Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Occurrence Investigation – AO-2006-154

(previously 200601076)

Final

Warning device event
232 km south of Paraburdoo, WA
28 February 2006
VH-NXH
Boeing Co 717-200

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CONTENTS

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Figure 1. Modified from the Boeing Co 717 Flight Crew Operating Manual
Figure 2. Reproduced from the Boeing Co 717 Aircraft Maintenance Manual
Figure 6 and 7. Reproduced courtesy of the National Transportation Safety Board

Abstract

On 28 February 2006, a Boeing Company 717-200 aircraft, registered VH-NXH, was being operated on a scheduled passenger service from Paraburdoo to Perth, WA. The flight was being conducted under the instrument flight rules (IFR). Onboard the aircraft were two flight crew, four cabin crew and 66 passengers. The aircraft departed Paraburdoo at about 0837 Western Standard Time and was in instrument meteorological conditions (IMC) during the climb.

The stick shaker stall warning system activated soon after the aircraft reached top of climb at Flight Level (FL) 340 and while the aircraft was accelerating to cruise speed. The flight crew did not receive any ‘STALL’ annunciation on their respective primary flight displays, nor any ‘STALL STALL’ aural warning or klaxon alert.

The flight crew initiated an immediate on-track descent and advised air traffic services of their requirement to change level. There was an infringement of the relevant procedural separation standards as the aircraft descended through the cruise level of an opposite direction aircraft.

An analysis of the flight recorder data indicated that the activation of the stick shaker was as a consequence of the angle-of-attack sensors becoming static during the climb. The investigation concluded that the immobilisation of the angle-of-attack sensors was consistent with ice restricting the movement of the ‘slinger’ on which the sensor vane is mounted.

The investigation assessed that the aircraft was not near a stalled condition of flight when the stick shaker warning activated. However, because the angle-of-attack sensors provided input to the aircraft’s stall warning system, the immobilisation of those sensors adversely affected the reliability of the aircraft’s stall warning system and could have render the automatic stall recovery system inoperative.

As a result of this incident, the aircraft and angle-of-attack sensor manufacturers initiated a detailed design review of the angle-of-attack sensor.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external organisations.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports

How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, risk controls and organisational influences.

Contributing safety factor: a safety factor that, if it had not occurred or existed at the relevant time, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Safety issues can broadly be classified in terms of their level of risk as follows:

- **Critical safety issue**: associated with an intolerable level of risk.
- **Significant safety issue**: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable.
- **Minor safety issue**: associated with a broadly acceptable level of risk.

FACTUAL INFORMATION

Occurrence sequence

On 28 February 2006, a Boeing Company 717-200 (717) aircraft, registered VH-NXH, was being operated on a scheduled passenger service from Paraburdoo to Perth, WA. The flight was being conducted under the instrument flight rules (IFR). Onboard the aircraft were two flight crew, four cabin crew and 66 passengers.

The aircraft departed Paraburdoo at about 0837 Western Standard Time[1], with an air traffic services (ATS) requirement to reach Flight Level (FL) 340[2] by 0852. That requirement was imposed by ATS to provide a procedural separation standard between the aircraft and opposite direction traffic that was maintaining FL320.

The flight data recorder (FDR) showed that the flight crew selected maximum continuous thrust[3] as the aircraft climbed through FL163 and that, during the climb above FL256, the flight management system was engaged in the 'Pitch FMS' mode, with climb speed being controlled by the flight management system (FMS) and that the flight crew selected the FMS to maximum climb[4] (MAX CLB). The result was that the aircraft climbed at about 60 kts below the aircraft manufacturer's recommended climb speed of 290 kts calibrated airspeed (CAS)/0.72 Mach[5] (M). [6,7]

The auto flight system levelled the aircraft at FL340. The flight crew recalled that the aircraft accelerated normally to cruise speed and that the pitch attitude and engine power settings were normal for that stage of flight. During the acceleration, the flight crew detected that, over a period of several seconds, the speed displayed on their primary flight displays (PFD) for stick shaker activation (V_{ss}) began converging towards the indicated airspeed, overtaking the amber caution speed range associated with the flight management computer-calculated minimum operating speed (V_{min}). The relevant indications on the aircraft's PFDs are annotated at Figure 1.

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1 The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST), as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC) + 8 hours.

2 The aircraft's operating altitude, expressed as hundreds of feet above the standard pressure datum of 1013 hPa. That was, an operating altitude of 34,000 ft in the standard atmosphere.

3 Maximum continuous engine power setting.

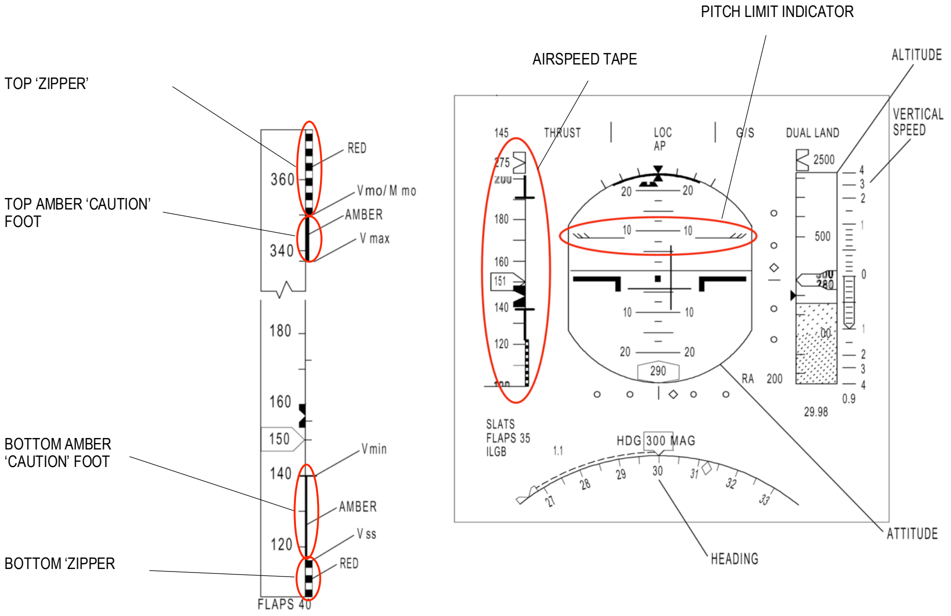
4 In MAX CLB mode, the FMS commanded the recommended airspeed for the best angle of climb. That speed schedule was slightly above V_{min} and approximately 1.4 V_s. The Flight Crew Operating Manual for the 717 indicated that selecting MAX CLB provided the opportunity to exchange excess speed for altitude.

