SERIOUS INCIDENT

Aircraft Type and Registration:	Saab-Scania SF340B, G-LGNB
No & Type of Engines:	2 General Electric Co CT7-9B turboprop engines
Year of Manufacture:	1990 (Serial no: 340B-216)
Date & Time (UTC):	5 June 2017 at 1415 hrs
Location:	During climb after departure from Edinburgh Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 3 Passengers - 33
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	34 years
Commander's Flying Experience:	6,638 hours (of which 6,387 were on type) Last 90 days - 109 hours Last 28 days - 49 hours
Information Source:	AAIB Field Investigation

Synopsis

During the climb after departure from Edinburgh Airport, the aircraft encountered severe icing and turbulence. During this period the stick shaker activated three times, before the aircraft descended to regain airspeed. After flying clear of the icing conditions and the area of turbulence, the aircraft continued to the destination without further incident.

History of the flight

The aircraft took off from Edinburgh Airport at 1402 hrs for a scheduled passenger flight to Sumburgh Airport. The weather forecast showed an occluded front lying to the north of Edinburgh which was moving north-east. There was also an upper level warm front parallel to the occluded front[1]. These fronts brought some rain showers with isolated embedded cumulonimbus clouds in the area around Edinburgh and the initial part of the route north towards Sumburgh.

In the climb out from Edinburgh, the aircraft encountered light turbulence in cloud. With the autopilot engaged the aircraft starting pitching up and down to maintain the selected IAS. Suddenly the turbulence intensified and ice began to form quickly on the aircraft. The stick shaker activated and the autopilot disconnected. The co-pilot, who was pilot

Footnote

[1] Figures 3 and 4 show the detail of the weather forecast.

flying (PF), attempted to accelerate the aircraft by reducing the pitch attitude. He then re-engaged the autopilot but, after 13 seconds, the stick shaker activated again and the autopilot disconnected. Shortly afterwards, the stick shaker activated for a third time and the co-pilot began a descent to accelerate the aircraft. The aircraft lost around 500ft during the manoeuvre during which it accelerated and recovered to normal flight. The crew did not select maximum continuous power during the recovery.

Recorded information

Recorded data for the incident flight was available from the aircraft's FDR. Information from the CVR was not available as it had been overwritten. Salient parameters from the FDR included the engagement status of the autopilot system, angle of attack (AOA), normal acceleration, pitch attitude, and parameters to derive engine power. The AOA parameter is recorded at a rate of twice per second and therefore the peak value may not always be recorded. No parameters are recorded on the FDR regarding the activation of the stall warning system.

Figure 1 shows salient parameters during the period when the aircraft experienced an increase in turbulence during the climb and the autopilot disconnected.

About eight minutes after takeoff, as the aircraft climbed through FL100, perturbations of normal acceleration started to increase, consistent with the aircraft encountering light turbulence. The OAT was -5°C. The turbulence then continued to increase in intensity, with variations in AOA that closely correlated with changes in load factor, pitch attitude and airspeed; the average airspeed was 162 KIAS at this time. The aircraft then briefly levelled off at FL103, before climbing again. Shortly afterwards, the AOA increased rapidly over one second from just over 0° to a recorded value of +5.3°, which coincided with the autopilot disconnecting; the airspeed was 160 KIAS and the pitch attitude was 6.3° nose-up. The coincident disconnection of the autopilot meant that the peak AOA value was in excess of the 5.3° recorded.

The pitch attitude then reduced quickly to 2.8° nose-up, before increasing to 13° nose-up in four seconds. During this period, the recorded AOA also varied rapidly, reducing to a minimum of -7°. The autopilot was then re-engaged and the pitch attitude reduced to about 2° nose-up. The airspeed reduced to 149 KIAS, after which it started to increase towards 160 KIAS.

Thirteen seconds later the aircraft pitched up quickly to 5.6°, the recorded AOA also increased rapidly, reaching a recorded 6°, and the autopilot disconnected again; the airspeed was 159 KIAS. The aircraft then briefly levelled off, during which the pitch and AOA both increased rapidly again, with the recorded AOA peaking at 6.3°. The aircraft then descended about 500 ft to FL105, during which the airspeed progressively increased to about 190 KIAS. At no time during this period of the flight was engine power increased to the 'maximum continuous' setting. The autopilot was then re-engaged, which coincided with a reduction in turbulence, and the aircraft climbed to its cruise altitude of FL170.

