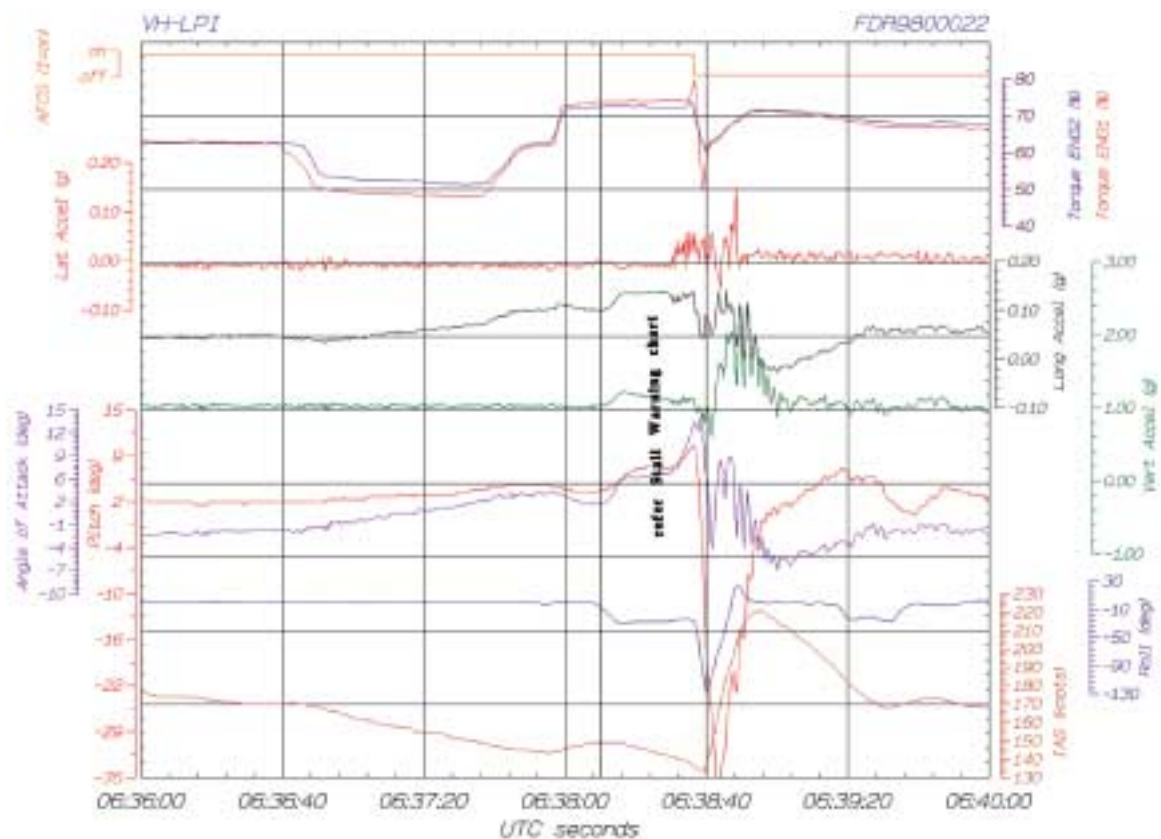
The aircraft was fitted with both a cockpit voice recorder and a flight data recorder. After the occurrence the aircraft completed a further 2 flights before the operator became aware of the full nature of the incident. The cockpit voice recorder only recorded the last 30 minutes of crew communications and radio transmissions. It was therefore unable to provide information about the occurrence as more than 30 minutes of flight had subsequently taken place and so the occurrence sequence had been overwritten.

The flight data recorder was a Lockheed Aircraft Services Co. digital flight data recorder coupled to a Telephonics Flight data acquisition unit. It recorded 54 different parameters. The data was successfully recovered using the Bureau's Recovery, Analysis and Presentation System.

UTC time was correlated to the data using a VHF transmission from the aircraft correlated with the corresponding recording on the Airservices Australia aerodrome voice recording (AVR) tape.

Figure 2 shows a graphical representation of the recorded values of indicated airspeed, pitch, roll, angle of attack, vertical, longitudinal and lateral accelerations, engine torque and autopilot setting in the time leading up to the occurrence and immediately after it.

FIGURE 2:
Recorded values



At 06:29:15 the aircraft reached the top of climb at FL 150. The recorded torque value was 63%. The aircraft remained in this configuration until 06:36:38 when the torque was reduced to 47%. The angle-of-attack before the reduction of the torque was -1.4 degrees. The reduction in torque occurred over 12 seconds. The indicated airspeed at the beginning of the reduction was 170 KIAS. At 06:37:36, when the airspeed was 149 KIAS, the torque increased to 62%. The increase in torque took 14 seconds. The airspeed continued to decrease until 06:37:50 when it reached 144 KIAS, where it remained constant for

8 seconds. At 06:37:56 the torque was increased to 74% over 5 seconds. The airspeed began to increase at 06:37:58 and reached 149 KIAS at 06:38:07. The aircraft began a left-hand turn at 06:38:08, with a recorded bank angle of 28 degrees. The indicated airspeed remained at 149 KIAS. The recorded angle-of-attack then was 4.5 degrees.

At 06:38:16 the indicated airspeed began to decrease again, and the angle-of-attack reached 5.6 degrees. A small decrease in the angle of bank was recorded at 06:38:30, and the angle-of-attack was approximately 6 degrees.

At the same time the ailerons moved in a direction to roll the aircraft to the left. This was in response to the autopilot trying to return the aircraft to the full-bank mode angle preset by the crew on the autopilot. The indicated airspeed was 141 KIAS. An increase in the recorded lateral, longitudinal and vertical acceleration data began at 06:38:31. At 06:38:32 the angle of bank was 23.5 degrees to the left, and the indicated airspeed was 140 KIAS. The pitch attitude of the aircraft was 7.7 degrees nose up and the angle-of-attack was 7.5 degrees. The angle-of-attack reached 12.7 degrees at 06:38:36.13 and at 06:38:36.33 the autopilot disconnected. The indicated airspeed was 136 KIAS and the angle of bank was 27 degrees to the left.

The aircraft began to roll rapidly to the left at 06:38:37, and the angle-of-attack reached 13 degrees. The airspeed continued to decrease to 135 KIAS. One second later the roll attitude was 75 degrees to the left and the nose began to pitch down. At 06:38:39 the minimum recorded airspeed of 133 KIAS was reached. At that time the angle of bank was 112 degrees to the left and the pitch 6.3 degrees nose down. The angle-of-attack was 9.6 degrees. The maximum angle of bank of 126.6 degrees to the left was reached at 06:38:40. The aircraft speed increased to 139 KIAS and the pitch was 19 degrees below the horizon. At 06:38:41 pitch was 25 degrees nose down and angle of bank was reducing to 110 degrees to the left. Airspeed had increased to 147 KIAS, and angle-of-attack was -2.8 degrees.

The aircraft reached the maximum nose down pitch of 35.8 degrees at 06:38:43, and the angle of bank had decreased to 71 degrees to the left. The airspeed had increased to 164 KIAS and the angle-of-attack was 5.1 degrees. The aircraft regained a wings level attitude at 06:38:47, at which stage the airspeed was 194 KIAS and increasing and pitch was 21 degrees nose down. At 06:38:53 when the aircraft was descending through 12880 ft, the airspeed of 220 KIAS. The angle of bank was 1 degree to the right and the pitch attitude was 6 degrees nose down.

The aircraft reached the lowest recorded altitude of 12704 ft at 06:38:56. The pitch attitude was zero and the airspeed was 220 KIAS. At 06:39:53 the AVR tapes record the crew making a call to the controller asking for a lower altitude due to icing. The autopilot was re-engaged at 06:42:48.

1.11.1 Control surface sensors

The control position sensors for the ailerons, elevator and rudder are potentiometers. They measure control surface positions and relay this information to the flight data acquisition unit. As the sensors begin to wear, the data becomes unreliable, particularly around the zero deflection point. As the control position sensor moves away from the centre position, the data becomes more reliable. In this occurrence it was apparent that the recorded data for the right and left aileron positions suffered from this phenomenon.

To satisfactorily overcome this problem, obvious errors in the data were removed. Except for the data immediately surrounding the incident, a cubic spline routine⁵ was used to

⁵ A mathematical routine used to interpolate a data stream.

interpolate the data. Data from the left elevator and the rudder provided consistently erroneous values and was not analysed.

1.11.2 Manufacturer's analysis of recorded data

BASI provided the manufacturer with the recorded data to permit them to conduct their own analysis of the occurrence. The manufacturer advised that it had found the data reliable and had performed a number of comparison analyses against flight test data obtained under various test flight conditions.

The manufacturer concluded that the aircraft had stalled and that it was likely this resulted because a significant amount of ice had been allowed to accumulate on the leading edges of the wing. This amount of ice was considered to have been greater than that allowed on the protected areas of the wing prior to the activation of the de-ice boots as prescribed in the aircraft operating manual.

The manufacturer advised that it considered there was a significant increase in drag just prior to the stall and that this could not be interpreted as a rapid build up of ice, nor could they rule out a moderate increase in the ice present during that time.

Drag levels at lower lift coefficients (corresponding to the period some 4 to 5 minutes before the stall) were also analysed and these revealed there was a significant amount of drag increase above that recorded during flight testing with 1 inch artificial ice shapes (without roughness).

The manufacturer's analysis confirmed that the autopilot tried to return the aircraft to the commanded 27 degrees angle of bank when the airflow separation on the inner section of the right wing began. As this progressed and more airflow separated from the wing, the aircraft rolled to the right. The autopilot was programmed for 27 degrees angle of bank in a full rate turn. The manufacturer stated that if the angle of bank increased above or decreased below 27 degrees, the autopilot would command the flight controls to move in the appropriate direction to regain the programmed angle of bank.

The manufacturer's analysis concluded there was nothing in the data suggesting a fault with the autopilot, or was there evidence of any system fault within the aircraft that may have contributed to the occurrence.

The manufacturer advised that the buffet experienced by the crew before the stall and loss of control was pre-stall buffet and that this had not been recognised by the crew. They also advised that no excessive flight loads had been imposed on the aircraft during the stall or subsequent recovery.

1.12 Wreckage and impact information

Not relevant to the investigation.

1.13 Medical information

There was no evidence that either crewmember was suffering from any condition that may have affected their performance.

1.14 Fire

Not relevant to the investigation.

1.15 Survival aspects

Not relevant to the investigation.

1.16 Tests and research

Following the occurrence the aircraft was test flown by the operator's Chief Pilot and CASA flying operations inspectors. They advised that the aircraft had performed in accordance with the aircraft flight manual criteria, including stall warning and identification.

1.17 Other information

1.17.1 Other occurrences involving Saab 340 aircraft in icing conditions

ATSB (then BASI) requested both Luftfartsverket and the manufacturer to provide information on other Saab 340 loss of control events while operating in icing conditions. Luftfartsverket reported they were not aware of any, other than the tail icing incidents that occurred shortly after the aircraft was introduced to service, and the occurrence that is the subject of this report. The manufacturer reported the only loss of control event that it was aware of had occurred in June 1994.