5 The speed of the aircraft expressed as a ratio to the local speed of sound.

6 The FDR indicated that, during the climb above FL260, the aircraft was flown at MAX CLB with speeds ranging from 230 to 239 kts CAS.

7 The aircraft manufacturer's recommended climb speed was 250 kts CAS until reaching 10,000 ft, then 290 kts CAS until reaching the airspeed crossover altitude, from where 0.72 M was flown.

Figure 1: Primary flight display and airspeed tape



The flight crew stated that the stick shaker[8] activated as V_{ss} merged with the current airspeed. The speed indicated for V_{ss} continued to increase and merged with the maximum operating speed (V_{mo}/M_{mo}), such that the right edge of the airspeed tape gave the appearance of being one continuous red and white 'zipper'[9]. Similar indications were observed on both the pilot's and the copilot's PFDs. The flight crew reported that they did not receive any other cautions, alerts or warnings on the aircraft's engine and alert display (EAD).

The flight crew recalled that there was no 'STALL' annunciation on their PFDs, and no 'STALL STALL' aural warning or klaxon alert. The stick pusher stall recovery system did not activate and the crew did not identify any secondary indications of an impending stall, such as aerodynamic buffet or an abnormally high pitch attitude for the manoeuvre being flown. The crew initiated an immediate, on-track descent and advised ATS of their requirement to change level. In response, ATS provided the crew with traffic information about the opposite direction traffic. Although there was no indication of any ice on the windscreen or windscreen wiper posts, the crew elected to select airframe anti-ice ON. They stated that they did not otherwise change the configuration of the aircraft.

ATS estimated that the two aircrafts' time of passing was 0902. There was an infringement of the relevant ATS procedural separation standard.

The stick shaker continued to operate as the aircraft was descended at a rate of about 2,500 ft per minute. The flight crew recalled that the indicated V_{ss} on the PFD returned to normal as the aircraft descended through FL290, and that the stick shaker warning ceased at that time.

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8 The stick shaker was a tactile warning to alert the flight crew that the aircraft was at or near an aerodynamically stalled condition of flight. It was one of several warning systems designed to alert the crew of that flight condition.

9 The 'zipper' consisted of alternating red and white rectangles and were displayed on the extreme upper and lower ranges of the side of the airspeed indicating tape, indicating airspeeds above V_{mo}/M_{mo} and below V_{ss}.

At about 0858, the flight crew reported to ATS that they were maintaining FL280.

Closer to Perth, the crew were able to climb the aircraft to FL300, clear of cloud. During the cruise at FL300, the total indicated air temperature[10] (TAT) reduced to below 0° C, but the angle-of-attack sensors continued to operate normally.

Maintenance action

Following the aircraft's arrival in Perth, company maintenance engineers performed a built-in-test equipment check[11] of the aircraft's Flight Control Computers (FCCs). That check showed no recorded faults during the occurrence flight, and the aircraft was released for service. Subsequent flights were completed without incident.

On 3 March 2006, an entry was made in the aircraft's maintenance log, reporting the intermittent operation of the OFF enunciator light for the air data heat switch after its selection to OFF following landing. The maintenance log attributed that fault to worn bases of the indicator globes. In response, company maintenance engineers replaced the globes within the switch assembly, the switch was tested serviceable, and the aircraft was returned to service.

Aircraft information

Design/certification

The 717 was issued a Type Certificate as a Transport Category Airplane by the US Federal Aviation Administration (FAA) under Federal Aviation Regulation (FAR) Part 25.

Angle-of-attack sensors

The angle-of-attack sensors were certified in accordance with an FAA Technical Standard Order (TSO). That certification was issued on the basis of the 'Qualification by Similarity' of the sensor with another previously TSO-certified angle-of-attack sensor that was produced by the same component manufacturer. The original sensor's certification demonstrated its compliance with the requirements and performance standards that were stipulated in SAE Aeronautical Standard AS 403A and were applicable to a 'Stall Warning Instrument'.

The qualification test procedure for the original sensor included a demonstration of its ability to comply with the relevant ant-icing and de-icing standards. That procedure was based on the sensor's performance during wind tunnel testing, in which the sensor was subjected to simulated flight in icing conditions at various temperatures and airspeeds.

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10 The total indicated air temperature was measured by the ram air temperature probe. Due to the effects of compressibility, the measured temperature was significantly higher than the environmental air temperature.

11 BITE equipment check. A check of that equipment for any fault codes that were stored during the flight for maintenance examination and fault isolation.

An appendix to the qualification test report noted that ice formed on the mounting hub and 'slinger' assembly during some of those tests. A note on one of the wind tunnel test reports indicated that, during one of those tests, the sensor vane immobilised when water spray was directed at the hub and required a 5^{o} rotation of the sensor assembly to free the vane and allow the test to resume.[12] Those observations on the qualification test report were consistent with the sensor becoming immobilised as a result of ice formation during test conditions, including at times when the sensor vane was heated.

The original vane-slinger-shaft assembly that was certified during the initial testing was of identical construction and material specification to the sensors used on the 717 aircraft type. However, the original sensor's case assembly was equipped with two variable-resistance, self-regulating heaters, unlike the sensor installed on the 717, which was equipped with a single fixed-resistance case heater. Those heaters were intended to help stabilise the temperature within the case assembly and helped prevent condensation inside the case. The stabilised temperature also limited any increase in the viscosity of the damper fluid at low temperatures, thereby improving the unit's transient response and the accuracy of the angle-of-attack sensor.

The manufacturer of the sensors indicated that there had been evidence on a number of occasions of moisture ingression into the sensor case of units that were returned for service/defect rectification. In those instances, the sensor had typically been returned after the detection of faulty sensor output by the affected aircraft's systems.