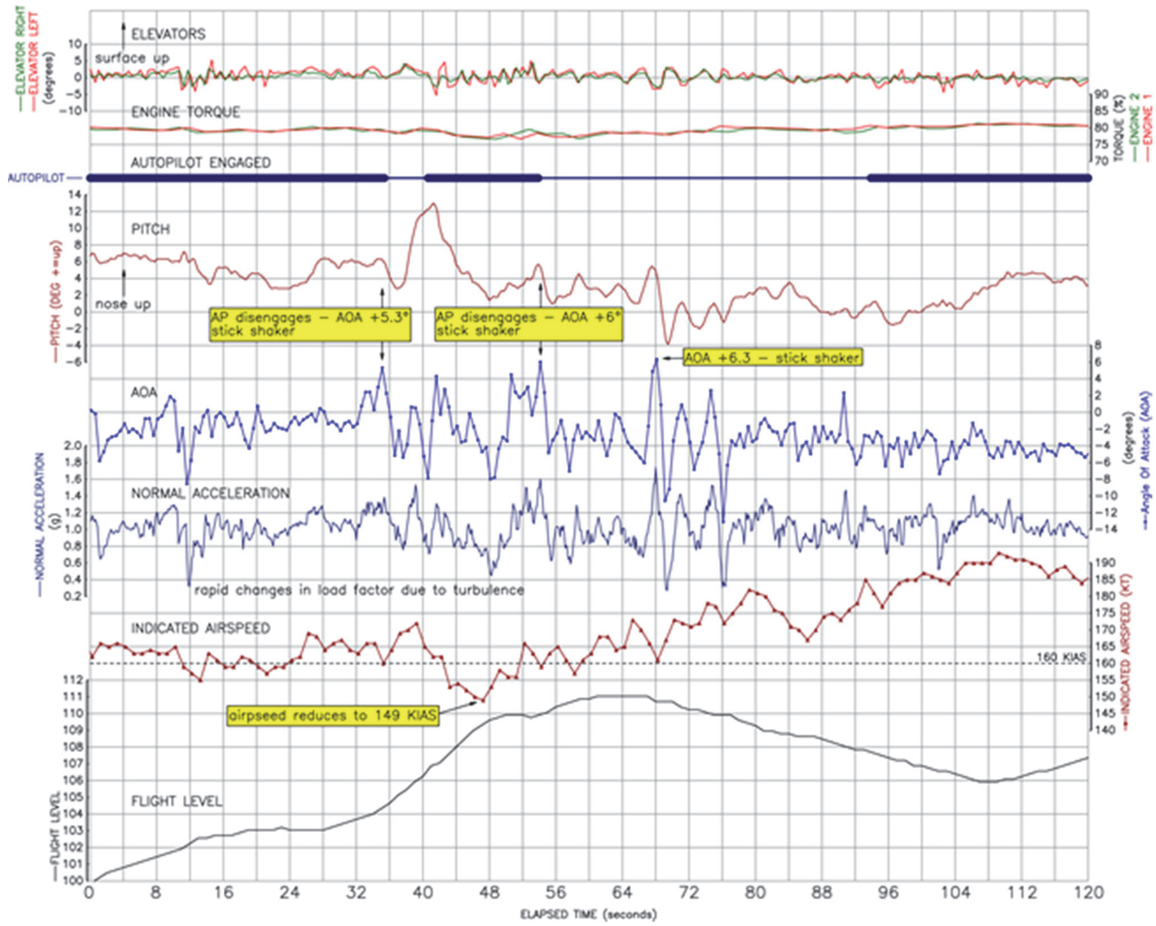

Figure 1

FDR data overview of event

Analysis of FDR data by the aircraft manufacturer

The FDR data was provided to the aircraft manufacturer for analysis. It was concluded that the rapid changes in pitch attitude and AOA were caused by turbulence. The aircraft did not enter an aerodynamic stall at any point, and the activation of the stall warning system was triggered by the AOA threshold being momentarily exceeded.

Flight Data Monitoring (FDM) data review

The aircraft operator reviewed its FDM data archive for its fleet of Saab-Scania SF340B (Saab340) aircraft. At the request of the AAIB, the data was analysed for occurrences when the autopilot disconnected coincidently with the recorded value of the AOA being greater than 5°. Between June 2015 and June 2017, a total of 23 occurrences were identified. Analysis of these indicated that, on 16 occasions, the autopilot had probably disconnected automatically due to the aircraft entering turbulence that resulted in the AOA exceeding the stall warning system trigger threshold with the anti-ice system selected ON.

