



Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT

Boeing 757-224, N41140

80 NM Southwest of Dublin, Ireland

20 October 2013



**An Roinn Iompair
Turasóireachta agus Spóirt**

Department of Transport,
Tourism and Sport

FINAL REPORT

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13¹ to the Convention on International Civil Aviation, Regulation (EU) No 996/2010² and Statutory Instrument No. 460 of 2009³, safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

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¹ **Annex 13:** International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.

² **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.

³ **Statutory Instrument (SI) No. 460 of 2009:** Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.



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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of S.I. No. 460 of 2009, the Chief Inspector of Air Accidents, Mr Jurgen Whyte, on 20 October 2013, appointed himself as the Investigator-in-Charge to carry out an investigation into this Serious Incident and prepare a Report. Mr John Owens and Mr Howard Hughes, Inspectors of Air Accidents, assisted with the investigation.

Aircraft Type and Registration:	Boeing 757-224, N41140	
No. and Type of Engines:	2 x Rolls Royce RB211-535E	
Aircraft Serial Number:	30353	
Year of Manufacture:	2000	
Date and Time (UTC ⁴):	20 October 2013 @ 05.05 hrs	
Location:	Approximately 80 nautical miles southwest of Dublin	
Type of Operation:	Commercial Air Transport – Scheduled Passenger	
Persons on Board:	Crew - 8	Passengers - 131
Injuries:	Crew - 4 (Minor)	Passengers - 13 (Minor)
Nature of Damage:	Significant	
Commander's Licence:	Air Transport Pilot Licence (ATPL) issued by the Federal Aviation Administration (FAA), USA	
Commander's Details:	Male, aged 59 years	
Commander's Flying Experience:	11,606 hours as Pilot in Command ⁵	
Notification Source:	Dublin Air Traffic Control	
Information Source:	AAIU Report Form Submitted by the Operator AAIU Field Investigation	

⁴ UTC: Co-ordinated Universal Time. All times in this report are UTC (UTC plus one hour equals local time).

⁵ See **Section 1.4** in the report.

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SYNOPSIS

While on a scheduled passenger service from Newark Airport (KEWR) USA, to Dublin Airport (EIDW) Ireland, the aircraft encountered conditions that became increasingly turbulent during the descent. As the turbulence eased, the Co-Pilot noticed that the indicated airspeed, as presented on his instruments, was reading low. Fearing that the turbulence had caused the aircraft to lose airspeed which could lead to a stall, the Co-Pilot applied forward force on the control column to pitch the aircraft down, and increased engine thrust. Following this manoeuvre, the Co-Pilot reported that the airspeed as indicated on his instruments began to recover, before reducing again. Consequently, the Co-Pilot repeated the pitch down manoeuvre.

It was then determined that the Commander's airspeed instruments were reading correctly, and the Commander took control of the aircraft. The aircraft was returned to normal flight and the Commander handed back control to the Co-Pilot. Subsequently, the Flight Crew were alerted to a system message indicating a loss of hydraulic pressure in the centre hydraulic system. Shortly thereafter, reports were received from the cabin that a number of passengers and Flight Attendants suffered minor injuries during the event.

The Commander reported to Dublin Air Traffic Control (ATC) that they had experienced some turbulence and that medical assistance would be required on landing. In addition, airport emergency services were requested to be in attendance due to the hydraulic problem. The aircraft landed at 05.22 hrs without further incident. The aircraft sustained damage to the centre hydraulic system service bay and ceiling panels in the cabin as a result of the occurrence.

1. FACTUAL INFORMATION

1.1 History of the Flight

The aircraft, a Boeing 757-224, was on a scheduled passenger service from KEWR to EIDW with 8 crew and 131 passengers on board. The Commander was Pilot Monitoring (PM), and the Co-Pilot was Pilot Flying (PF). The flight departed KEWR at 23.22 hrs and the en route transatlantic phase of the flight was uneventful. Approaching EIDW, the aircraft was given an initial descent clearance to FL170⁶ by ATC.