Ice protection

The certification requirements of FAR 25.1419 applied to transport category aircraft that were intended to operate in icing conditions. Included was testing to demonstrate the effectiveness of the various aircraft components' ice protection during the operation of the aircraft in conditions specified for continuous and intermittent maximum icing conditions. Those conditions were defined in terms of variables such as the cloud liquid water content, the mean effective diameter of the cloud droplets, the ambient temperature and the interrelationship of those variables.

Flight environment data sensors

System description

The aircraft's air data system included sensors that collected information on the static air pressure[13], pitot air pressure[14], ram air temperature[15] and angle-of-attack

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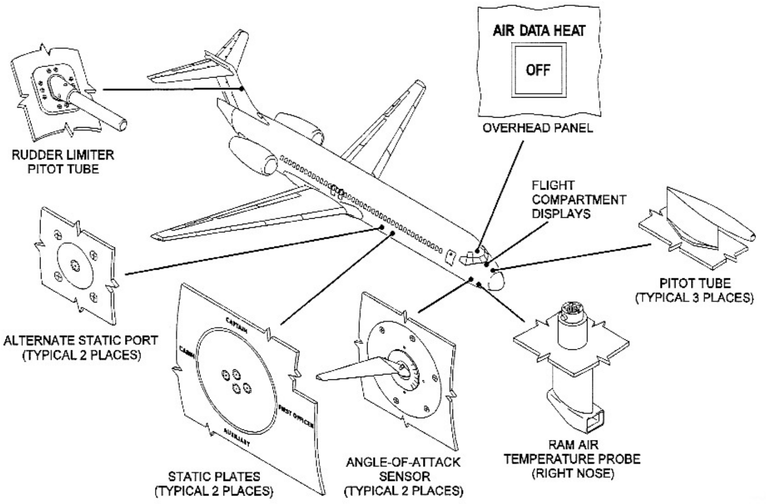
12 The sensor manufacturer advised that icing tests conducted in a wind tunnel do not take into account the air flow boundary layer effects typically encountered by an aircraft in flight, and that 'during the referenced wind tunnel test the water spray was intentionally directed at the most vulnerable areas (face plate and slinger) of the angle of attack sensor. In flight this area would be less susceptible to water droplet concentrations because of the boundary layer effect.'

13 Static air pressure is the pressure of the still air through which an aircraft is moving. Static pressure is measured to provide information about an aircraft's altitude, and the rate of change of static pressure is used to derive the aircraft's vertical speed.

affecting the aircraft (Figure 2). Data modules converted the pitot-static information into digital signals and supplied those signals to the aircraft's air data inertial reference units which, in turn, sent parameters computed from that data to the aircraft's flight computers and navigation systems. Flight environment data was displayed to the flight crew on the aircraft's electronic instrument system displays, including information on its altitude, airspeed, Mach number, vertical speed and air temperature.

Figure 2: Flight environment data sensors



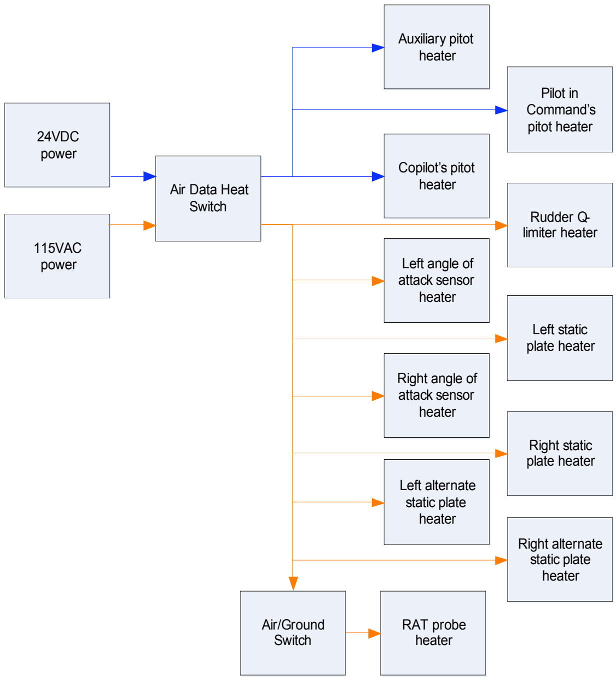
Ice protection

Each of the flight environment data sensors (Figure 3) was able to be electrically heated in order to ensure the continued availability of data during flight, including when operating in icing conditions. Sensor heating was controlled by the AIR DATA HEAT switch, an illuminated, four-pole, double-throw (alternate action) latching switch that was located on the cockpit forward overhead panel. The crew were required to select the switch ON as part of the pre-flight checklist.

14 Pitot air pressure is the total air pressure affecting an aircraft as it moves through the air, comprising the static air pressure and the increase in pressure as a consequence of bringing the moving air to rest.

15 Ram air temperature is the outside ambient air temperature, uncorrected for the compressibility heating effect of airspeed. That data is indicated to the flight crew as the TAT.

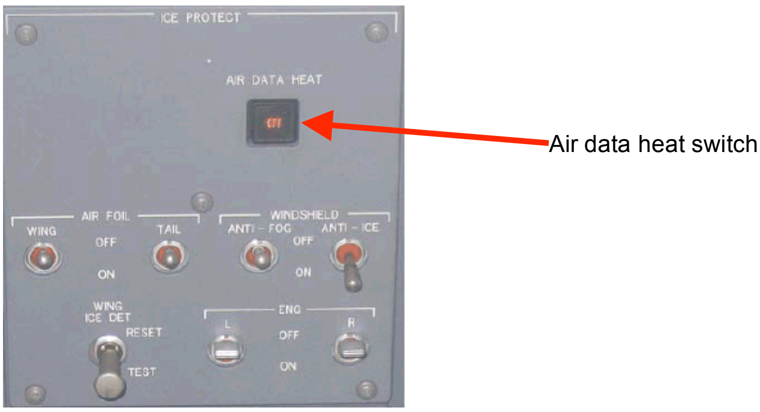
Figure 3: Air data heating system



The air data heat switch was part of the aircraft's ice protection control panel (Figure 4). That switch was the only push-button switch on the ice protection control panel, and the only push-button switch in that vicinity. The aircraft's electrical systems were configured so that, when the switch was latched (OFF), the heaters for the aircraft's flight environment data sensors were off, and the switch was illuminated with an OFF annunciation. In that position, the switch protruded about 5.5 mm from the surface of the control panel.