The operator introduced a new FDM event which identifies when the autopilot disconnects due to AOA exceedences.

Aircraft information

The Saab340 is a twin-turboprop aircraft which can seat up to 36 passengers.

Ice protection systems

The Saab340 is fully equipped for all-weather operations. It has wing and stabilizer de-icing[2], engine and propeller de-icing, and heating for the windshield, outside air temperature probe and AOA sensor. Bleed air is used for the wing and stabilizer boots[3], and the engine intake. Electrical power is used for the remainder of the ice protection system.

Weather Radar

The Saab340 is equipped with a weather radar which transmits focused microwave pulses which are reflected by any moisture present in clouds in front of the aircraft. The amount the pulses are reflected back to the receiver gives a measure of the amount of moisture present. This information is then presented to the flight crew using different colours to represent the level of moisture.

Weather radars can provide useful information about potentially hazardous flight conditions. The most hazardous flight conditions are mostly concerned with hail and turbulence. Whilst the weather radar can detect wet hail, it cannot detect turbulence that is not associated with moisture (such as clear air turbulence or wind shear). The radar also has limitations in how well it can detect weather beyond areas of heavy rain due to the inability of the microwave pulses to penetrate beyond the rain. This means that more distant targets may appear less intense than they really are or may not appear at all. The weather radar controls include the ability to change its range, tilt and gain. This allows the flight crew to adjust the radar for optimum display of weather that may be on their path.

Stall warning system

The Saab340 is fitted with a dual channel stall warning system which provides the crew with five distinct warnings of an impending stall. The aircraft has a stick shaker channel for each control column which provides a physical warning in the form of vibration, and this is reinforced with an aural warning in the form of a continuous clacker. At the same time as the stick shaker activates, the autopilot disengages. If sufficient action is not taken after the stick shaker and aural warning are triggered, the stick push system provides a forward movement of the control columns to pitch the aircraft to a slightly nose-down attitude. If the stick push activates, visual warnings on the central warning panel and on the instruments panels also illuminate. The stall warning is generated by a combination of AOA, flap position and information from the wing anti-ice system.

Footnote

2 De-icing: Removal of ice accretion by thermal, mechanical or chemical means.
3 Boots: Flat array of flexible tubes bonded to the leading edge of wings, fins and other aircraft surfaces to break up ice.

History of modification

Due to incidents within the worldwide fleet of the Saab340, in which the aircraft encountered a stall without any prior stall warning, the manufacturer developed a modified stall warning system which incorporated an improved stall warning logic. Fitment was mandated in 2014, with operators given 18 months to complete the fitment of the new stall warning computer.

Ice Speed modification

The modification to the stall warning computer adjusted the logic of the stick shaker and introduced the Ice Speed system. This increased the stall warning speed trigger levels to compensate for possible ice accretion on the wings. The trigger AOA for the stick shaker activation was lowered from 12.1° to 5.9° but the stick push logic remained unchanged. This Ice Speed function is activated by switching on the engine anti-ice system. It remains activated even when the engine anti-ice system is selected off because a separate ICE SPEED switch must be additionally selected OFF. The engine anti-ice system must remain on for five minutes after exiting icing conditions. Any time the Ice Speed system is active, the aircraft speed on approach must be increased in order to maintain the margin over the stick shaker activation AOA.

Stick shaker event history

The Ice Speed system has presented a challenge to operators of the Saab340, especially if operating into performance-limiting runways. The additional 10 kt of airspeed required for the approach, if the Ice Speed system is active, when added to any wind correction can lead to a high approach speed limiting the payload on some shorter runways. This higher approach speed also means the aircraft often makes the approach with a relatively low nose attitude, which is unusual for the flight crew.

Analysis of Saab340 stick shaker events reported to the CAA via the MOR[4] system revealed that, after the introduction of the stall warning modification, the number of reported events increased from an average of 3.8 per year between 2010 and 2014 to 22 in 2015, 42 in 2016 and 35 in 2017 (Figure 2). These events were particularly prevalent in the approach and landing phase of flight.

The operator believed that this increase in events was directly related to the requirements of the stall warning computer modification and the trigger AOA being significantly lower than before. If the aircraft is in turbulence, or there is a sudden gust of wind at touchdown, the pitch of the aircraft can alter rapidly, triggering the stick shaker.