Subsequent investigation by BASI and the ATSB identified several other such events involving Saab 340 aircraft, and that the manufacturer had investigated three of these.

On 23 September 1991, a European operated Saab 340 experienced pre-stall buffet during climb in icing conditions. Subsequently, the left wing dropped and shortly afterwards the autopilot disconnected. The crew regained control and descended the aircraft approximately 4,000 ft. The crew reported that only a moderate amount of ice was present on the wings and that they had operated the de-icing boots at least once during the climb. It was also reported that there was 'a sandpaper like' deposit of ice on the wings and propeller spinners. Analysis of this event by the manufacturer revealed the crew had been operating the aircraft in an incorrect autopilot mode during climb.

The manufacturer's performance analysis of this event concluded drag increase from ice on the aircraft was between 4–6%. The manufacturer stated:

As the nature of ice accretion is very unpredictable there are reasons to believe that the predicted performance will cover the main part of icing encounters but there might be occasions that will result in an increased performance degradation.

The manufacturer's report also contained the following analysis of the stall speed in the occurrence:

Experience from flight test with simulated ice shows a 10% increase in stall speed...with 3 inches of simulated ice on the inner wing, flight test has shown an increase in stall speed of 18% in clean (flaps up) configuration. It has also been proven during all our flight tests with natural and simulated ice that the aircraft does not exhibit any uncontrollable roll and pitch manoeuvres at stall.

As a result of this event the manufacturer issued an aircraft operating manual bulletin. This was issued as Operations Bulletin number 44 to the Saab 340 aircraft operating manual on December 21 1994. Subsequently, the bulletin was incorporated into the aircraft operating manual as 'Supplement No. 1 Operation in Icing Conditions' (refer footnote 3 for information on aircraft operating manual supplements concerning icing and cold weather operations).

The supplement included information that the stall speed would increase in icing conditions. This increase was quoted as being '10% for flight with 1/2 inch of simulated ice and 18% with 3 inches of simulated ice' (clean, flaps up configuration). It also included information that stall warning in the form of buffeting may be experienced at speeds up to 25% above the clean (ice free) stall speed.

Investigation by BASI also revealed that similar events had occurred with two other Saab 340 aircraft operated by the same European operator during the preceding two days. These events also took place in icing conditions. No analysis was available for these other incidents.

On 23 March 1994, a United Kingdom operated Saab 340 encountered icing conditions during climb. Although the rate of ice build-up observed by the crew did not appear to be heavy, aircraft performance progressively deteriorated. The wing de-ice boots were not activated. A severe vibration commenced and the crew thought that ice on the left propeller was responsible. The autopilot then disconnected, and the aircraft rolled rapidly to the left to about 60 degrees angle of bank. Analysis of the event by the manufacturer revealed that the aircraft had stalled and rolled to the left with little or no warning to the flight crew. A contributory factor of the occurrence was that the crew had been operating the aircraft in an inappropriate autopilot mode during the climb.

On 12 June 1994 a New Zealand operated Saab 340 aircraft was involved in an incident while operating in icing conditions. The aircraft was instructed to enter a holding pattern at 11,000 feet. The crew had operated the engine and propeller anti-ice systems in accordance with the flight manual instructions and had just cycled the wing de-ice boots to remove a small amount of ice accretion. The indicated airspeed dropped from 180 KIAS to 140 KIAS and the aircraft sustained severe vibration from a suspected propeller imbalance due to ice deposits. The crew disconnected the autopilot and lowered the nose to regain airspeed. As this happened the aircraft began to roll up to 30 degrees to the left and right, with little response from the flight controls. This continued until the airspeed increased to 180 KIAS.

Subsequent analysis of this occurrence by the manufacturer concluded that the aircraft had entered a stall condition. The roll control difficulties experienced by the crew were similar to the flight test experience with the Saab 340 during the Canadian certification tests. The manufacturer reported that the ice accumulation on the aircraft involved in this occurrence would have been rough due to the temperature of minus 7 degrees Celsius.

In February 1998, the crew of a United States operated Saab 340 reported that during the climb to 16,000 ft they had experienced icing conditions. After the crew had levelled off, the stall warning system activated and the left wing dropped. The aircraft continued to react sluggishly to aileron and elevator control until the crew had descended the aircraft to 11,000 ft. The pilot in command reported there was a small amount of mixed ice on the airframe and that he did not want to activate the de-icing boots for fear of 'ice bridging'. He also described the ice shape as being 'odd, like a mushroom'.

1.17.2 Accidents and incidents involving other turboprop aircraft in icing conditions

In August 1991, a British Aerospace ATP aircraft sustained severe vibration while climbing to altitude in icing conditions. The aircraft subsequently stalled. The crew did not receive a stall warning prior to the stall. As part of this investigation, data from the University of Wyoming revealed two facts.

One, that aircraft involved in icing study research had encountered conditions that were outside the maximum continuous icing envelope in FAR part 25.

Two, there had been icing encounters where conditions were within the FAR part 25 appendix C icing envelopes. The subsequent ice accretion however, resulted in performance degradation not equal to the ice observed on the aircraft at the time. In fact, the crew of one research aircraft had to take rapid action to leave icing conditions. Once the aircraft had left icing conditions, and with residual ice remaining, the aircraft was subjected to manoeuvres to assess its performance. Results from these manoeuvres revealed significant buffet could be experienced at airspeeds far above the expected stall speed.

In October 1994 an ATR-72 aircraft crashed at Roselawn Indiana, USA while holding in icing conditions. The National Transportation Safety Board (NTSB) of the USA investigated the accident. Twenty-four recommendations that dealt with operations in icing conditions were issued. The NTSB determined that the probable cause of the accident was a loss of control attributed to a sudden and unexpected aileron hinge moment reversal that occurred after a ridge of ice accreted beyond the de-ice boots.

There is no evidence that this phenomenon occurred during the loss of control event involving VH-LPI over Eildon Weir.

On 9 January 1997 an Embraer 120 aircraft crashed at Monroe Indiana, USA while operating in icing conditions. The NTSB also investigated that accident. It issued 17 recommendations that dealt with operations in icing conditions. The NTSB determined that the probable cause of the accident was the failure of the FAA to establish adequate aircraft certification standards for flight in icing conditions.

The NTSB has also made recommendations dealing with the adequacy of FAR part 25, appendix C to define safely the icing conditions in which an aircraft is to operate.

2.1 Introduction

The main purpose of the investigation of air safety occurrences is the prevention of aircraft accidents. To that end, a primary objective of such an investigation is to establish what happened, how it happened, and why the occurrence took place. It is of equal and often greater importance for the investigation to determine also what the occurrence reveals about the safety health of the broader aviation system. That information is used to make recommendations aimed at reducing or eliminating the probability of a repetition of the same type of occurrence, and where appropriate, to increase the overall level of air safety.

To produce effective recommendations, the information collected and the conclusions reached must be analysed in a way that reveals the relationships between the individuals associated with the occurrence, and the design and characteristics of the systems within which those individuals operate.

For the purposes of broad systems analysis, the Bureau uses an analytical model researched and developed by Professor James Reason of the University of Manchester. The principles of the Reason model are described in detail in his book *Human Error* (1990), and further developed in a paper presented to the International Society of Air Safety Investigators 22nd Annual Seminar 1991 (*Identifying the Latent Causes of Aircraft Accidents Before and After the Event*).

The Reason model is becoming an industry standard, and has been recommended by ICAO for use in investigating the role of management policies and procedures in aircraft accidents and incidents (ICAO Accident Investigation (AIG) Divisional Meeting (1992) Report, para,1.10.2.2).

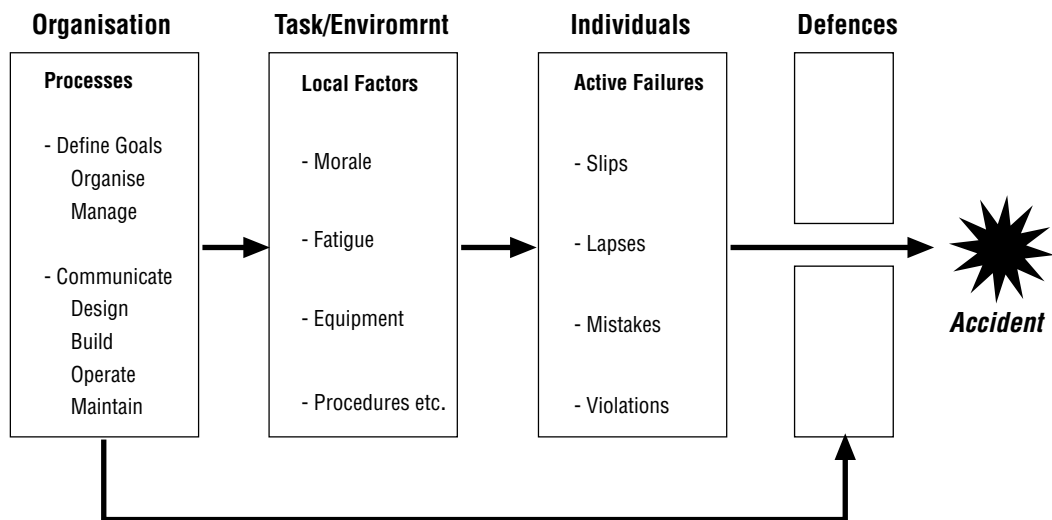
Central to Reason's approach is the concept of the 'organisational accident', in which *latent failures* arising mainly in the managerial and organisational spheres combine adversely with local triggering events (weather, location, etc.) and with the *active failures* of individuals at the 'sharp end' (errors and procedural violations)(Reason, 1991 p. 1).

Common elements in any organisational occurrence are;

- a. **latent failures** which arise from deficiencies in managerial policies and actions within one or more organisations. Often these organisational factors are not immediately apparent and may lie dormant for a considerable time
- b. **local factors** are conditions which can affect the occurrence of active failures. These include such things as task and environmental conditions
- c. **active failures** are errors or violations which have an immediate adverse effect. These unsafe acts are typically associated with operational personnel
- d. **inadequate or absent defences** which failed to identify and protect against technical and human failures arising from the three previous elements.

The relationship between these elements in the process of accident causation is shown in the accompanying diagram (figure 3).

FIGURE 3:
Diagram of the basic Reason Model showing the elements of an ‘organisational accident’.



Experience has shown that occurrences are rarely the result of a simple error or violation but are more likely to be due to a combination of a number of factors, any one of which by itself was insufficient to cause a breakdown in safety. Many of those factors can lie hidden within organisations for a considerable time prior to the occurrence, and can be described as latent failures. When combined with local events such as active failures and possibly unusual environmental circumstances, the resulting combination of factors may result in a safety hazard.

Should the system’s defences be absent, or inadequate, a failure of the system is inevitable.

An insight into the safety health of an organisation can also be gained by an examination of its safety history, and of the environment within which it operates. A series of apparently unrelated safety events may be regarded as tokens of an underlying systemic failure of the overall safety system; typical examples being: training deficiencies; ineffective supervision of flight operations; and inadequate aircraft maintenance procedures.

The following analysis is structured in accordance with the Reason model, and utilises its terminology.