When the switch was unlatched (ON), the flight environment data sensor heaters were on and the switch was not illuminated. In that position, the switch protruded about 7.6 mm from the overhead panel.

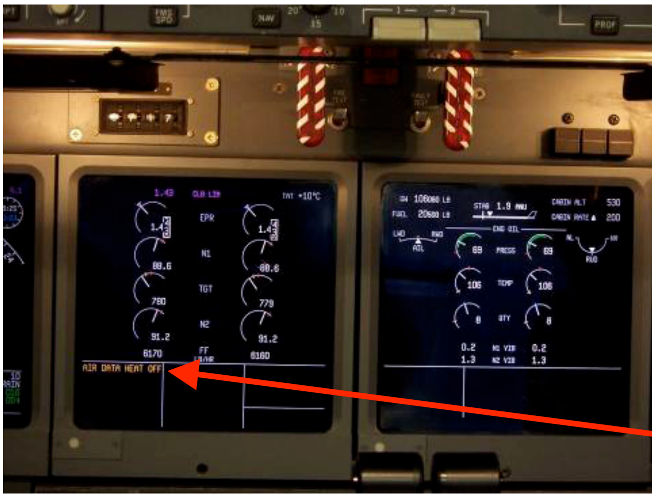
Figure 4: Ice protection control panel - air data heat switch selected OFF



The aircraft manufacturer applied the concept of a 'dark cockpit' during the process of aircraft systems design in the 717. In that case, 'normal' system conditions were not enunciated. Because the normal system condition was for the air data heat to be

ON during flight, its status was only enunciated to the flight crew when it was selected to the OFF position. That annunciation was displayed as an OFF illumination of the switch button and by a system status message 'AIR DATA HEAT OFF', which was displayed on the lower left corner of the EAD on the centre console (Figure 5). That system design was certified under the indicating system requirements of FAR 25.1419.

Figure 5: AIR DATA HEAT OFF annunciation



AIR DATA HEAT OFF annunciation on the EAD

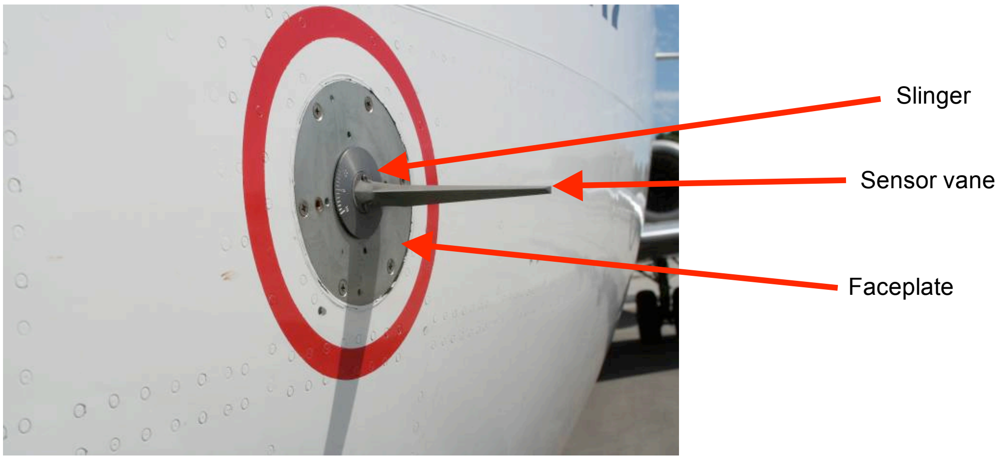
The design of the air data heat system incorporated the continuous monitoring of the operation of each of the heating circuits when the heating system was selected ON. If an individual heating circuit failed, the flight crew was advised by a system status message on the EAD.

The EAD was incorporated in the manufacturer's recommended standard instrument scan pattern for the aircraft and was included in the aircraft's operational documentation as a discrete checklist item. That item required a review by the flight crew of EAD alerts and messages before takeoff, and when following the aircraft manufacturer's published procedure for application during the initial climb.

Angle-of-attack sensors

The aircraft was equipped with two angle-of-attack sensors that were mounted on each side of the aircraft's forward fuselage. Each included an aerodynamically-shaped swept sensor vane that was designed to align with the local airflow (Figure 6).

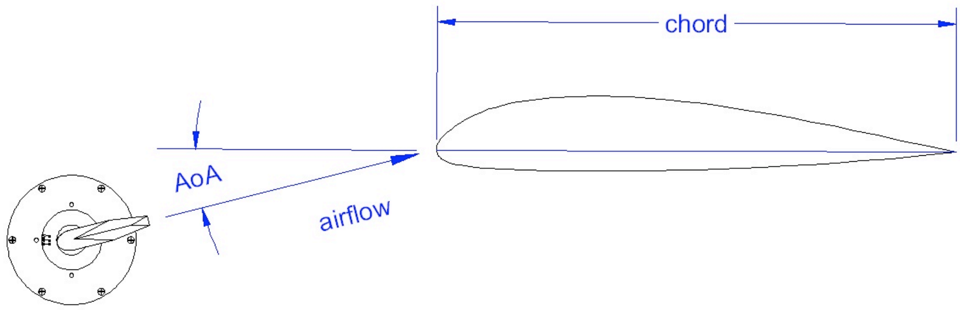
Figure 6: Angle-of-attack sensor



Each angle-of-attack sensor vane was mounted on a 'slinger' and a central shaft assembly. The main structural component was the sensor mounting section, which included a sealed bearing to support the vane-slinger-shaft assembly. The component manufacturer reported that a labyrinth path between the slinger and the mounting section was resistant to water ingestion, while still allowing the sensor to 'breathe'.