EASA requested that the manufacturer review the system architecture and logic to look for any possible adaptation which would address the safety concerns associated with the repeated warnings.

Footnote

[4] MOR: Mandatory Occurrence Report, An occurrence means any safety-related event which endangers or which, if not corrected or addressed, could endanger an aircraft, its occupants or any other person

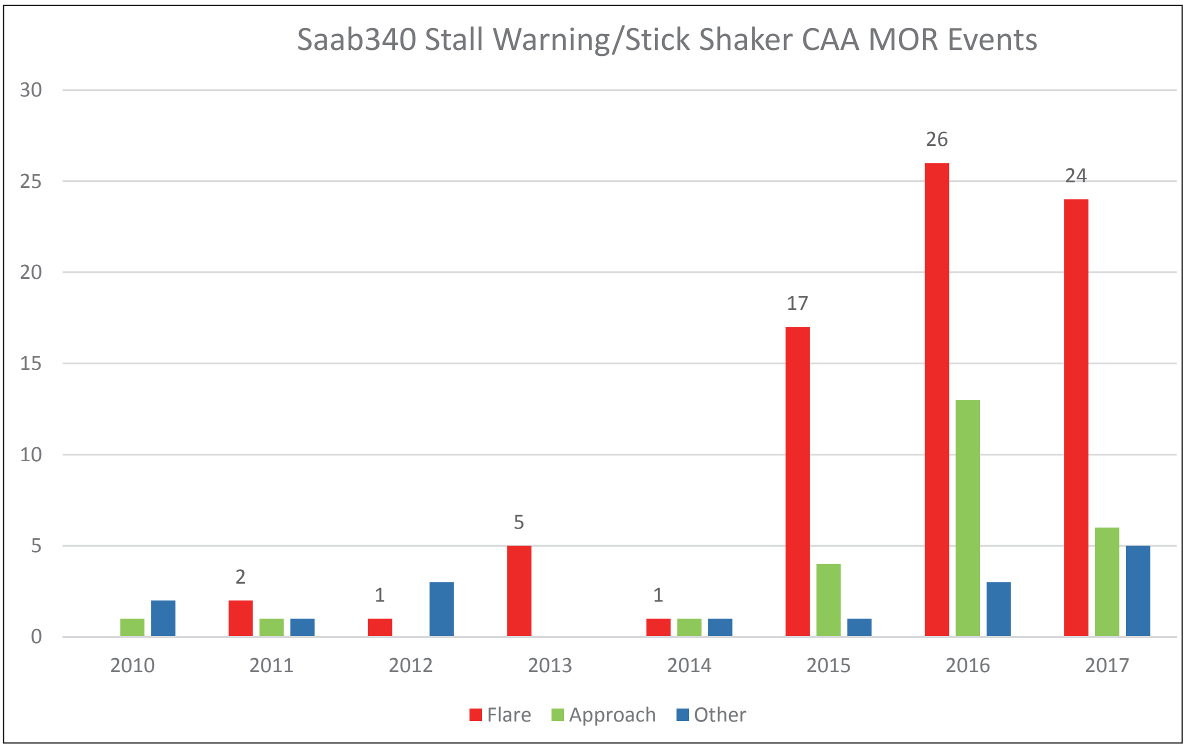

Figure 2

Saab340 Stall Warning/Stick Shaker CAA MOR Events 2010 to 2017

Aircraft performance

Autopilot mode

G-LGNB was climbing in IAS mode in which the flight control computers adjust the pitch attitude of the aircraft in order to maintain the selected IAS. The mode was engaged with an IAS of 163 kt.

Event trigger

The stick shaker was triggered three times by the aircraft AOA reaching 5.9°. The aircraft was in turbulence with the pitch and IAS of the aircraft varying.

Meteorology

Aftercast

An aftercast, obtained from the Met Office, showed that the weather in both Edinburgh and Sumburgh was affected by the presence of an occluded front lying just to the north of Edinburgh, moving eastwards. There was also a warm front lying parallel to the occlusion. Visibility outside the cloud was good but there were isolated moderate or heavy showers. There were also isolated, embedded cumulonimbus clouds (CBs) with bases from 1,500 to 3,000ft amsl and tops above 10,000ft. Freezing levels were between 4,000 and 5,000ft amsl.