The aircraft stalled shortly after entering the holding pattern at ELW. The co-pilot had allowed the airspeed to decrease below the holding speed for the aircraft weight. However, the pilot in command had noticed this and brought it to the attention of the co-pilot, who had taken corrective action. Although it appeared that the crew were acting in accordance with two-crew normal operating procedures, following this initial interaction, very little evidence is available that supports a continuance of it as the aircraft entered the holding pattern.

The operator’s and the manufacturer’s operating manuals were not clear in the presentation of information, procedures and guidance that would have prevented this occurrence.

The aircraft had also accumulated a deposit of ice, which was known to the crew, who had activated the engine and propeller anti-ice systems. However, the deposit of ice was not interpreted by the crew as meeting the criteria for the activation of the wing de-ice system as outlined in the aircraft operating manual and aircraft flight manual. This non-

activation of wing de-ice systems has been a major factor in numerous accidents and incidents involving other turboprop aircraft. This has been largely due to crews not wanting to form an 'ice bridge' around the inflated de-ice boot and therefore render them ineffective. 'Ice bridging' has been a 'myth' that is founded on little factual evidence in modern turbopropeller driven aircraft.

As the aircraft speed decreased and the aircraft approached the stall, airflow separation in the form of a buffet, which forms part of the normal stall sequence in this aircraft type was noticed by the crew as a vibration within the aircraft. They misinterpreted this vibration as an ice induced propeller imbalance. Correct certification required that a stall warning should not be misinterpreted by the flight crew.

When the aircraft met the criteria for the activation of the stall warning system, the autopilot disconnected, prior to the activation of either the stick shaker or aural stall warning. The time between the disconnection of the autopilot and the subsequent stall was less than a second. The crew did not receive a stall warning and as a result the aircraft stalled and experienced a loss of control, a serious event in the operation of any aircraft. Had the event taken place in a holding pattern closer to terrain the outcome would probably have been catastrophic and involved loss of life. The stall warning system acts as a last line of defence prior to a stall, and in this occurrence it did not activate and therefore failed to provide any warning to the crew.

Inadequate stall warning in icing conditions had been a concern of Transport Canada when the aircraft was introduced for operations in Canada in 1994. Despite a modified stall warning system for the Saab 340 being mandated for operations in that country, the system was not mandated to other aircraft worldwide. Application of the warning margins of the modified system to this occurrence revealed that had the aircraft been equipped with this system and it was activated by the crew, there would have been a warning provided to the crew.

Although the crew had performed stall recognition and recovery training during their initial endorsements and subsequent recurrent simulator training, there was no formal training in recognition and recovery from unusual attitudes. This was evident from the description of the of the electronic attitude director indicator by both crew members following the upset. Even though a simulator had been recently utilised for crew training, the operator had not fully utilised its capabilities, nor had the operator transferred the training from the aircraft to the simulator in an appropriate fashion.

The crew were controlling the aircraft using the autopilot, despite recent accident investigations revealing that the use of the autopilot in icing conditions may mask telltale signs of aerodynamic performance degradation.

Also the operator had been instructed by the regulator to use an autopilot mode in holding patterns that was incompatible with icing operations.

A number of recommendations were made during the course of this investigation. (See section 4.2)

2.2 Non operation of de-icing boots

The crew was aware that icing conditions were forecast for the return flight to Melbourne. They had monitored the outside air temperature as the aircraft climbed and activated the engine and propeller anti-ice systems when appropriate.

The crew was also aware that the windscreen wiper arms presented the best method for detecting ice on the aircraft. This was the method that the manufacturer had discovered as

a result of icing certification flight testing. The conclusion of the flight test report was that the first and best method of detecting ice deposits was the windscreen wiper arms. However, the information in the aircraft operating manual conflicted with this because it indicated that ice could be present on the aircraft without any indication to the flight crew.

The information contained in the aircraft operating manual and aircraft flight manual, on activation of the de-ice boots supported the 'myth' of ice bridging. Even the icing certification flight test report provided a requirement to activate the de-ice boots when at least a 1/4 inch of ice had accreted, adding further weight to the concept that ice bridging was a concern with the Saab 340. The crew's previous experience on the Saab 340, and the information contained in the manuals caused them to be influenced by the 'ice bridging myth'. Although it referred to ice bridging in their certification test reports, the manufacturer was not aware of any occurrence involving ice bridging resulting from early activation of de-ice boots on any models of their aircraft. Consequently the manufacturer provided no guidance in the aircraft flight manual or the aircraft operating manual and its supplements that ice bridging was not a concern.

The information presented in the aircraft operating manual was inconsistent. One section of the manual advised to wait for a 1/4 inch of ice to accrete, yet in another section it advised to wait for a 1/2 inch of ice to accrete. Neither section provided guidance on how crews were to judge these amounts of ice.

The aircraft was operating in icing conditions, however it was not in the temperature band (defined in the flight test report as being colder than -20 degrees Celsius) where residual ice remains after activation of the boots. Although this information on differing shedding rates at differing temperatures was discovered in the flight testing for the certification of the aircraft, it was not included in any of the operating manuals for the aircraft. Despite the manufacturer making revisions to the operating manuals as a result of occurrences involving Saab 340 aircraft in icing conditions, this information is still not included in either the aircraft flight manual or aircraft operating manual for the aircraft, and remains unavailable as guidance to operational flight crews.

A number of other accidents and incidents in icing conditions have resulted from flight crews misinterpreting the significance of the thickness of ice deposits. Consequently, they failed to activate the wing de-ice boots. Although the Saab 340 has not been involved in an accident in icing conditions, it has nevertheless been involved in a number of incidents in icing conditions.

In 1998, the NTSB recommended that this information be included in flight manuals as a result of the accident investigation into the crash of an EMB-120 aircraft. The manufacturer amended the aircraft operating manual/aircraft flight manual in October 1999 to include a requirement to activate the wing de-ice boots in the continuous mode at the first sign of ice accretion on the aircraft. Had this information been included in the aircraft operating manual as a standard operating procedure, the crew of the aircraft would then have had appropriate guidance on when to activate the de-ice boots. Had this guidance been available and followed by the crew it is likely that the ice deposit would have been removed. Even though the crew was not monitoring airspeed as closely as they should have, if the boots had been activated and the ice deposit removed, then it is more than highly probable that the incident would not have occurred.

In the absence of specific guidance on operation of wing de-ice boots in the continuous mode at the first sign of ice accretion, the decision by the crew not to use wing de-ice boots was understandable. Their reliance to detect and act upon a not easily quantifiable and often misjudged amount of ice, coupled with the absence of an ice detector system,

and the fact that neither crewmember was overly concerned about the ice deposit, contributed to this decision. However, failure to activate the wing de-ice boots did not afford the crew the necessary protection against an inadvertent stall, especially when the amount of ice on the wings had been misinterpreted.

The ice deposit on the aircraft's wings probably started as a thin deposit of rime ice. However it is likely that a layer of clear ice subsequently accreted over the rime ice as the flight progressed. The deposit of ice was unlikely to have exceeded the 3 inch layer on unprotected surfaces that had been required during certification, as even this amount of ice would obviously have been detected by the crew. It is possible however, that the deposit of ice exceeded the 1/2 inch requirement on protected surfaces. The analysis of recorded flight data by the manufacturer revealed that the increase in drag just prior to the incident could not be interpreted as a rapid build-up of ice nor could they rule out a moderate increase in ice during that time.

In previous occurrences a rapid build up of ice had resulted in an easily detected and rapid decrease in indicated airspeed. In this occurrence the recorded information revealed no evidence that a rapid decrease in airspeed had occurred. It is therefore concluded that the ice was unlikely to have rapidly increased in the period just prior to the stall, rather the deposit slowly accreted over time.

Evidence from other flight testing and research has found that the layer of ice does not need to be thick to cause degradation in aircraft performance. In the occurrence on 23 September 1991, the crew described the ice deposit as resembling 'sandpaper', indicating it was likely to have been a thin deposit. Despite operation of the wing de-ice boots the aircraft still stalled.

In the New Zealand Saab 340 occurrence a temperature of minus 7 degree Celsius had resulted in a rough deposit of ice being accreted which adversely affected the performance of the aircraft. If there was a rough surface to the ice deposit then the degradation in aerodynamic performance could have easily exceeded any certification results.

The FAA issued airworthiness directive 99-19-14 on 27 December 1999 requiring that the aircraft flight manual of the Saab 340 aircraft be modified. The modifications were to include a requirement for activation of the pneumatic de-ice boots at the first sign of ice accretion anywhere on the aircraft or annunciation of an ice detector system (if installed), whichever occurred first. The airworthiness directive also required continued activation of the de-ice boots whenever the aircraft remained in icing conditions. The FAA also stated that fitment of reliable ice detection systems would assist crews' recognition and interpretation of ice accretion.

Equipping the Saab 340 with an airframe ice-detector system would assist crews, and the implication in the aircraft operating manual is that this optional system is for airframe ice detection. However, the manufacturer has subsequently advised that the system only alerts the crew to the fact that they have not turned on the engine anti-ice system

The decision not to mandate fitment of an airframe ice detection system is questionable. The performance of any aircraft in icing conditions is less than optimal, as was the case in this occurrence.

The FAA also assessed 'ice bridging' during the development of airworthiness directive 99-19-14. Following considerable discussion amongst a large cross section of the aviation community, the general consensus was that there is little if any evidence to support the phenomenon that ice bridging can occur when aircraft are equipped with modern high pressure de-ice boots.

2.3

Speed allowed to decrease below the holding speed

The pilot in command cautioned the co-pilot to monitor his airspeed when it reduced below the target speed of 154 KIAS. The co-pilot responded by increasing the engine torque from 47% to 62%. He then further increased the torque to 73% when the speed was not increasing as fast as he would have liked.

The original power setting of 47% torque was expected to achieve the holding fuel flow of 400 lph. Neither crew member appears to have been concerned that it became necessary to increase torque by 26% in order to remedy the underspeed situation. Nor did they identify the reason for the initial speed degradation that required such a large power increase to overcome.

The speed initially stabilised after power was increased. However, the resultant torque setting of 73% was greater than that required during the cruise. Neither crewmember appears to have been concerned at this apparent anomaly. It appears likely that they both lacked situational awareness about what was causing the adverse effect on the aircraft performance.

After the co-pilot had corrected the under-speed it is likely he became preoccupied with entry into the holding pattern at ELW. As a consequence, he did not continue to monitor the airspeed. It is likely that he suffered from a 'confirmation bias'. By confirming that the underspeed had been remedied, continued attention to the underspeed condition was therefore unnecessary.

The Saab 340 requires two pilots to operate in accordance with its Type Certificate Data sheet. Consequently the flight crew must operate in a team environment. The pilot in command detected a decrease in airspeed below that which was required. He brought this to the attention of co-pilot, who then rectified the situation. Because the initial decrease in airspeed had been brought to the attention of the co-pilot (indicating that normal procedures were in place and working), it seems reasonable to assume that the co-pilot believed any further speed anomalies would be brought to his attention. This did not occur.