The sensors were calibrated to determine the direction of the airflow relative to the chord of the wing, enabling a measure of the aircraft's angle-of-attack (Figure 7). The FCCs performed a test of the angle-of-attack sensor data immediately after takeoff and before the stall warning system changed to the flight mode. After that check, the output of the angle-of-attack sensors was not monitored to detect and alert flight crews of an immobilised sensor. There was no comparison of the angle-of-attack data between the sensors during a flight.

Figure 7: Angle-of-attack sensor schematic



Heating for each angle-of-attack sensor was operated from a separate pole of the air data heat switch. Embedded in each sensor's vane was a solid state ceramic heater that self-regulated its surface output temperature to a nominal 125° C. To minimise condensation inside the sensor case, one small-capacity, fixed-resistance heater was situated at the rear of the case assembly. The slinger, central shaft and faceplate were not directly heated.

Stall warning system

The aircraft's stall warning system was a function of the FCCs, each of which was capable of independently warning the flight crew of their aircraft's approach to an aerodynamic stall, and monitored a number of parameters to calculate the pre-stall angle-of-attack. Those parameters included the position of the:

- flap and flap handle
- horizontal stabiliser
- wing slats.

The pre-stall angle-of-attack was then compared with the measured angle-of-attack affecting the aircraft. In addition, input to the FCC from the horizontal stabiliser provided for a centre of gravity correction to the stall warning system. That correction was zero with flaps and slats retracted, as was the case at the time of the incident.

Stick shaker activation

The aircraft's stick shaker was designed to activate when the aircraft's measured angle-of-attack exceeded the FCC-calculated angle-of-attack for activation of the stick shaker. In addition, the angle-of-attack for activation of the stick shaker was affected by the aircraft's speed and, as a result of the effects of compressibility, reduced with increasing Mach number.

Concurrent with stick shaker activation was a change in colour of the pitch limit indicator[16] on the PFD.

Once activated, the stick shaker continued operating until the aircraft's measured angle-of-attack was 0.5 degrees less than the FCC-calculated angle-of-attack for activation of the stick shaker. The airspeed range for activation of the stick shaker was displayed on each PFD as a red and white zipper on the lower portion of the airspeed indicator tape (Figure 1).

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16 The pitch limit indicator depicted the difference between the aircraft's measured and stick shaker angles-of-attack respectively and was displayed on the PFDs at all times. The pitch limit indicator was usually cyan in colour, however, as the stick shaker activated, its colour changed to red.

Visual and aural stall warnings

Visual and aural stall warnings were provided to the flight crew as a result of the comparison of an FCC-calculated supplemental stall recognition angle-of-attack, with the aircraft's measured angle-of-attack. When the measured angle-of-attack exceeded the supplemental angle-of-attack, the flight crew were provided with the following visual and aural warnings:

- a visual 'STALL' warning that was enunciated on the PFD
- the activation of an aural 'STALL STALL' warning and klaxon.

The visual and aural warnings continued until the aircraft's measured angle-of-attack reduced to 0.5 degrees less than the angle-of-attack for activation of the stick shaker.

Stick pusher activation

In the event of an aerodynamic stall, the aircraft was equipped with a stick pusher that automatically decreased the aircraft's angle-of-attack. In that case, the FCC commanded the stick pusher servo actuator to push the control column forward to recover the aircraft from stalled flight.

Either of the flight crew could inhibit the operation of the stick pusher by activating the 'STICK PUSHER PUSH TO INHIBIT' switch override (dump switch). The FCC inhibited the operation of the stick pusher above 240 kts CAS.[17]

Meteorological information

The weather conditions for the flight were under the influence of a decaying tropical cyclone that crossed the north-west coast of WA earlier that day. Rain and heavy cloud persisted through most of the region and the aircraft was operating in instrument meteorological conditions (IMC). The meteorological forecast indicated a temperature of -39° C at the aircraft's planned cruise altitude.

The flight crew recalled that it was raining heavily during the turnaround at Paraburdoo. In response, the flight crew requested the ground handling agent to attend the aircraft on a number of occasions to mop excess water from the floor area adjacent to the left forward entry door.

The flight crew stated that they entered IMC soon after departure and that, during the climb, they encountered moderate turbulence and areas of rain until passing about FL200. The aircraft's weather radar did not indicate any thunderstorms or areas of heavy rainfall/precipitation along their flight path. Neither member of the flight crew recalled detecting any ice accumulation on the aircraft's wiper blades[18]

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17 Other parameters could also inhibit the operation of the stick pusher, including: an invalid sensor input; a radio altitude of less than 150 ft; the selection of the aircraft's windshear guidance ON; an aircraft loading of less than 0.5g; and the position of the slats disagreed with each other, or disagreed with the position of the flap handle.

18 The 717 Flight Crew Operating Manual indicated that, when flying in icing conditions, 'ice is built up on edges of windshield and other visible portions of the airplane'.

during the climb. The flight crew reported that, once above FL200, the flying conditions were generally smooth, with no significant rain/precipitation.

The Bureau of Meteorology conducted a review of data from a number of meteorological computational models for the time of the incident. Those models depicted conditions that could be conducive to the formation of supercooled water droplets[19].

Recorded information

The aircraft's flight data recorder (FDR) and the electronic recording media for the Flight Data Acquisition Management System (FDAMS) were removed for analysis.

Flight data

Australian Transport Safety Bureau review of data

An analysis of the FDR data showed that the aircraft was operated between 230 and 250 kts CAS during the latter part of the climb. In addition, as the aircraft climbed through FL269, the TAT decreased to below 0° C.

About 1 minute later, as the aircraft climbed through FL287 at 230 kts CAS, and at a TAT of about -4° C, data from each of the aircraft's angle-of-attack sensors became static at angles of 3.7 and 3.8 degrees respectively. That indication was not consistent with information that was recorded concurrently for a number of other angle-of-attack-related parameters, such as variations in the aircraft's pitch attitude and load factor. The parameters for those recordings showed variations that were typical for that stage of flight. The investigation calculated that, at that time, the environmental temperature was about -20° C.

The FDR data showed that the flight crew selected the engine anti-ice protection ON as the aircraft climbed through FL290. The aircraft was levelled off at FL340 at about 0854.