Hi-resolution satellite images taken at 1500 hrs showed a large amount of stratus or fog in the area of the event. Areas of brighter/white cloud on the images indicated the presence of embedded CBs and this was confirmed by both the rainfall radar images and observations in Edinburgh, where large hail stones were recorded at 1220 hrs.

The Met Office assessed that, between 1300 hrs and 1500 hrs, there was a high probability of severe icing on the route, with the risk decreasing during the afternoon to a high probability of light or moderate icing by 1500 hrs.

Information available to the crew

The crew received a briefing pack when they reported for duty. This pack included the route, NOTAMS, weather at departure and destination as well as charts of wind, weather and temperature along the intended route. The Met Office chart F215 details the weather in the UK below 10,000ft. The chart for 0800 hrs to 1700 hrs issued on the day of the incident is shown at Figure 3.

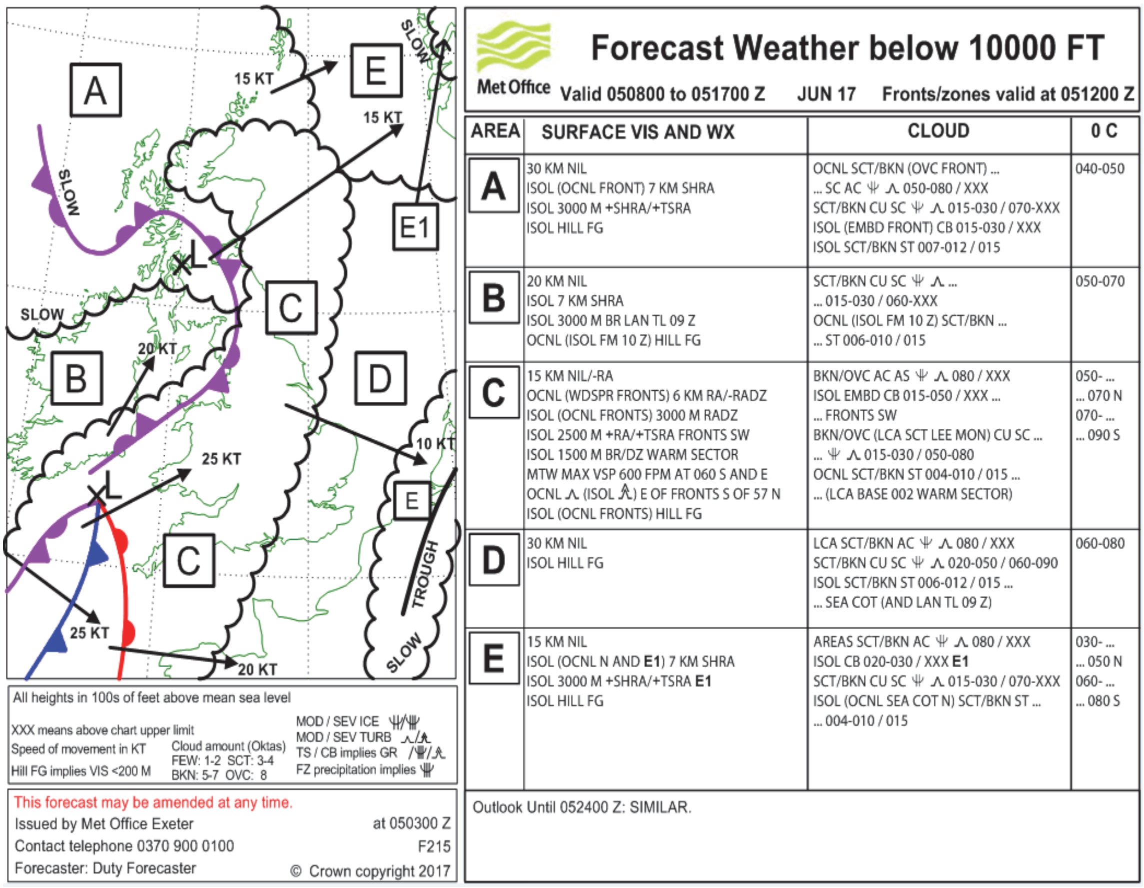

Figure 3

Chart F215 Valid 1200UTC on 5 June 2017 produced by the UK Met Office

The crew received a significant weather chart which was supplied by the operator's flight planning contractor. This chart shows weather which may have affected the aircraft such as icing, turbulence or CB activity from FL100 to FL450. Although the chart the crew had access to was not produced by the UK Met Office, it was generated from the data supplied by them. Figure 4 shows the Met Office chart for 5 June 2017.