The operator's Saab 340 flight documentation specified that the non flying pilot must monitor the entry to the holding pattern. The documentation contained no other standard operating procedures for holding manoeuvres. The holding pattern that the crew proposed to execute at ELW was not a normal holding pattern. Their original intention was to adjust the outbound leg to enable them to meet the onwards clearance time. The pilot in command (the non-flying pilot) was not sure of what he may have been doing as the aircraft entered the holding pattern. The lack of standard operating procedures for holding was a missing defence.

2.4

Crew coordination

There is sufficient evidence to suggest that a clearly developed error chain was present in the events preceding the loss of control experienced by the aircraft. A significant factor in the development of the error chain was a loss of situational awareness by the crew.

The maintenance of situational awareness is an essential task for flight crews. It results in an ongoing internalised and current mental model of the state of the flight environment that facilitates appropriate decision-making and actions. Situational awareness therefore involves the perception of critical factors in the flight environment, an understanding of the meaning of those factors, and finally, an assessment of how they will affect the flight.

The pilot in command correctly identified that an underspeed condition existed, and the co-pilot responded by increasing engine torque to remedy that condition. However, the resultant torque setting of 73% to maintain speed was substantially above the aircraft operating manual holding torque setting of 30% - 40%. As such, there was an unresolved discrepancy between the torque setting required to maintain speed. Neither crewmember appears to have been concerned by this conflict of information. Consequently there was a failure to correctly perceive the information and to correctly comprehend its meaning and significance.

Crew Resource Management (CRM) is an effective tool for improving individual situational awareness. This leads to the effective development of shared mental models in multi-crew aircraft operations. However, unless the individuals have sufficient knowledge, skills or experience, it is impossible to develop optimum levels of shared mental models. The information contained in the aircraft operating manual was less than adequate for flight in icing conditions, and the specified holding speeds were insufficient to prevent the loss of control experienced by the aircraft. Additionally, the training provided to the crew for recovery from loss of controls in the Saab 340 was less than adequate, and did not include the recovery information provided by the electronic attitude director indicator during flight at extreme pitch and roll attitudes.

CRM training for flight crew was not mandated by CASA at the time of the occurrence involving the aircraft, and will not become a mandatory regulatory requirement until the introduction of Civil Aviation Safety Regulation 121 in 2003.

Following an occurrence involving a Saab 340 in 1992, the Bureau of Air Safety Investigation (BASI, now ATSB) suggested that the Civil Aviation Authority (now CASA) consider developing programs of CRM for low capacity transport operators. It was suggested that these programs would ensure that all crews would be able to effectively apply the principles of CRM. It was also suggested that the authority consider introducing surveillance of CRM practices. Following an occurrence involving a Boeing 747 in 1994, BASI issued a recommendation that CASA require operators involved in multi-crew air transport operations to ensure that pilots received effective training in CRM principles. It was recommended that CASA publish a time table for the phased introduction of CRM training to ensure that:

- i) CRM principles were made an integral part of the operator's recurrent check and training program and where practicable, such training should be integrated with simulator LOFT exercises;
- ii) CASA provided operators and/or CRM course providers with an approved course syllabus based on international best practice; and
- iii) such training integrated cabin crew into appropriate aspects of the program; and
- iv) the effectiveness of each course is assessed to the satisfaction of the CASA.

Aircraft icing continues to be one of the major safety threats to aircraft operations during hazardous weather conditions and can result in catastrophic accidents unless adequate precautions are taken. These precautions include the provision of proper information to crews on operations in icing conditions, and appropriate training programs for crews. These should include training for improved situational awareness as part of structured training for CRM, and training for all phases of flight that may be encountered.

Effective CRM training has the potential to assist crews in developing appropriate shared mental models for all phases of flight. However, an essential defence in the prevention of

recurrence of similar events will remain missing until such time as CRM becomes a mandatory component of an operator's training program.

The Operator in this occurrence had implemented a CRM program, despite it not being mandated by CASA.

2.5 Unusual attitude recovery training

The operator had trained its crews in recognition and recovery from unusual attitudes during their initial aircraft training. Pitch and roll limits had been imposed during unusual attitude training on the aircraft. When the Saab 340 flight simulator was introduced to the operator's training program the same pitch and roll limits were retained. The operator therefore did not fully utilise the simulator capabilities for the crew training program. This was a latent failure.

The aircraft flight manual and aircraft operating manual did not contain any information regarding recovery from unusual attitudes. The comment by the crew that the EADIs were a 'mess of blue and brown' is not surprising. None of the operator's crews had been exposed to the extreme flight attitudes that the crew of the aircraft encountered during the loss of control. The lack of information in the aircraft flight manual and aircraft operations manual on unusual attitude recovery was a missing defence.

The electronic attitude director indicator display presentations on the operator's CASA-approved Saab 340 flight simulator differed from those described in the aircraft operating manual when pitch exceeded 30 degrees nose up, 20 degrees nose down, or 65 degrees roll. When the manufacturer published revised information on recovery from unusual attitudes in 1999, it provided pictorial information on the electronic attitude director indicator display presentations that could be expected at extreme attitudes. These pictures corresponded with the electronic attitude director indicator display presentations on the operator's Saab 340 flight simulator. However, they differed from the information in the aircraft operating manual. Both the operator and CASA did not detect these errors.

2.6 Acknowledgment of ability to stall with no warning to crew

The manufacturer was aware that the aircraft could stall with little or no warning to the crew. This was despite the Saab 340 being certified to all applicable regulations at the time of certification. However, there was no information in the aircraft operating manual to make this fact known to crews. A properly certified aircraft should not be able to do this. A stall warning is a defence. It should therefore be capable of providing a warning to crews of impending aerodynamic stall. This is considered even more important in icing conditions, when there is an acknowledged degradation in aerodynamic performance.

The manufacturer conducted icing stall testing, both at initial certification and during modified trials prior to the introduction of the Saab 340 to Canadian operations. These tests had resulted in the production of a table of stall speed with ice deposits on the aircraft. However, this information was only made available to Canadian Saab 340 operators.

A similar chart had also been produced as part of the normal icing certification, but had not been translated to an operational chart for inclusion in the aircraft operating manual. The manufacturer had chosen to include speeds for operations in icing conditions in the aircraft operating manual, but had not included any information about increased stalling speed during flight in icing conditions. It therefore remained an unknown factor. Had this information been available operators and crews would have had a greater general

awareness of how much the stall speed increased in icing conditions. This would have generated more concern about speed loss in icing conditions, with the crew taking appropriate action quickly. This lack of information provided to crews, despite it being available to the manufacturer was a latent error producing condition.

2.7 Stall warning

The intent of FAR and JAR part 25.203 is that a stall warning should be presented to crews in a such a manner that cannot easily be misinterpreted. In this occurrence the buffet which forms part of the normal stall pattern was misinterpreted by the crew as propeller ice imbalance.

The manufacturer had concluded during flight testing that the aircraft would not meet specified stall warning requirements. The Saab 340 was therefore equipped with an artificial stall warning and identification system (stick shaker and stick pusher). This system had operated correctly during the daily and handover checks that were conducted on the aircraft.

The manufacturer found no evidence in the recorded flight data to indicate any malfunction of the stall warning system. It is therefore reasonable to assume that the stall warning system was capable of normal operation and would provide a warning to the crew before a stall. The failure of the stall warning system to warn the crew of the impending stall was an inadequate defence.

2.8 Relevant findings from previous accident investigations involving other aircraft types

The findings of the NTSB on the Roselawn ATR-72 accident investigation determined that probable cause for the loss of control was the build up of ice behind the de-ice boots on the wing. This build up resulted when the aircraft was operated in conditions outside those specified for certification of the ATR-72 for flight in icing conditions. Following the Roselawn accident, Saab participated in research testing to assess the probability of ice build up behind the de-ice boots on the wing of Saab 340 aircraft. The results of these tests showed indicated that this is was not a problem for the Saab 340.

The investigation into the EMB-120 accident determined that loss of control had occurred because the crew allowed the speed to decrease below the speeds specified in the EMB-120 flight manuals. The probable cause listed by the NTSB determined that the FAA had not adequately defined aircraft certification standards for flight in icing conditions. The recent introduction of advisory circular 25.1419-1 addresses some of these shortfalls, however there is no retrospectivity clause included in the advisory circular to cover aircraft previously certified.

There is evidence that at the time of the occurrence, VH-LPI was being operated at speeds less than those specified for flight in icing conditions. There is no evidence, however, that it was operated in icing conditions that were outside its certification parameters. Also, there was no evidence to suggest that the loss of control experienced by the aircraft resulted from build up of ice behind the de-ice boots on the wing.

2.9 Stall recovery training

The training provided to the crews at initial training covered stalling in a number of different configurations. This complied with the endorsement syllabus in the CAO's. Stalls are not generally experienced during normal operations, and exposure to stall recognition

and recovery is confined to the training environment. The introduction of the Saab 340 flight simulator provided a better opportunity for crews to receive training in stall recovery than they had previously been offered. In recognition of this factor, the operator scheduled crews to receive stall recognition and recovery training in the second exercise of the recurrent training program undertaken in the simulator.

This training however was predicated on the correct functioning of the stall warning system. In the simulator the stall warning system will function as it is intended, because the simulator computer program generates the correct stall warning response when the required flight parameters are met. However, although the aircraft's stall warning system was capable of operating correctly, the combination of slow speed and accumulated ice resulted in a reduced speed margin between autopilot disconnect (part of the stall warning 'cascade') and entry into the aerodynamic stall.

The crew had never been exposed to the situation of stall recovery with no stall warning, nor is there any regulatory requirement to do so. This lack of regulatory requirement suggests that the stall warning system will always function correctly, as defined in the certification requirements. In this occurrence the stall warning system did not provide the crew with prior warning of the impending aerodynamic stall.

2.10 Use of the autopilot in icing conditions

US FAA airworthiness directive 96-09-21 was applicable to Saab 340 aircraft. It was issued in response to a recommendation arising from the Roselawn ATR-72 accident investigation. The airworthiness directive noted that the Saab 340 autopilot could mask tactile cues that indicated adverse changes in aircraft handling characteristics when an aircraft was in icing conditions. It further prohibited the use of autopilot in icing conditions.

Recommendation A-98-97 was issued by the NTSB following the accident investigation into the crash of an EMB-120 aircraft in 1997. The recommendation required pilots of turbo-propeller aircraft to disconnect the autopilot and fly the aeroplane manually when anti-ice systems are activated.

Although different causes were found in both the Roselawn ATR-72 and the EMB-120 accidents, control of both aircraft by their respective autopilots had been similar. Both had masked subtle cues that may have alerted the crews to the degraded aerodynamic performance of each aircraft prior to the subsequent loss of control.

Airworthiness directive 96-09-21 required that all operators of all Saab 340 aircraft amend their flight manuals to include (among other things) a requirement prohibiting the use of the autopilot while operating in icing conditions.

In this occurrence, changes in the aircraft trim occurred as the autopilot attempted to maintain zero torque on the flight controls as the aircraft speed slowed. This resulted in a subtle increase in nose up trim from 1.4 units nose up to 5.6 units nose up over a period of 239 seconds. There is no trim wheel to alert the crew to trim movement. The sole means of alerting the crew to trim changes was a trim indicator gauge. The trim indicator gauge is located on the bottom-right corner of the centre instrument panel, outside the normal flight instrument area of each pilot. It is likely that both crewmembers had become preoccupied with the holding pattern entry and the aircraft speed. Without any aural warning to alert them of autopilot trim changes, the crew did not notice the trim had almost reached its full nose-up limit. The lack of an aural warning was a missing defence. Audible trim tones and trim wheels are common features of similar turboprop aircraft.