The stick shaker activated about 90 seconds later. At that time, the aircraft was accelerating through 258 kts CAS at a TAT of -10° C. About 16 seconds later, the recorded data indicated the commencement of a descent. The FDR recorded that the flight crew selected airframe anti-ice ON about 27 seconds after the stick shaker activated.

The FDR indicated that the aircraft passed through FL320, the level of the opposite direction aircraft, at about 0857.

The TAT increased above 0° C as the aircraft descended through FL315 at 294 kts CAS, and above 4° C as the aircraft descended through FL298.

The stick shaker operated for 2 minutes 38 seconds, ceasing as the aircraft descended through FL288, at 308 kts CAS and a TAT of about 7° C. A review of

19 Supercooled water droplets are droplets of water at subzero temperature that are held in suspension in the atmosphere, but have not formed into ice crystals. Those droplets freeze as they impact areas of an airframe that are not protected by anti-ice systems.

the FDR data showed that the angle-of-attack measured by the right sensor decreased as the aircraft descended through FL290 and that the angle-of-attack measured by the left sensor decreased as the aircraft descended through FL288.

The status of the air data heating system (ON/OFF) was not a parameter recorded by the FDR. It was not a regulatory requirement to record the status of the air data heating system.

Aircraft manufacturer review of data

The FDR data was also reviewed by the aircraft manufacturer. That review concluded that the observed aircraft performance during the climb was consistent with the aircraft's normal performance envelope, and that there was no data to indicate that the aircraft's performance during the climb was degraded by environmental factors.

The manufacturer reported that, following the recorded immobilisation of the angle-of-attack sensors, the aircraft's actual angle-of-attack would have reduced as the airspeed increased, the weight of the aircraft reduced, and as the aircraft was levelled out at the top of climb. The actual angle-of-attack at stick shaker activation was estimated by the manufacturer to have been about 1.6 degrees. Analysis of the FDR data by the manufacturer confirmed that the aircraft's measured angle-of-attack exceeded the FCC-calculated angle-of attack for activation of the stick shaker. Consequently, in the context of the static measured-angle-of-attack, the stick shaker activation was valid.

Flight data acquisition management system

The FDAMS media was found to contain no recorded data. An examination of that file showed that the recording media was incorrectly formatted for use in that equipment.

Tests and research

The aircraft's angle-of-attack sensors and air data heat switch were removed from the aircraft and dispatched for examination by the component manufacturers under the direct supervision of the US National Transportation Safety Board (NTSB) on behalf of the ATSB.

Data was subsequently recovered from the non-volatile memory of the aircraft's FCCs. The manufacturer of the aircraft's FCCs analysed each computer's non-volatile memory, and confirmed that there was no recorded fault history for the day of the incident.

Examination of the angle-of-attack sensors

Prior to their disassembly, each angle-of-attack sensor was subject to the sensor manufacturer's Acceptance Testing Procedure[20] (ATP). That procedure was used to test newly manufactured and overhauled sensors to certify that they were serviceable components for installation on an aircraft.

Sensor S/N 215 (installed on the right forward fueslage – Figure 2)

Sensor S/N 215 passed each of the ATP tests, with the exception of the static friction[21] affecting the sensor vane as it was rotated through its operating range. Examination of the damper from the sensor's transmitter assembly revealed a minor damper oil leak onto the bearing support and faceplate.[22] There was no evidence of water contamination, corrosion or other anomaly with the potential to have affected the serviceability of the sensor.

Sensor S/N 263 (installed on left forward fuselage – Figure 2)

Sensor S/N 263 passed all of the ATP tests. There was no evidence of water contamination, corrosion or other anomaly with the potential to have affected the serviceability of the sensor.

Examination of the air data heat switch

Prior to its disassembly, the air data heat switch was x-rayed and subjected to the switch manufacturer's ATP. The x-ray examination of the switch found no anomaly that would have affected its normal operation.

The ATP test indicated a higher-than-normal contact resistance of 462 ohms across the pins of switch pole 2 with the switch in the OFF position. All other switch poles returned a normal contact resistance. The higher-than-normal resistance across switch pole 2 reduced the electrical potential across the incandescent switch globes to about 9.4 V, which would have resulted in the incandescent globes burning at about 40% of their normal luminance. [23]

Pole 4 of the air data heat switch provided input to the aircraft's systems that displayed the AIR DATA HEAT OFF system status message on the EAD.

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20 ATP. A testing procedure that included the testing of a sensor's: electrical bonding, electrical insulation resistance, static friction, heater current draw, vane travel, indicating range and zero alignment accuracy, manufactured dimensions, materials, markings and workmanship.

21 The static friction test measured the friction affecting a sensor vane as it moved through its operating range of +30 to -30 degrees. The test of the right forward sensor measured 25 grams of friction at room temperature and about 25 degrees of vane rotation, and 23 grams after being heated. The acceptance test criteria required a maximum static friction of 20 grams throughout the vane's operating range.

22 That oil leak was considered by the sensor manufacturer to not be significant to the sensor's operation during the incident flight.

23 Switch pole 2 provided switching for the incandescent globes inside the air data heat switch assembly that illuminated when the switch was in the OFF position (see the air data heating system description at page 13).

Disassembly of the switch revealed a build-up of dark coloured deposits on all pins for switch poles 2 and 4, and some of the pins on pole 3. The results of an analysis of those deposits had not been received by the investigation at the time of compiling this investigation report.

The switch manufacturer reported that the switch contacts were self-cleaning, with a mechanical wiping action of the contacts with each 'make' and 'break' of the circuit. In addition, the manufacturer reported that increased electrical resistance due to contaminant build-up would burn away during the operation of the switch, and that the luminance of the globes would increase with time spent illuminated.

The typical pattern of use for the switch included selecting the air data heat ON prior to takeoff, and its selection OFF after landing. Consequently, there was one closure of the pins of switch pole 2 at the conclusion of each flight sector.