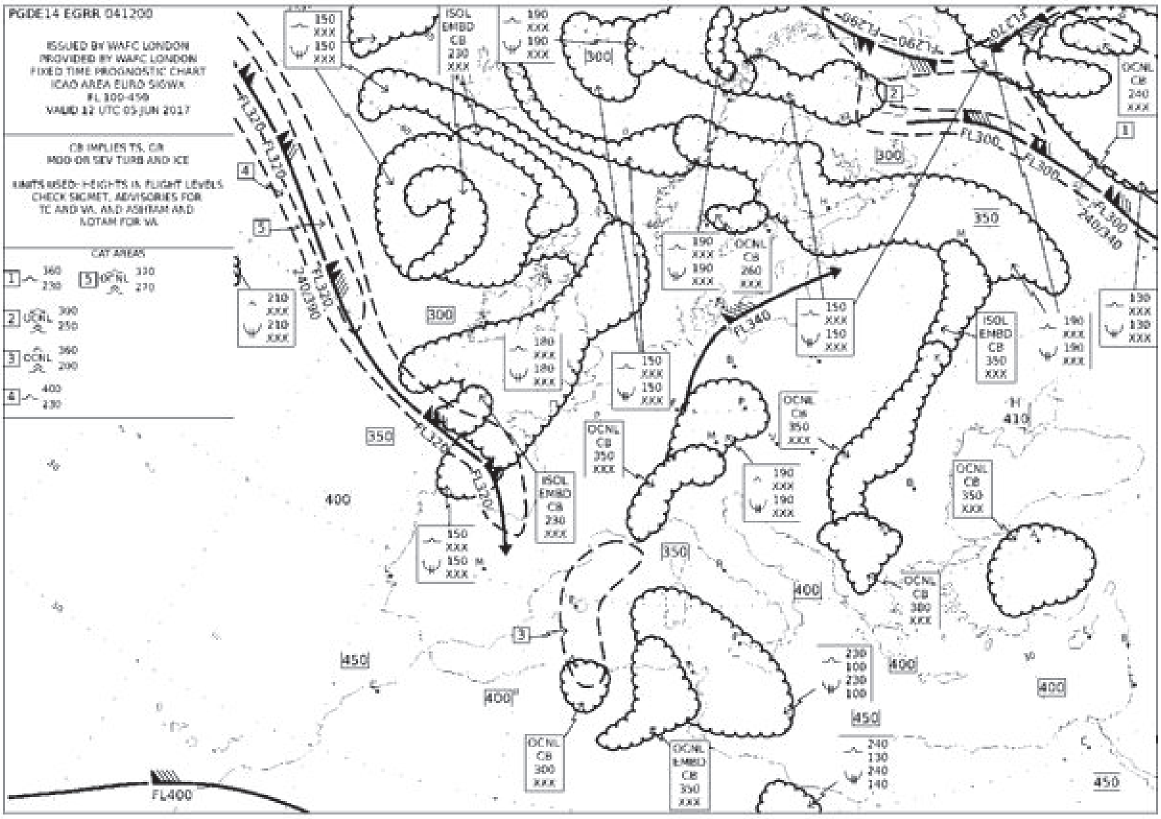

Figure 4

Significant Weather Chart Valid 1200UTC on 5 June 2017 supplied by the UK Met Office

Icing conditions definitions

Aeronautical terms for describing icing intensity are 'trace', 'light', 'moderate' and 'severe' yet there are no internationally accepted definitions of these terms. Different aircraft types may experience ice accumulation differently in the same conditions due to their different anti-icing and de-icing equipment as well as their individual propensity to pick up ice on wings and structures.

The UK Aeronautical Information Publication (AIP) gives information for the reporting of icing levels by pilots. It states that 'moderate' icing is when:

> *'The rate of accumulation is such that even short encounters become potentially hazardous and the use of de-icing/anti-icing equipment, or diversion, is necessary.'*

For 'severe' icing:

> *'The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.'*

The term 'diversion' in this context implies diverting from intending routing including changing speed, height or heading.

The Met Office does not define icing conditions absolutely but considers the many different factors in preparing forecasts of icing conditions such as type, depth and extent of cloud, temperature and relative humidity. It also appreciates that aircraft have differing levels of susceptibility to icing.