Also, in the same time period the pitch attitude displayed on the EADI increased from 2 degrees nose up to over 10 degrees nose up. This considerable nose up pitch change went unnoticed by the crew.

When the aircraft entered the holding pattern, the autopilot continued to control the aircraft. When the aircraft first started to experience buffet from the airflow separation over the inner part of the right wing, the aircraft naturally tended to roll to the right as a result of the loss of lift from the right wing. The autopilot commanded an increase in aileron deflection to the left to attempt to return the aircraft to the pre-determined setting of 28 degrees. As the speed decreased further the airflow separation increased and the autopilot again tended to increase the aileron input to compensate for the loss of lift.

When the autopilot disconnected at the point of stall, there was a significant amount of left wing down control input as a result of the input from the autopilot. This significant amount of left wing down control input added to the left rolling motion as the aircraft stalled, and most probably contributed to the excessive bank angle that resulted. It is unlikely the excessive bank would have occurred if the autopilot had not been engaged, in accordance with the recommendations for flight in icing conditions.

There are other considerations for the non-use of an autopilot in icing conditions. The crew of the aircraft was operating the autopilot in HDG/ALT modes when they entered the holding pattern. In these modes, the manufacturer has acknowledged that there is no protection against penetrating the required stall speed margin. However, operations with the autopilot engaged in these modes are authorised in icing conditions. The manufacturer has subsequently advised that the use of the only autopilot mode that will provide stall margin protection, is not to be used in level flight conditions. In this occurrence there was no stall warning whilst operating in icing conditions and the use of the autopilot provided no additional protection against an inadvertent stall. Had the crew been operating the aircraft manually, they would have been aware that additional aileron control input was needed to maintain the aircraft in the left bank and counter the pre-stall right roll.

In icing and holding conditions the use of the autopilot can minimise the workload for crews. However, this must be balanced against the use of sound operating procedures that cover known deficiencies in the system. In this case there were no such procedures. The crew was not aware of the deficiencies in the autopilot system and continued its use despite being in icing conditions.

2.11 Use of autopilot half bank mode

The operator had previously used autopilot half bank mode to afford a better ride for passengers. The manufacturer recommended that half bank mode be used to afford a greater margin above the stall while manoeuvring. Following a scheduled surveillance inspection by CASA, the operator was instructed to use full bank when holding.

CASA's instruction was inappropriate and not in accordance with the recommendations contained within the aircraft flight manual. Furthermore, it ignored the safety considerations for operations in icing conditions. Had the operator still been permitted to use half bank mode, the aircraft stall speed would have been lower, and it is likely that the crew would have acted to remedy the situation prior to the aircraft reaching that lower speed.

2.12 Guidance on operations in holding patterns

Neither the aircraft operating manual nor the operator's Policy & Procedures Manual provided sufficient guidance to crews on holding procedures, specifically in icing conditions. This was a missing defence.

2.13 Application of ice speed modification to this occurrence

Analysis of the Canadian stall speed chart with residual ice accretions revealed that the predicted stall speed (with 1 inch of ice on protected surfaces and 3 inches on unprotected surfaces) would have been 132 KIAS. The aircraft actually stalled at a higher speed, indicating that the performance loss from the ice accretion was greater than that experienced from Canadian certification flight tests.

The crew of the aircraft reported that the deposit of ice on the aircraft did not appear to be great. This tends to support the notion that it is extremely difficult to predict performance loss from visual observations of ice accretion on an airframe. Ideally, the conditions under which anti-ice and de-ice systems must be operated should be clearly defined. They should not solely rely on visual observation and interpretation of the amount of ice accretion.

The stall speed from the manufacturer's initial icing certification flight tests was lower than that at which the aircraft stalled. This supports the fact that performance loss due to the ice accretion in this specific occurrence was greater than that experienced in those tests.

Figure 4 shows a graphical representation of the angle of attack, indicated airspeed and autopilot status in the moments leading up to the occurrence. The graph also contains the limitations imposed by both the normal and ICE SPEED modified stall warning systems. The onset of the stall buffet is also indicated.

The graph shows that had the aircraft been equipped with the ICE SPEED modified stall warning system and it had been activated by the crew, the stall warning would have activated at approximately 06:38:21. The airframe buffet occurred at approximately 06:38:30. The buffet experienced was identified by the manufacturer as being pre-stall buffet due to airflow separation from the left wing. The chart also shows that the ICE SPEED modified stall identification angle of attack was reached before the aircraft actually stalled. The aircraft only reached the non-modified stall warning activation point after both modified triggering levels had been exceeded.

This evidence reinforces the NTSB recommendation A-98-96:

require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions.

Accordingly, this evidence supports interim recommendation IR19990072. (Refer to Section 4 for information on interim recommendations issued by BASI).

2.14 Australian introduction of Saab 340A

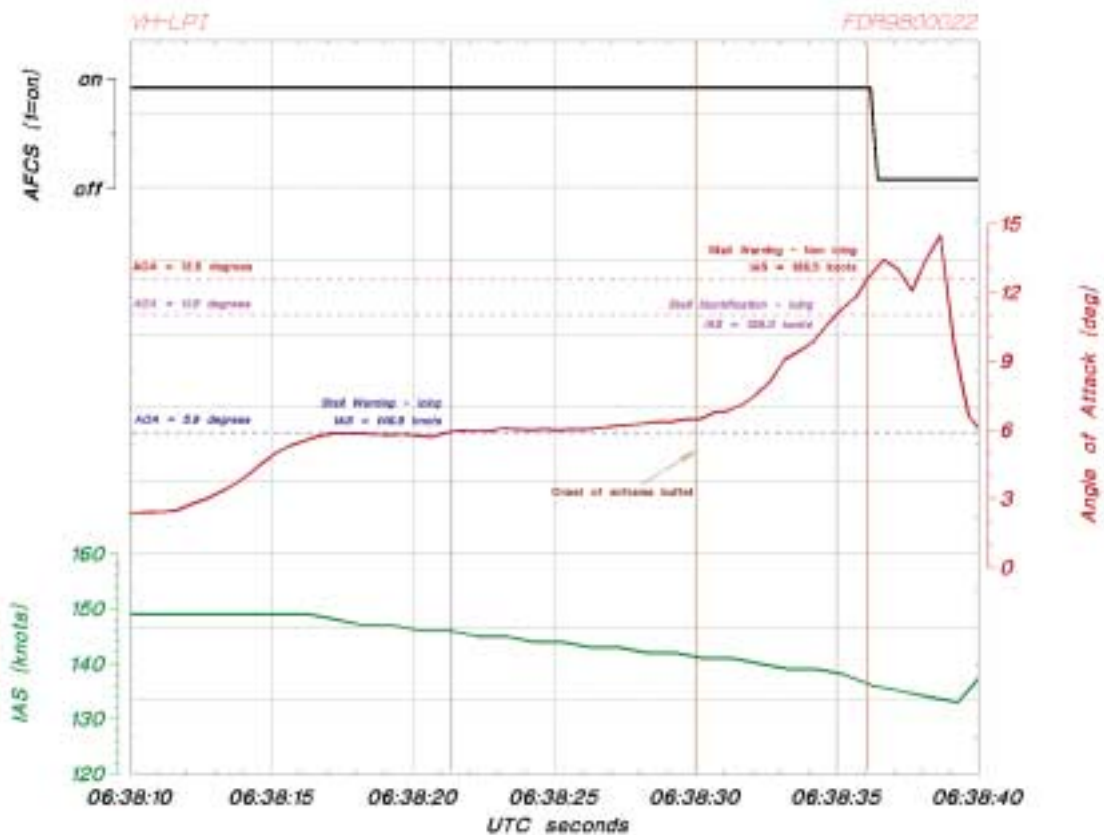
At the time the Saab 340 was introduced into Australia, the DoA did not have equivalent airworthiness requirement for JAR's. In order not to delay its introduction, the department specified that FAR 25 was to be the certifying standard for the aircraft. As a result the aircraft was issued with an airworthiness certificate on the basis of the FAR 25 type certificate data sheet issued by Luftfartsverket.

The Australian Civil Aviation Regulations (CAR) were amended subsequent to the introduction of the Saab 340 into Australia. Under the amended regulations, CAR 22A permitted acceptance of the certification basis of an aircraft without imposing any specific Australian airworthiness requirements. allowed for the unilateral acceptance of aircraft certification without the need to impose any additional Australian specific requirements.

The Saab 340 was certificated in Canada to FAR 25, the same standard that the DoA accepted in 1984 when it first certificated the aircraft for operations in Australia. The Canadian interpretation of the guidance material for flight in icing conditions differed from that of the Australian and even that of the USA, from which the FAR's are drawn. It appears that the one set of aircraft certification rules have been interpreted in at least two differing ways and has been applied in at least three different ways when the application of airworthiness directives are taken into consideration. The result is that the Saab 340 is operating around the world in at least two different configurations, when taking the stall warning system into consideration, and an unknown number of airworthiness standards, when taking the issuing and compliance with airworthiness directives into consideration.

This situation results in differing levels of safety, based upon acceptance of the FAR or JAR certification basis and responsibility for continued airworthiness. It also results in having different levels of a defence in place to protect against an inadvertent stall in icing conditions. While this may sound as though aircraft are not being maintained in accordance with continuing airworthiness standards, despite the differences, all of the above is in accordance with ICAO Annex 8 – Airworthiness of Aircraft.

FIGURE 4:
Analysis of stall event and application of Canadian stall warning parameters



2.15 Air Traffic control response

The controller was unaware of the formation of ice on any aircraft until the aircraft following VH-LPI requested a lower level due to icing. The level subsequently assigned to this aircraft was below the original level of VH-LPI. At the time of that request, VH-LPI was recovering from the loss of control. ATC did not clear VH-LPI to any level lower than flight level 150 until the crew requested to hold at flight level 130 following the loss of control. Although VH-LPI was on radar, the rapid and sudden loss of control and resultant loss of altitude initially went unnoticed by the controller. In any event, the consequences of the loss of control were beyond the influence of the controller. It was fortuitous that there were no other aircraft in the holding pattern below VH-LPI at the time.