Examination of similar incidents

A search was carried out of the ATSB occurrence database, together with those of a number of international investigation and other agencies in order to determine the incidence of stick shaker activations in the 717 and its earlier derivatives[24] similar to that in this incident. That search showed that a similar event occurred in the USA in April 2007. In that case, the incident was described as a 'spurious stall warning in [the] climb' and the flight crew elected to return to their departure airport.

Additional information

Procedural separation standard affecting the flight

The Manual of Air Traffic Services (MATS), Part 10: Separation promulgated the procedural separation standards affecting the flight. In this instance, those standards had the effect that:

- 2,000 ft vertical separation was required between the aircraft
- where that vertical separation did not exist, a 10-minute time separation standard between the aircraft was to be applied by ATS at the aircrafts' estimated time of passing (TOP)
- in order for the required vertical separation to have been maintained, the 717 was required to have been established at or below FL 300 by the TOP minus 10 minutes.

In the case of an emergency, MATS[25] required that traffic information shall be provided to affected aircraft.

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24 The 717 aircraft had early links with the McDonnell Douglas DC-9 series of aircraft, and was redesignated as the 717 after that company and Boeing merged in 1997. Prior to that merger, the aircraft was designated by McDonnell Douglas as the MD-95, which was a third-generation derivative of the DC-9.

25 Part 10: Separation, 10-10-820-Traffic information.

Alert Service Bulletin 717-30A003

In an effort to minimise the potential for the failure of a single aircraft system to critically affect that aircraft's continued safe flight, FAR 25.1333(b) required the separation of an aircraft's essential flight instrumentation, stating that:

> The equipment, systems, and installations must be designed so that one display of the information essential to the safety of flight which is provided by the instruments including attitude, direction, airspeed, and altitude will remain available to pilots, without additional crew member action, after any single failure or combination of failures that is not shown to be extremely improbable.

In order to ensure compliance with that and other relevant FARs, the aircraft manufacturer issued an Alert Service Bulletin on 1 September 2005. That bulletin followed an investigation into the circumstances of incidents during March 2002 and May 2005, where the affected aircrafts' air data sensor heating systems were inoperative during flight. The result in each instance was a temporary loss of the aircrafts' auto-flight function and unreliable or erratic airspeed indications being presented to the aircrafts' flight crews.

The manufacturer's service bulletin altered the wiring to the copilot's pitot tube and ground-sensing relay, and assured heating for the aircraft's pitot system at all times the aircraft was airborne, irrespective of any anomaly with the status of the air data heat system. That modification also ensured functional separation between the pitot tube heating circuits to ensure the availability of airspeed information to the flight crew.

The alert service bulletin did not modify the heating system for the angle-of-attack sensors.

The aircraft manufacturer recommended that all operators should implement the service bulletin within 24 months. The bulletin was revised during March and November 2006.

To ensure the 717's continued compliance with the relevant airworthiness certification standards, the FAA issued an airworthiness directive in July 2007 that required operators to comply with the provisions of the manufacturer's service bulletin within 24 months. Similarly, CASA issued an airworthiness directive in August 2007 that reflected the requirements of the FAA directive.

The operator reported that the requirements of Alert Service Bulletin 717-30A003 were not incorporated in the occurrence aircraft at the time of the incident.

ANALYSIS

Loss of procedural separation

The decision by the flight crew to commence an immediate descent meant that, in order for a procedural separation standard to be maintained, the aircraft needed to be established at or below Flight Level (FL) 300 by 0852. The commencement of the descent at 0854 meant that an infringement of the separation standard was unavoidable.

The remainder of the analysis will examine the influence of the aircraft systems on the flight crew's decision to initiate the immediate descent.

Stick shaker activation

The aircraft's climb profile resulted in a climb speed lower than that recommended by the aircraft manufacturer and in the aircraft being flown at a measured angle-of-attack greater than would be experienced during a normal climb and cruise. Consequently, when the output from the angle-of-attack sensors became static as the aircraft climbed through FL287, they were measuring an angle-of-attack greater than would be measured during a normal climb or during cruise.

The recorded variations in pitch, load factor and other angle-of-attack-related parameters as the aircraft climbed through FL287 were normal. The inconsistency of those recorded parameters with the recorded static angle-of-attack as measured by the aircraft's angle-of-attack sensors at that time suggested a problem with the output from those sensors.

As the aircraft accelerated at the top of climb, the stick shaker activation angle-of-attack being calculated by the Flight Control Computers (FCC) would have reduced as a result of the increasing airspeed, and of the correction applied by the FCCs for the effects of compressibility. The stick shaker activated when the FCC-calculated stick shaker angle-of-attack converged with the measured angle-of-attack that had, as already discussed, become static at a higher-than-normal climb angle-of-attack due to the low climb speed.

The flight crew did not receive a 'STALL STALL' annunciation or klaxon alert because the supplemental stall recognition angle-of-attack that was being calculated by the FCC was greater than the aircraft's measured angle-of-attack.

An analysis of the recorded information confirmed that the aircraft was not near a stalled condition of flight when the stick shaker activated. That was also consistent with the flight crew's recollections of the aircraft's pitch attitude, engine power settings and increasing airspeed at that time.

Immobilisation of the angle-of-attack sensors

The aircraft's FCCs did not record any fault messages during the occurrence flight. In addition, the information contained on the flight data recorder prior to, and immediately following the recorded information from the angle-of-attack sensors becoming static was consistent with their normal operation. The static output from each angle-of-attack sensor was likely the result of each sensor vane becoming physically immobilised. The confirmed post-occurrence serviceability of those sensors indicated that some in-flight event may have contributed to their temporary immobilisation.

The almost simultaneous immobilisation of the separate and independent sensor vanes suggested that each was affected by the same in-flight condition. Furthermore, the immobilisation occurred within 1 minute of the total indicated air temperature (TAT) decreasing below 0° C and continued until a short time after the TAT increased above 0° C during the descent. That, and the nature of the in-flight immobilisation of the angle-of-attack sensors, was consistent with ice having physically restricted the movement of each sensor's unheated slinger and faceplate assembly, before melting with increasing TAT during the descent.