Procedures

The manufacturer produces an Aircraft Operations Manual (AOM) which contains the technical details of the type, as well as operations procedures for normal, abnormal and emergency situations. The operator has the abnormal and emergency procedures reproduced in booklet form and available in the flight deck for each pilot as an Emergency and Abnormal Checklist (EAC).

The operator produces a suite of Operations Manuals (OM) which contain the information flight crews require. Part A (OMA) is non type-specific and contains policies, instructions and procedures for the operator. Part B (OMB) is type-specific and contains information to supplement the AOM. The AOM is the definitive source of information and the aircraft should be operated in accordance with the AOM unless OMB specifically states otherwise.

Flight in icing conditions

The AOM Section 25, '*Flight Procedures'*, has a section on icing conditions. It specifies the use of IAS mode when the engine anti-ice is selected ON with a general rule of a minimum speed of 160 KIAS. It describes specific situations and limitations for when the speed may be reduced below 160 KIAS in order to exit severe icing conditions. These limitations include the selection of maximum power and limiting the bank angle to less than 15° below 160 KIAS.

In OMB the operator sets out the '*Minimum Operating Airspeeds in Icing Conditions'* within the limitations section. This section describes V_{CM} which is the '*conservative manoeuvring*' speed to be used when climbing above minimum safe altitude. In the clean configuration this speed is 160 KIAS. If there is a significant performance loss, and a slower speed is required to exit icing conditions, then the autopilot must be disengaged and the speed may be reduced to V_{CLEAN} +15. Maximum continuous power must be selected until V_{CM} can be re-established. OMB describes reducing speed below V_{CM} as a '*Non-standard situation and the risk of this action* [must be] *assessed*.'

Flight in turbulence

The AOM describes the likelihood of a transient stall warning being generated due to sudden movement of the AOA vane when the Ice Speed system is active and the aircraft is experiencing moderate to severe turbulence. It states that momentary warnings (one second or less) can be disregarded if it is confirmed that the aircraft is at a safe speed and altitude. It suggests that under all circumstances it would be advisable to increase the speed when encountering more than light turbulence but not to a value above the turbulence penetration speed[5] of 190 KIAS, up to 21,000ft, and Vmo-30 kt above. This increase in speed means there will be a greater margin over the stick shaker trigger AOA and makes a transient warning less likely.

Response to reducing airspeed and the stick shaker

In the AOM, Saab makes the following statement:

> *'If experiencing severe icing conditions and safe speed and/or climb rate cannot be maintained, do not hesitate to temporarily set TAKEOFF PWR/ MAX CONTINUOUS PWR, if that is required to escape from the situation. Severe icing conditions do not necessarily imply a large amount of ice but ice accumulation causing a large impact on performance making airspeed decrease towards the minimum safe speed in icing conditions.'*

The operator's OMB emphasises not to delay any request to descend when the aircraft is experiencing difficulty maintaining airspeed:

> *'Speed can reduce at a rate of 1 knot per second or more in severe icing with cruise power set. If severe icing is encountered it may take less than 20 seconds for airspeed to reduce from 180 knots to 160 knots. Typically it takes around 30 seconds to request and initiate a descent from ATC, if there is no traffic.'*

The recovery procedure from a stall warning or a stall is not listed in the Abnormal or Emergency checklists, it is in the Flight Procedures Training section of the AOM. It states:

> *'− CALL: "STALL − MAX POWER"*
>
> *− PITCH: Immediately decrease the pitch by approximately 5 degrees or as commanded by the stick pusher. Do not fight the pusher stroke. Do not hesitate to trade altitude for speed, however, avoid unnecessary dive.*
>
> *− SPEED: Accelerate to minimum* V_{clean}*+5, with ice on the wing* V_{clean}*+15. After initial recovery, do not pull up with too high rate. Consider the possibility for a secondary stall.*
>
> *− ALTITUDE: When positive climb rate is indicated, select gear up and recover altitude loss. Climb to safe altitude with* V_{clean}*+5, with ice on the wing* V_{clean}*+15*
>
> *− FLAPS: If flaps are down, leave them where they are. However, if in landing configuration, after the initial recovery and in climb, select flaps (7/20 as for go-around).'*

Footnote

5 Turbulence penetration speed: maximum speed at which a gust will not overly stress the aircraft.

Training

Both flight crew received training in stall identification and recovery during their conversion to type. The commander had also received refresher training as part of the operator's recurrent training programme where stalling featured as one of the abnormal/emergency scenarios. The co-pilot had very recently completed his conversion to type and had yet to undergo any recurrent simulator training. His training was therefore only that which he received on his conversion.