3.1 Findings**3.1.1 Crew and training**

1. The crew were correctly licensed and had current medical certificates for the flight. The pilot in command had complied with the restrictions that were endorsed on his medical certificate.
2. There were no medical or other factors that would have affected the crew's performance.
3. The crew had activated the propeller and engine ice protection systems, however they did not activate the wing de-ice system as they perceived that the amount of ice present on the wings did not meet the manufacturer's criteria for the activation of the system.
4. The crew were instructed to hold in icing conditions. The controller was not aware of the icing conditions at the time.
5. The crew were aware of the correct holding speed for the aircraft's weight, however, they allowed the aircraft to decelerate to a speed less than this.
6. The company had recently gained the use of an approved flight simulator for crew training, however when the training was transferred to it, the same limits that were imposed on the aircraft during flight training were imposed on the simulator.
7. The operator's crews were not exposed to the presentation of the electronic attitude director indicator at extreme attitudes during training, and were therefore not familiar with the display presented to them at extreme attitudes.
8. The pilot in command recovered the aircraft with the aid of the standby attitude indicator.
9. The crew were operating the aircraft using the autopilot at the time of the occurrence. Further, the crew were operating the autopilot in full-bank mode. Use of this mode was required by CASA, however, the manufacturer does not recommend the use of this mode in icing conditions.
10. The crew reported the event as a turbulence encounter.
11. The crew did not notice a significant increase in pitch attitude prior to the stall.

3.1.2 Company documentation and procedures

12. The operator's policy and procedures manual and operations manual contained minimal information to guide crew during flight in icing conditions.
13. The operator's operations manuals contained references to speeds that were not defined by the manufacturer.
14. The operator's operations manuals did not prohibit the use of the autopilot in icing conditions.
15. The operator's manuals contained minimal information on crew duties in holding patterns, especially when the holding pattern was non-standard.

16. The operator's simulator training syllabus did not contain formal training in recovery from unusual attitudes.

3.1.3 Aircraft

17. There were no aircraft system malfunctions that would have contributed to the occurrence.
18. The aircraft was correctly certified to operate in known icing conditions in accordance with JAR and FAR part 25 Appendix C.
19. The aircraft sustained an airframe vibration (buffet) prior to the stall warning which was misinterpreted by the crew as uneven propeller ice.
20. The aircraft entered an aerodynamic stall at a speed higher than that listed in the aircraft flight manual due to ice accretions on the wing. The stall speed was higher than the stall speed derived from icing certification flight testing with 3 inches of ice on unprotected surfaces and 1/2 inch of ice on protected surfaces. The stall speed was also higher than that derived from icing certification flight testing under Canadian conditions of 3 inches of ice on unprotected surfaces and 1 inch of ice on protected surfaces.
21. The Saab 340 aircraft is capable of stalling with an ice deposit on the wings without providing aircrew with any artificial warning of the impending stall, but with a natural prestall buffet. However it should be noted that the prestall buffet can be misinterpreted by the crew, as it was in this case.
22. The ice accretion was likely to have been a thin rough deposit which significantly degraded the aerodynamic performance of the aircraft.
23. Ice accretions were seen to break away from the wings following the activation of the wing de-ice system following the occurrence.
24. There is a different stall warning system fitted to Canadian operated Saab 340 aircraft and this different stall warning system (when activated) provides an increased warning margin to the stall when operating in icing conditions.
25. The aircraft operating manual and aircraft flight manual did not contain any information to assist crews and operators in developing procedures for recovery from unusual attitudes.
26. There is only one autopilot mode that will provide protection against penetrating the required stall margins.
27. In the period of 180 seconds before the stall, the autopilot commanded nose-up pitch which was automatically trimmed by the autopilot. This was not noticed by the crew.
28. The aircraft was not fitted with an audible trim warning to alert crews when the autopilot was trimming the aircraft, nor was this required by certification. The only visual indication to crews of trim movement is the movement of an index on the trim position indicator which is not located in the crew's primary field of vision.
29. The Saab 340 aircraft is not fitted with an ice detection system. The optional system is only applicable to engine operation.
30. The aircraft is capable of accreting ice on the airframe without visual cues being available to the crew.

31. The manufacturer produced an aircraft operating manual chart showing stall speeds with ice on the aircraft following icing flight testing for certification in Canada, however this chart was only included in the Canadian supplement to the aircraft operating manual. A similar chart was produced during initial icing certification flight testing, but was not included as part of the aircraft operating manual.

3.1.4 Certification and regulation

32. The then Australian Department of Aviation recognised Federal Aviation Regulation Part 25 as the certification basis when the aircraft was placed on the Australian register.
33. CASA did not make operators aware of the requirements of airworthiness directive 96-09-21 nor was it required to do so under international convention. As such operators were not aware of problems in operating turbopropeller powered aircraft in icing conditions as a result of investigations into two accidents involving other aircraft types.
34. Transport Canada did not recognise advisory circular 20-73 as an acceptable guide to the certification of aircraft for flight in icing conditions.

3.2 Significant factors

1. The stall warning system did not activate prior to the stall.
2. The crew allowed the aircraft's speed to slow below the published holding speed.
3. The crew interpreted the ice deposit as being less than that specified in the aircraft flight manual for activation of the wing de-ice system.
4. The crew misinterpreted the pre-stall buffet as propeller ice vibration.
5. The Saab 340 aircraft is capable of accreting ice deposits without visual clues being provided to the flight crew.
6. The aircraft was not fitted with the Canadian Stall warning system. If this had been fitted and activated, it would have (and activated) provided the crew with between 10 to 18 seconds warning of the impending stall.

4 SAFETY ACTIONS

4.1 Recommendations

As a result of this investigation the Australian Transport Safety Bureau reiterates its position as outlined in IR19980072, that:

The Bureau of Air Safety Investigation recommends that Saab modify the stall warning system of the worldwide fleet of Saab 340 aircraft to include the ice speed modification, as a matter of priority.

The Australian Transport Safety Bureau also issues the following recommendations at the completion of this investigation.

R20010049

The Australian Transport Safety Bureau recommends that Saab include information in both the aircraft flight manual and the aircraft operating manual advising of the differing shedding capabilities of the wing de-ice boots at different temperatures.

R20010050

The Australian Transport Safety Bureau recommends that Saab advise operators that use of autopilot modes that do not include IAS mode will not afford protection against penetration of the required stall margins.

4.2 Local safety actions

4.2.1 Operator

Following the occurrence, the operator issued a number of Operational Memoranda to its crews. The first memorandum was issued on 12 November 1998, the day after the occurrence. The memorandum warned crews about the weather conditions conducive to icing and emphasised the need to maintain at least V_{HOLD} speed and to disconnect the autopilot before ice accretion to ensure that any trim changes or other unusual control inputs were detected.

Further memorandums to crews were issued in the following weeks on 25 November, 27 November, 2 December and 3 December. In summary, these memorandums:

- reiterated that the autopilot must be disengaged in icing conditions (other than light rime) when speed is reduced below normal cruise and/or entering a holding pattern;
- mandated 170 KIAS as the minimum holding speed under all conditions until the occurrence investigation was complete;
- drew attention to the NTSB findings from the investigation into a fatal EMB-120RT icing accident, particularly those concerning, speeds, the use of autopilot, and the use of de-icer boots; and
- drew attention to sections of the SAAB flight procedures manual and reiterated that minimum holding speed was to be 170 KIAS.

The operator also modified the simulator training to include mandatory training in unusual attitude recognition and recovery. They also modified the simulator training program to ensure that all crews replicated the occurrence scenario in the simulator and

were made aware of the subtle changes to the trim and attitude while the aircraft was being flown by the autopilot.

4.2.2 Airservices Australia

There was one recommendation arising from the internal Airservices Australia investigation of the occurrence.

This recommendation dealt with the need for Airservices Australia to provide ongoing training to ATC personnel to heighten the awareness of the risks involved in icing encounters. It also recommended the need for ATC to provide information to all aircraft operating in an area of known icing in the interest of flight safety.

4.3 Interim Recommendations

During this investigation the ATSB (then known as BASI) issued a number of interim recommendations.

Interim Recommendations IR19980269 to IR19980272

The following Interim Recommendation (IR 19980269) was issued to Kendell Airlines, on 18 December 1998.

The Bureau of Air Safety Investigation recommends that Kendell Airlines note the circumstances of the above occurrence and alert their aircrew accordingly.

The Bureau of Air Safety Investigation simultaneously issues this interim recommendation to Hazelton Airlines, Macair and the Civil Aviation Safety Authority as IR980270, IR980271 and IR980272 respectively.

Response to IR19980269

The following response was received from Kendell Airlines on 1 April 1999 informing BASI that the company had issued 'Operational Memorandum No.1' to crews on 7 January 1999. The document is reproduced below:

The company has taken the following action:

The sequence has been flown in the simulator and under certain circumstances, the Sim will stall at approximately 150 KIAS with the necessary stall warning indications. The aircraft has the potential to stall WITHOUT these warnings.

The next two Sim sessions will have some element of icing problems and an exercise involving unusual attitudes.

The particular aircraft has been test flown by [the Chief Pilot] and CASA with various stalling configurations and the aircraft performed normally to aircraft flight manual criteria.

BASI have completed a video of the incident, and after some fine-tuning, we will be scheduling ALL crew to view this video as a learning tool. It will also be included in future courses.

The holding pattern speed for SAAB has been increased to 170 KIAS in the interim. New speed data cards are to be supplied which indicate two VHOLD speeds:

Min speed when holding in icing conditions – 170 KIAS (less than +5 degrees in cloud)

Min speed when holding in non-icing conditions will remain at the present V_p clean speed.

More emphasis will be placed during training on icing considerations and speed management when holding. It is obvious that holding power **MUST** be increased when initiating the turn to ensure that speed does not decay below V_{HOLD} .

SAAB speeds are now to be considered as **MINIMUM** speeds when holding.

A recommendation was issued to all turbo prop manufacturers to include in their manuals the order to disconnect the autopilot when holding in icing conditions. This is now Kendell Airlines policy for the SAAB. When holding in icing conditions, the autopilot is to be disengaged and the procedure is to be hand flown.

There is still some debate regarding the effectiveness of the deicing boots in the continuous mode due to the possibility of 'bridging'. If you consider the ice buildup to be excessive, do not hesitate to use the auto cycle system to give maximum protection. This applies to Metro and SAAB.

Monitoring all aspects of aircraft performance is important. When operating in icing or potential icing conditions, it is **CRITICAL** that both crew monitor the aircraft performance and operation at **ALL** times.

Response Status: CLOSED-ACCEPTED

Response to IR19980272

The following response was received from the Civil Aviation Safety Authority on 20 April 1999:

CASA notes the circumstances of this occurrence.

Response Status: CLOSED-ACCEPTED

Interim Recommendations IR19980273 and IR19980274

The following Interim Recommendations IR19980273 and IR19980274 were issued to SAAB Scania AS, on 18 December 1998:

The Bureau of Air Safety Investigation recommends that Saab amend the SAAB 340 Aircraft Operations Manual to more appropriately alert pilots that the stall warning system may not activate when the aircraft is operating in icing conditions.

The Bureau of Air Safety Investigation recommends that Saab note the circumstances of this occurrence and alert SF340 operators accordingly.

Response to IR19980273 and IR19980274

The following response was received from Saab Aircraft Company on 18 February 1999:

Please find enclosed SAAB Aircraft AB response to your Air Safety Interim Recommendation IR980273. These aircraft operating manual operation bulletin (one for 340A, 340B) have been released and will be distributed to the operator in the near future.

Operations Bulletin No. 56

Artificial Stall Warning in Icing Conditions

Effectivity

Applicable to all Saab 340 aircraft.

NOTE: With Mod. No. 2650 (ice speed system) installed and selected, the stall warning triggering level is changed to give stall warning at a higher speed.