There was no evidence of the accumulation of any airframe ice at the time the angle-of-attack sensors immobilised. That meant that ice accumulation on the vane-slinger-shaft assemblies as a consequence of the in-flight conditions was similarly unlikely. Therefore, it was probable that any ice formation within those assemblies was as a result of some other event. The investigation considered the localised factors necessary for the formation of ice in the vane-shaft-slinger assembly.

The results of the previously carried out qualification test of a similar vane-slinger-shaft assembly showed that, despite the sensor vane being heated, the temperature of the slinger could decrease below 0° C, allowing ice to form in the vicinity of the slinger base. In that case, the movement of the vane-slinger-shaft assembly could be restricted. That was similar to the circumstances of this occurrence, wherein the heavy rain while on the tarmac at Paraburdoo, and rain in the climb may have impacted the slinger, or become trapped between the slinger-shaft assembly and the sensor housing. The reduction of the TAT during the climb to below 0° C had the potential to have frozen that trapped moisture, restricting the movement of the vane-slinger-shaft assembly as a result. The lower-than-normal climb speed may have reduced the capability for the air flow to remove any moisture from behind the slinger, or for the airflow to reduce the likelihood of water ingression during the climb.

The continued normal operation of the angle-of-attack sensors later in the flight, when the aircraft climbed to FL300 and the TAT again decreased to below 0°C, may have been as a result of the higher airspeed during that climb and subsequent cruise. That increased airspeed may have either cleared the moisture from behind the slinger, or subjected the sensor vane to higher air loads that prevented any ice that may have formed having any effect.

Air data heat

The investigation considered whether there may have been a failure of the aircraft's air data heating system, or whether it may have been inadvertently left OFF by the flight crew. Had that been the case, there was an increased risk that icing of the angle-of-attack sensor vanes may have occurred.

However, the lack of any indication of the anomalous operation of the aircraft's other flight environment air data sensors was consistent with those sensors' heaters being free of any significant ice contamination during the flight. On that basis, the investigation concluded that there had not been a failure of the aircraft's air data heating system nor had it been in the OFF position. In addition, the flight crew did not recall receiving any system status messages on the Engine and Alert Display (EAD) to indicate anomalous operation of any components from the aircraft's flight environment data sensor heating system.

The high resistance detected during testing of the air data heat switch was consistent with the likely effect of the contamination residue that was identified on the switch poles during switch disassembly. In particular, the high resistance across switch pole 2 would have dimmed the switch's incandescent indicating globes, and made the OFF indication less conspicuous to the flight crew. That test result was consistent with the maintenance log entry on 3 March 2006, which noted the intermittent operation of the switch's OFF annunciation.

However, the overcast sky and heavy rain during the turnaround would have decreased the ambient light level in the cockpit. In addition, the dimly-illuminated air data heat OFF annunciation would have been more conspicuous in those circumstances, than had the cockpit been illuminated by bright sunlight.

The confirmed normal operation of the EAD's AIR DATA HEAT OFF status message meant that the system status alerting function was capable of normal operation at the time of the incident. The reported lack of any alert messages during the checks of the EAD by the flight crew suggested that it was unlikely that there had been a failure of the air data heaters, or that they had been left OFF.

Stall warning systems

The immobilisation of the angle-of-attack sensors adversely affected the reliability of the aircraft's stall warning system and could have rendered the automatic stall recovery system inoperative. As a result, there was the potential for an incorrectly-advised or un-alerted stall, the recovery from which relied solely on input from the pilot(s). As a consequence, in the event of a stall with the automatic stall recovery system inoperative, there was an elevated risk of the loss of control of the aircraft.

FINDINGS

From the evidence available, the following findings are made with respect to the warning device event involving Boeing Company 717-200 aircraft, registered VH-NXH, that occurred approximately 232 km south of Paraburdoo, WA on 28 February 2006. They should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The aircraft's angle-of-attack sensors immobilised during the climb at a relatively low airspeed and high angle-of-attack. That sensor immobilisation was probably the consequence of ice restricting the movement of the sensors' vane-slinger-shaft assembly.
- The flight crew's decision to commence an immediate descent in response to the activation of the stick shaker made an infringement of the separation standards unavoidable.

Other safety factors

- The immobilisation of the angle-of-attack sensors adversely affected the reliability of the aircraft's stall warning system and could render the automatic stall recovery system inoperative. *(Safety issue)*

Other key findings

- The aircraft was not near a stalled condition of flight when the stick shaker warning activated.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Aircraft manufacturer

Immobilisation of angle-of-attack sensors

Safety issue

The immobilisation of the angle-of-attack sensors adversely affected the reliability of the stall warning system and could render the automatic stall recovery system inoperative.

Aircraft manufacturer response

The aircraft manufacturer reported that, in response to this incident, they initiated a detailed design review of the angle-of-attack sensor with the sensor manufacturer. That review focused on: the original qualification/certification test plan/results for the sensor, the electrical characteristics and operability of the vane and case heater, and the mechanical/hardware design of the vane assembly and slinger-faceplate.

At the time of finalising this investigation report, the design review was ongoing and no final design decisions had been made by either manufacturer.

ATSB comment

The ATSB notes the action by the manufacturer to address this safety issue, and will monitor the progress of the design review until evidence is received of its completion.

APPENDIX A: SOURCES AND SUBMISSIONS

Sources of information

The sources of information for this investigation included the:

- aircraft's flight data recorder
- flight crew
- aircraft operator
- Civil Aviation Safety Authority
- Airservices Australia
- Bureau of Meteorology
- US National Transportation Safety Board
- US Federal Aviation Administration
- aircraft manufacturer
- manufacturer of the angle-of-attack sensor
- manufacturer of the air data heat switch
- manufacturer of aircraft's flight control computer.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the Executive Director may provide a draft report, on a confidential basis, to any person whom the Executive Director considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the Executive Director about the draft report.

A draft of this report was provided to the flight crew, aircraft operator, the Civil Aviation Safety Authority, Airservices Australia, US National Transportation Safety Board, US Federal Aviation Administration, the aircraft manufacturer and the manufacturers of the aircraft's angle-of-attack sensors and air data heat switch.

Submissions were received from the aircraft manufacturer and the manufacturer of the aircraft's angle of attack sensor. Those submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.