Crew comments

The crew said that stick shaker activation is a reasonably regular occurrence on the Saab340 with the operator of G-LGNB. This is because of a combination of the frequency with which the engine anti-ice is used on the approach and the relatively short length of some of the runways into which the aircraft operate. Pilots often discuss the possibility even if they have yet to encounter it themselves.

The incident crew commented that they were fully aware of the stall procedures. However, the lack of the trigger call "Stall – Max Power" from either pilot in response to the stall warning meant neither recognised the situation as one which required the actions listed above. They also noted how quickly the ice built up on the aircraft. The commander had encountered the stick shaker on previous flights.

Analysis

Icing condition encounter

The aircraft encountered icing on departure from Edinburgh Airport. The severity and extent of ice accumulation on the upper wing surface led to a significant performance loss, which meant the aircraft was unable to maintain the selected airspeed at the aircraft altitude and a descent was necessary to regain lost airspeed. This level of icing would match the UK AIP pilot reporting definition of severe icing and this, combined with the information available from the Met Office, suggested that the crew probably encountered a CB on their route. Whilst these CBs were forecast, it is possible they did not show on the aircraft's weather radar, which would have made it less likely that the crew would become aware of their presence before encountering them.

The severe icing and turbulence they encountered caused the AOA to increase beyond the 5.9° trigger for the stick shaker on three occasions due to short duration transient variations. On two occasions this caused the autopilot to disconnect (during the third activation the autopilot was not engaged). Re-engaging the autopilot without fully reducing the pitch attitude of the aircraft, meant that the stick shaker was triggered for the second time after 10 seconds. The subsequent descent saw the aircraft clear both the icing and turbulent conditions whilst increasing the airspeed.

Procedures

Procedures in the AOM and the OMB gave the crew clear guidance on the actions to be taken on entering areas of turbulence and icing. The AOM advised increasing the airspeed when encountering turbulence to give a wider margin over the stick shaker trigger, and both the AOM and OMB listed actions to be taken when the speed decays in icing condition.

Once the stick shaker triggered, the AOM listed the actions to be taken which included decreasing the pitch of the aircraft, setting maximum power and accelerating. However, these procedures relied on the flight crew recognising the situation and responding accordingly. In this case, the situation was not recognised and the trigger call of “Stall – Max Power” was not verbalised by either crew member. Consequently, maximum power was not set and the other trained responses were not carried out.

The third stick shaker did trigger the crew to descend the aircraft and regain the required airspeed but at no point was maximum continuous power set. Increasing the airspeed when the aircraft encountered turbulence, as recommended in the AOM, might have avoided this event because it would have increased the AOA margin over the stick shaker.

Human factors

The modification to the stall warning computer has had the unintended consequence of increasing stick shaker activation for the operator’s Saab340 aircraft on which it has become a regular occurrence. Therefore, it is possible that pilots no longer take the activation as seriously as they did previously as they may interpret it as a nuisance and not react. The AOM specifically allows the crew to disregard transient (less than 1 second) warnings as long as the aircraft is at a safe speed and height. In this case, for two of the stick shaker activations the speed was below V_{CM}, and the stick shaker could not be disregarded. Whilst there is no suggestion that the crew on G-LGNB deliberately ignored the warning, or considered it a nuisance, it is human nature to give less regard to a warning known to be triggered regularly even when it is not required.

Safety Action

EASA, the operator and the manufacturer considered making deactivation of the ICE SPEED logic independent of the requirement to maintain the engine anti-ice system on for five minutes after leaving icing conditions. This change, considered feasible by the manufacturer, would address the concerns about repeated activation of the stick shaker in the latter stages of an approach and in the flare.

EASA expected to mandate the implementation of this improvement to address the safety concern.

Conclusion

After encountering severe icing, probably associated with a CB, the Saab340 stall warning system functioned as it was designed to by alerting the crew, through the stick shaker, of an AOA in excess of 5.9°. The crew actions did not initially address the problem sufficiently and the stick shaker occurred again. Following the third activation of the stick shaker the crew descended the aircraft to regain a safe airspeed. Although maximum power was not set, the aircraft did accelerate and the crew were able to clear the icing and turbulent conditions before continuing their flight without further incident.