Reason

To highlight the fact that the design of the artificial stall warning system does not always provide a stall warn before stall is encountered if there is ice on the wing.

Background

Even a small amount of ice on the wing will reduce the lifting capability and increase the stall speed of the aircraft. The aircraft will stall at a lower angle of attack than for the normal clean (free of ice) case.

Most artificial stall warning systems are designed to give an artificial stall warning (shaker and aural warning) and subsequent pusher at preset angles of attack for a clean wing. In the case of the SAAB 340 the artificial stall warning will activate approximately 8 knots before stall with a clean wing. The stall warning system has one trigger level, which is designed for a clean wing. This means that with ice on the wing, the aircraft may stall at an angle attack which is lower than the preset warning angle of attack and stall may be encountered before the artificial stall warning is activated.

Procedure

With reference to the above, it is essential that the crew is aware of the adverse effects of ice on the aircraft. The operational speeds shall be increased according to aircraft flight manual (section 5) and aircraft operating manual (section 27/11) if ice is observed on the aircraft or if it is not certain there is no ice on the aircraft. The amount of ice allowed to build up shall be kept at a minimum.

Abnormal emergency procedures

No change.

Response Status: CLOSED-ACCEPTED**Interim Recommendation IR19990072**

The following Interim Recommendation IR19990072 was issued to Saab on 3 June 1999:

The Bureau of Air Safety Investigation recommends that Saab modify the stall warning system of the worldwide fleet of Saab 340 aircraft to include the ice speed modification, as a matter of priority.

Response to IR19990072

The following response was received from Saab on 6 August 1999:

After careful consideration Saab has the following comments to your Air Safety Interim Recommendation IR990072 relating to the Saab SF340A stall incident 11 November 1998.

Comments on factual information and analysis

The comments are divided in different subjects to avoid repetitive comments on different parts of the text in IR990072. The following comments apply:

Experienced Stall warning in the occurrence summary

In 'FACTUAL INFORMATION', the last paragraph in 'occurrence' states that 'The crew received very little warning of the impending stall. Only the autopilot disconnect and the severe vibration indicated that a stall might have been about to occur.' Also in 'ANALYSIS', the second paragraph states that '... it appears that the only warning the crew received of the impending stall was the disconnection of the autopilot, and this occurred less than a second before the aircraft actually stalled....'.

As detailed in the Saab document 72ADS4196 (the DFDR analysis) there were several natural warnings of the impending stall. The stall buffet started slightly more than 6 seconds prior to the stall and 5 KIAS above the aerodynamic stalling speed. There was also a significant increase in pitch attitude prior to the stall, while the aircraft was still in level flight. This increase in angle of attack occurred with relatively high rate, more than one degree per second, and should have been noticed. The buffet and the sudden increase in angle of attack are both typical behaviours for an impending stall situation for any conventional aircraft. Finally, the speed was decreasing to values well below the minimum recommended speeds for holding which in itself challenges the stall margin.

Crew actions

In this particular occurrence the crew was entering the holding pattern with a too low speed which also was notified by the Captain and started to be corrected by the First Officer by applying more power than what was initially estimated to be required to keep the holding speed of 154 KIAS.

It must be remembered and emphasized that according to common practices and procedures during flight in IMC conditions with any aircraft, one of the two pilots should always monitor the flight instruments and especially speed and attitudes. Since the speed continued to be reduced during the turn after entering the holding pattern with as much as 18 KIAS below the holding speed, this must be questioned for this particular occurrence.

In 'FACTUAL INFORMATION', in the second paragraph of 'Occurrence Summary' the IR990072 states that 'The crew reported that they had previously operated the aircraft with more than that amount of ice without problems.' Provided that the aircraft is flying at speed higher than the published minimum operating speed in icing conditions, and that the de-icing system is used as intended, such a statement is of course true.

In 'FACTUAL INFORMATION', in the 'Action of flight crew', the IR990072 states that 'The crew were operating the aircraft, as would any normal crew, in the knowledge that the stall warning and protection system would afford them the necessary margin above the stall, should it occur.'

According to information from the specific operator of the occurrence aircraft, the fact that the stall warning margins are only applicable to a clean wing is well known and fully understood. Also that being in icing conditions with ice accretion on the wings results in higher stall speeds, is well known within the operator organisation. Hence, the statement that a normal crew is using the stall warning as a kind of stall margin protection seems odd and not correct.

Also there are always minimum speeds detailed in the aircraft flight manual and aircraft operating manual for different segments and different conditions. These minimum speeds (like 1.4 Vs for icing) should be monitored by any crew, which is a natural part of any normal flight training as well as standard practices and procedures.

Ice accretion

The IR990072 states the following. 'The crew involved in the occurrence at Eildon Weir were not aware of the amount of ice accretion on the aircraft, as they were following the guidance in the aircraft flight manual. This guidance stated that there should be at least half an inch of ice built up before the activation of the wing de-icing boots.'

The guidance at the time for the occurrence, in both the airplane flight manual as well as the aircraft operations manual, states that the boot de-icing system should be

operated when the ice has accumulated to approximately 1/2 inch thickness on the leading edges. Both manuals also clearly define that all detailed minimum speeds and aircraft performance for ice accretion assumes 1/2 inch of ice accumulation on all protected surfaces.

The IR990072 continues with ‘The manual also stated that the crew should use ice accretion on the windscreen wiper as the method for determining this amount.’

The following is detailed in the airplane flight manual regarding the ice accumulation during flight: ‘Monitor the accumulation of ice. The windshield wiper arms give a visual cue of icing, although airframe ice can be present without any build up on the wiper arms.’ Hence, the windshield wiper arm is never used for estimating the ice thickness on the wing leading edges as indicated in IR990072. Also the wiper arm is a cue of ice build up, but never the sole cue. The wing leading edges must always be monitored as well.

Certification regulations

Regarding the certification basis the IR990072 details requirements in FAR 25 for Stall Warning and Operation in Icing conditions. The certification regulations applicable for a certain aircraft type is the regulations at the time for establishment of the certification basis for the particular type. For the Saab 340, JAR 25 Change 7 and FAR 25 Amendment 42 was used to form the certification basis. The applicable FAR requirements were also adopted for certification in Australia with some differences not related to operation in icing conditions.

The JAR 25 Change 7 as well as FAR 25 Amendment 42 details the requirements for aircraft performance and flying qualities for clean aircraft conditions. The interpretation of the FAR/JAR 25 paragraphs 101 to 255 are applicable for clean conditions only. A separate stall warning system was not required to fulfill the intentions and to show compliance with paragraph FAR 25.1419. This is also seen in other aircraft types developed prior to or at the same time as the Saab 340. Despite it was formally not required, Saab decided to publish minimum operating speeds in icing conditions in the aircraft flight manual as well as aircraft operating manual in order to create natural awareness of ice accretion effects on the stalling speeds among the Saab operators.

As informed earlier to BASI, for the Saab 340 there are different certification regulations between Transport Canada and the rest of the world in the aspect of operation in icing conditions. To fully meet the Canadian requirements stated in Transport Canada Airworthiness Manual Advisory (AMA) 525/5-X, the stall warning and stick pusher systems are modified in aircraft operating on the Canadian register. The supplementary certification according to the Canadian regulations was reviewed according to standard practices by both luftfartsverket and Transport Canada.

As a conclusion, the certification process of the Saab 340 has been adequately fulfilling all the intentions with the FAR and JAR regulations applicable at the time for the type certificate.

Ice detection systems

The IR990072 states that if this particular aircraft would have been equipped with the Saab ice detector option, the crew would have been assisted in assessing the level of ice accretion on the aircraft. The optional ice detector is related to the engine anti ice system and warnings from the ice detector is suppressed by selecting ENG A/I ON as was the case in this particular incident. Further the ice detector has the same viability as the windscreen wiper, it is a cue of being in icing conditions, but not the sole cue. Hence, you may be in icing conditions without experiencing a warning from the ice detector.

Ice detectors which are actually measuring the amount of ice accretion are currently not available certified for FAR/JAR 25 aircraft with de-icing boots.

Related Incidents

IR990072 mentions some other incidents with the Saab 340 and accidents with other aircraft types which are stated to be related to this specific occurrence. Regarding the first incident mentioned (23 September 1991), it should be clarified that the crew was operating the aircraft in an incorrect autopilot mode during the climb, which resulted in a speed drop well below the minimum speed in icing conditions.

The second incident on 23 March 1994, needs the following comments. Although the data provided to Saab for investigation was limited, the analysis conducted showed that the airplane drag just prior to stall was up to 70% higher than the total clean airplane drag. This corresponds to more than 4 times the drag from $\frac{1}{2}$ inch residual ice on the protected parts and 3 inches of ice on the unprotected parts. Hence the airplane was heavily iced up without any use of the boot de-icing system by the crew and the resulting stalling speed was significantly increased to about 129 KIAS. The inappropriate autopilot mode used in this case reduced the speed well below the minimum speeds for operation in icing conditions during the climb.

The third mentioned incident (12 June 1994) relates to an icing condition which was well outside the FAR 25 Appendix C specified conditions. Hence, the resulting ice build-up was outside the requirements in the icing certification regulations and this specific incident is not related to the occurrence at Eildon Weir.

The references to 'anecdotal evidence' is found inappropriate for a serious investigation.

The reference to the Roselawn accident with the ATR72 investigated by NTSB is also found inappropriate as a related accident. The ATR72 accident was of a different nature related to design deficiencies compared to the Saab 340 occurrence as well as outside the FAR 25 appendix C conditions used for certification.

Regarding the EMB 120 accident referenced to, there is a major difference which is not recognized, namely that in the EMB 120 documentation (aircraft flight manual and the corresponding aircraft operating manual) there was no information about minimum speeds in icing conditions. Such information has always been provided in the Saab 340 manuals and has been well known among the operators of the Saab 340. Comments regarding the comparisons between this occurrence at Eildon Weir and the different NTSB recommendations after the EMB 120 accident are detailed in previous chapters.

The ice speed option for the Saab 340

As indicated in the IR990072 there is an ice speed option developed for the Saab SF340A, 340B and B(WT) versions. The ice speed modification developed for the Canadian operation with some of the airliner versions of the Saab 340, is certified towards Transport Canada only. It is currently not certified in any other country. The functions of the ice speed modification certified according to Transport Canada regulations are as follows:

- The ice speed modification will decrease the angle of attack triggering levels for stall warning and stall pusher system, provided that the crew has selected ICE SPD on.
- The stalling speeds are developed using the most adverse ice accretion defined by Transport Canada. The resulting minimum operating speeds used for Canadian operation are therefore significantly higher than what is used in the rest of the world.

- For takeoff the lower angle of attack triggering levels are inhibited in 6 minutes from lift off when the ICE SPD is selected on, in order to prevent the crew from an undesired pusher activation in an OEI takeoff. The use of ICE SPD is limited in takeoff to a second segment procedure only with a prompt acceleration directly to enroute climb speed (defined for icing conditions). Consequently, other OEI takeoff procedures may be required for icing conditions compared to non icing conditions using the ice speed modification.
- In landing when the ICE SPD is selected on, the resulting reference speeds are about 20 to 25 KIAS higher than for the clean aircraft, which sometimes creates difficulties when landings are made with a less critical ice accretion which is the most common case. Also the required landing distances are significantly longer. Experience has shown that operational pilots dislike the ice speed modification, because of the resulting high landing speeds and there is a resistance to use it amongst the pilots.

SAAB position related to the interim recommendation IR990072

Saab does not agree with the interim recommendation to include the ice speed modification worldwide to the fleet of Saab 340 based on the above statements. The ice speed modification is available as an option, but introduces difficulties in high landing speeds since it is based on the most adverse ice accretion defined by the Transport Canada for the Canadian certification. This system also requires crew awareness of being in icing conditions since a manual selection is required.

We are looking forward to receive your investigation results as to why the crew allowed the airspeed to decrease 18 KIAS below the value selected for the holding pattern and 9 KIAS below the minimum speed in icing conditions according to the aircraft manuals despite the buffeting and, high pitch attitude prior to the stall. With reference to your information we understand that this part is still under investigation.

We also look forward to receive the Draft Final Report for review and comments.

If you need any additional information you are welcome to visit us or contact us at any time.

Response Status: OPEN

Interim Recommendation IR19990073

The following Interim Recommendation IR19990073 was issued to the Federal Aviation Administration on 3 June 1999:

The Bureau of Air Safety Investigation recommends that the Federal Aviation Administration note the circumstances surrounding this occurrence, and note the fact that the Bureau shares a number of concerns regarding aircraft certification procedures, particularly those involving flight in known icing conditions.

Interim Recommendation IR19990074

The following Interim Recommendation IR19990074 was issued to the Joint Airworthiness Authorities on 3 June 1999:

The Bureau of Air Safety Investigation recommends that the Joint Airworthiness Authorities note the circumstances surrounding this occurrence, and note the fact that the Bureau shares a number of concerns regarding aircraft certification procedures, particularly those involving flight in known icing conditions.

Interim Recommendation IR19990075

The following Interim Recommendation IR19990075 was issued to Luftfartsverket on 3 June 1999:

The Bureau of Air Safety Investigation recommends that Luftfartsverket note the circumstances surrounding this occurrence, and note the fact that the Bureau shares a number of concerns regarding aircraft certification procedures, particularly those involving flight in known icing conditions. The Bureau also recommends that Luftfartsverket as the initial certifying agency of the Saab 340 aircraft, review the certification aspects of the aircraft's stall warning system, particularly in icing conditions.

Response to IR19990075

The following response was received from Luftfartsverket on 7 July 1999:

We have studied the BASI air safety interim recommendations as notified to us in ref [sic]letter.

Before deciding upon any mandatory continued airworthiness action, if any, we have addressed a number of questions to Saab for their consideration and reply to us before Aug 2, 1999. Copy of our letter dated June 15, 1999 is enclosed for your information.

Please regard this information as an interim reply to your recommendations.

Further actions will depend upon Saab reply and our final position will not be available within 60 days as requested but hopefully late August.

Request for investigation of modifications or procedures to reduce the probability of stall in icing conditions

Ref.: BASI, Australia, 'Release for Air Safety Interim Recommendation IR990072, IR990073, IR990074, IR990075 and IR990076'.

LFV have studied the referenced recommendations, which you also have been informed of.

Although that SAAB 340 has been correctly certificated according to the requirements and their interpretations, applicable at the time, the concerns of BASI seems well founded. It is evident from many other cases that pilots may not follow correct procedures during high work load, when they are subjected to unusual situations, when procedures in or characteristics of another aircraft they have been flying earlier are slightly different, when they are complacent, etc. It seems obvious that the pilots involved in the Australian incident (to VH-LPI on Nov 11, 1998) did not follow the aircraft flight manual Normal Procedure: 'If it is not certain there is no ice accumulation on the aircraft; or if ice accumulation is observed on the aircraft, maintain an airspeed not less than 1.4 times the stall speed in any configuration.' In this case the pilots apparently knew they were in icing conditions.

Normally we are hesitant to require retroactive actions on one type of aircraft that should also apply to other aircraft of similar design. Such actions should be coordinated within JAA and possibly with other authorities. We understand that such actions in the icing area already are ongoing through the Ice Protection Harmonization Working Group, IPHWG, with participation of JAA, FAA, Transport Canada, and industry representatives.

However, notwithstanding that we believe that an action normally should be coordinated within JAA to include all aircraft of similar design and that the SAAB 340 aircraft flight manual procedures in icing conditions recently have been changed (i.e. a lesser amount of ice accreted before turning on the de-icing boots, and to consider using continuous mode to reduce pilot work load), we hereby request Saab

to provide the answers to the following questions. Our request is based on the fact that at least one modification that possibly might reduce the likelihood of a repeat occurrence of the Australian incident already is available as an option, i.e. the 'ice speed button'.

1. What modifications to Saab 340 or additional procedure changes in order to reduce the probability of an icing incident similar to that encountered by VH-LPI, taking into consideration pilot work load and possible pilot situation misjudgement, could be rather easily retrofitted to the aircraft? The 'ice speed button' is assumed to be one of them.
2. Do Saab believe that any of the studied modifications or procedure changes might reduce the probability of an icing incident similar to that encountered by VH-LPI? Could the modifications or procedure changes still result in the same or other unwanted effects? If so, what is the conclusion?
3. What modification or procedure change, if any, of those practicable, would according to Saab constitute the highest degree of improved safety, and the highest cost-effectiveness respectively? Cost of retrofit to Saab and operators?

A subsequent response was received from Luftfartsverket on 19 August 1999:

I hope you received my letter dated June 29, 1999 with copy of a letter to Saab dated June 15, 1999. We have now received Saab answer to our questions and are in the process of reviewing them together with our Flight Operations section.

You have also received Saab comments on recommendation IR990072. LfV supports in principle these Saab comments. (Letter dated 3 Aug 1999).

Our goal is to take a decision with regard to the line of action mid-September.

A further response was received from Luftfartsverket on 16 September 1999:

BASI Air safety interim recommendation IR990075 has now been considered by LfV and we have reached the following position.

Although the 'ice speed button', if used, probably would have contributed to preventing the stall incident on 11 Nov 1998, a mandatory requirement of implementation of this modification, as recommended in IR990076, is not supported by LfV. There are operational drawbacks as shown in Saab letter 72DSS0957 to BASI, dated 3 Aug 1999. This may result in the crew not using the button in icing conditions assumed to be light. Then, if they do not keep the aircraft flight manual normal procedure in mind ('If it is not certain there is no ice accumulation on the aircraft, or if ice accumulation is observed on the aircraft, maintain an airspeed of not less than VREF + 10 KIAS for landing and 1.4 times the stall speed in any configuration.') this may still result in stall incidents.

As you know, FAA NPRM 99-NNI-148-airworthiness directive proposes activation of the deicing boots at first sign of ice build up on the airplane. This eliminates the need for the crew to make judgements on when to activate the boots and at the same time reduces the amount of ice on the aircraft. This will reduce the likelihood of non-observed speed reductions due to drag increase and stall without warning. This in combination with the already existing aircraft flight manual text cited above, and pilot understanding of the reasons behind, would significantly reduce the probability of future stall incidents in icing conditions with the SAAB 340, we believe. The ice speed button, although also an acceptable approach, does not appear to be the ultimate remedy. Basic pilot knowledge and skills will always need to be applied.

Increased stall speed due to airframe icing is intrinsic to all aircraft. Any retroactive requirements that would significantly increase safety for all types of aircraft in icing conditions should therefore be coordinated world wide and not just be applied to

one type. This is another reason we do not support the 'ice speed button' as a retroactive requirement for the SAAB 340.

On the other hand, we welcome the FAA NPRM, which appears to solve a problem for all modern aircraft with de-icing boots with limited cost impact, mainly higher maintenance costs due to more frequent use of the boots.

A change implementing the FAA proposal, based on the new knowledge that ice bridging does not occur on modern type boots, will be introduced in all LFV Approved Airplane Flight Manuals (aircraft flight manual) and in the manufacturers Airplane Operation Manuals shortly. On the FAA side this change will most probably be addressed as an Airworthiness Directive which in the U.S legal system mandates the procedural change. Under the Swedish regulations operators are required to apply the latest version of the aircraft flight manual.

Response Status: OPEN

ATSB has classified both the responses from Saab and Luftfartsverket as OPEN pending final comments from both organisations following the interested party phase of the investigation. When these comments have been received, ATSB will then reclassify the responses to these recommendations.

Interim Recommendation IR19990076

The following Interim Recommendation IR19990076 was issued to the Civil Aviation Safety Authority on 3 June 1999:

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority examine the circumstances surrounding this occurrence and take whatever steps it considers necessary to ensure the safety of the Saab 340 fleet operating within Australia.

Response to IR19990076

The following response was received from the Civil Aviation Safety Authority on 13 August 1999:

BASI Interim Recommendation IR990076, resulting from occurrence 9805068, recommends that CASA examine the circumstances surrounding the stall of a SAAB 340 aircraft at Eildon Weir on 11th November 1998, and take whatever steps are necessary to ensure the safety of SAAB 340 aircraft operating in Australia.

The occurrence report noted that the crew had selected engine and propeller anti-ice systems on, but had not activated the leading edge de-icing boots. The autopilot was engaged, and the aircraft slowed under the icing conditions until stall occurred. Airframe buffet was experienced, but the crew mistook this buffet for propeller vibration.

The report favourably notes modifications mandated by Transport Canada. The report is thorough in evaluating the history of de-icing problems in SAAB 340 and similar aircraft.

However, actions by the crew in this instance appear to have made a poor situation worse.

CASA therefore does not believe at this time that there is an airworthiness problem with this aircraft type that requires immediate mandatory action.

Also, you will be aware of the intense debate a decade ago on the subject of Australian-specific design requirements for aircraft. The debate resulted in Australia's design requirements in Part 101 of the Civil Aviation Orders being

abandoned for aircraft types that have civil certification in a major aviation country. The public policy of CASA and the Government is now that CASA will impose requirements additional to those of internationally accepted certification standards only where those requirements can be publicly justified, including cost-benefit considerations.

The SAAB 340 and many other similar aeroplanes have been type certificated to internationally accepted certification standards and the argument for imposing the Canadian requirement on these aeroplanes, or even the SAAB 340 in isolation, does not yet appear to be adequate to meet CASA's criteria for an Australian specific design requirement.

Subsequent to the issue of this report, the US FAA has proposed some major changes to the way that modern propeller aircraft are handled under icing conditions. This includes a proposal to require that de-icing boots be activated as soon as an aircraft encounters icing conditions (FAA research has shown that 'ice-bridging' is not of concern with modern de-icing systems).

There is likely to be considerable discussion of these issues over the coming months, and CASA will be keeping a close watch on developments. Pending the outcome of the FAA proposal, CASA will write to Australian operators of this aircraft type to inform them of the BASI investigation, and recommend they review their training and operating procedures; and write to the manufacturer and associated regulatory authorities to seek their views, and to elicit comments on appropriate action.

We will provide you with information copies of this correspondence, and keep you informed of any further action initiated.

Response Status: OPEN