While descending through approximately FL250, in Instrument Meteorological Conditions (IMC⁷), the aircraft encountered turbulent atmospheric conditions. The Flight Crew noted the presence of St. Elmo's Fire⁸. As the descent continued through FL235, the Co-Pilot stated that the intensity of the turbulence increased "*abruptly*". At about the same time the intensity of the St. Elmo's Fire increased and the Co-Pilot stated he noticed "*the sound of abruptly entering precipitation*". The aircraft position at that time was approximately 80 nautical miles (NM) southwest of EIDW.

⁶ **FL170:** Flight Level 170, a three digit representation of aircraft altitude (17,000 ft in this case) referenced to standard pressure (1013.25 hPa).

⁷ **IMC:** Instrument Meteorological Conditions. Flight conditions that exist when the outside view from an aircraft is restricted in such a way that aircraft control and navigation can only be carried out using flight instruments.

⁸ **St. Elmo's Fire:** A visible electrical discharge when an aircraft flies through a heavily electrostatically charged atmosphere. It is often associated with nearby cumulonimbus or thunderstorm activity and/or flight through ice crystal.

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The Co-Pilot reported that when the turbulence eased, he noticed that his indicated airspeed (IAS), as displayed on his instruments, was low - in the region of 90⁹ kts. The Co-Pilot, believing that the aircraft was about to stall, immediately pushed the control column forward and applied full power without disengaging the autopilot or autothrottle. The Co-Pilot stated that following this, his airspeed *“went back up into the normal range”*, but as soon as he began to raise the nose and reduce power, *“it went back into a stall – or the indications of a stall”*. The Co-Pilot then commenced a second pitch down manoeuvre.

Following the second pitch down manoeuvre, the Flight Crew concluded that the Co-Pilot's airspeed indications were reading incorrectly and that the Commander's airspeed indications, which agreed with the standby airspeed indications, were correct. Consequently, the Commander took control of the aircraft and returned it to stabilised flight. When the Co-Pilot's airspeed indications returned to normal the Commander handed control back to the Co-Pilot.

At about this time, an alert was displayed on the Engine Indication and Crew Alerting System (EICAS), indicating a loss of hydraulic pressure in the centre hydraulic system. The relevant checklist was actioned, and the flight was continued towards EIDW. Reports were then received from the cabin that two Flight Attendants (FAs) and a number of passengers had sustained minor impact injuries.

The Commander advised ATC EIDW that they had encountered severe turbulence and that medical assistance was required on arrival because some passengers had been injured. In addition, the Airport Fire Service was also requested to be in attendance on landing due to the loss of the centre hydraulic system. A normal landing was performed at EIDW, without further incident. On inspection it was found that the aircraft had sustained significant damage.

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1.2 Injuries to Persons

Immediately following the event, eight passengers and two FAs reported minor injuries as a result of having come into contact with various parts of the aircraft's internal structure. All persons who presented themselves as having been injured were attended to, on scene, by the airport fire and ambulance service personnel. One of the injured passengers, who received a slight laceration to their head, subsequently attended a hospital in Dublin, where the passenger was treated and released.

On 2 December 2013, a passenger contacted the AAIU and described how he was in a lavatory in the rear cabin at the time of the event and had hit his head on the ceiling. He then fell, striking a handrail mounted on the rear wall of the lavatory.

The Operator later informed the Investigation that reports of minor injuries were subsequently received from four additional passengers. A subsequent written FA report indicated that the four unrestrained FAs received minor injuries.

⁹ In his initial statement the Co-Pilot said he saw 90 kts on his Airspeed Indicator (ASI). In a later written statement he thought this was possibly 125 kts. See also **Section 1.5.3**.



Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	0	0
Minor	4	13	0
None	4	118	

1.3 Damage to Aircraft

An AAIU Engineering Inspector conducted an external examination of the aircraft on stand at EIDW shortly after the aircraft had landed. Damage to the following components was identified:

- The door frame of the centre hydraulic system servicing bay and adjacent structure (**Figures No. 1 and No. 2**).
- The centre hydraulic system servicing bay door and hold-open rod.
- The electrical connector on the filter module pressure transmitter.
- The reservoir drain valve, quantity transmitter and associated electrical connector.
- The hydraulic service panel light.
- The wiring loom P-Clip at the rear of the hydraulic service bay.
- Some wing to body fairings had popped open.

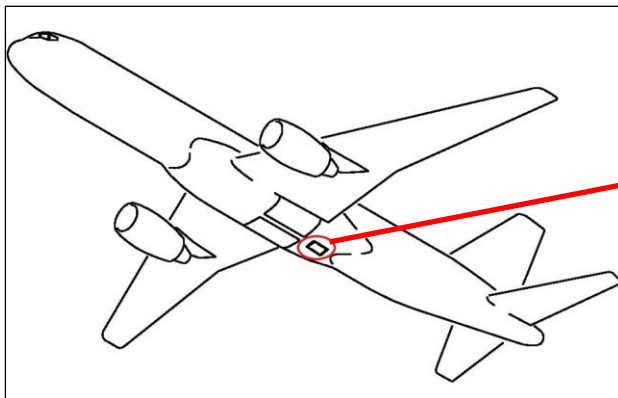


Figure No. 1: Location of the centre hydraulic system servicing bay



Figure No. 2: Photograph of Damage to Service Bay and Associated Structure

In addition, an internal examination of the aircraft determined that:

- A ceiling panel in the rear passenger cabin had suffered impact damaged.
- There were coffee and tea stains on various ceiling panels throughout the cabin.

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Both Flight Crew members were employed by the Operator. The Operator stated that both Pilots informed them that they were fully rested prior to the subject flight. The Commander informed the Investigation that he had approximately 32,000 hours, but that he did not keep a logbook. Therefore his exact flight experience could not be determined. However, the Operator furnished the Investigation with details of the Commander's flight hours, for the time that he was in their employment. These are times used in the tables below, for the Commander.

1.4.2 Aircraft Commander

Personal Details:	Male, aged 59 years
Licence:	ATP issued by FAA
Total as Pilot in Command:	11,606 hours
Total on type:	8,769 hours
Last 90 days:	242 hours
Last 30 days:	91 hours
Last 7 days:	21 hours
Last 24 hours:	6 hours
Date of Last Proficiency Check:	13 June 2013

1.4.3 First Officer

Personal Details:	Male, aged 43 years
Licence:	ATP issued by FAA
Total all types:	12,010 hours
Total on type:	5,384 hours
Last 90 days:	201 hours
Last 30 days:	47 hours
Last 7 days:	20 hours
Last 24 hours:	6 hours
Date of Last Proficiency Check:	12 January 2013

1.5 Interviews and Crew Reports**1.5.1 General**

On arrival of the AAIU investigation team at the aircraft, the Commander initially appeared to be unaware of his obligations with regard to the requirements and conduct of a safety investigation in a foreign state. Following a briefing from an AAIU Inspector, the Commander provided a verbal statement. The Co-Pilot made a frank, verbal, statement. Both verbal statements were obtained on board the aircraft, shortly after the event.

Additional written Crew Reports were later provided by both the Flight Crew and the Flight Attendants.



1.5.2 Commander

The Commander who was PM, stated in his initial interview, that during the descent, the aircraft encountered “severe turbulence” and that it “felt like we were hit by wind shear. It felt like wind shear because we dropped suddenly”. He said there was some light precipitation indicated on the weather radar. He also noted that there were small amounts of St. Elmo’s fire. He said: “We went through two drops” and that the aircraft “seemed like it accelerated, so we pulled the power off, tried to slowly level the aircraft up, looked at the standby instruments, and I took the aircraft over from the First Officer (Co-Pilot) and stabilised the aircraft”. He stated at this stage he noticed a problem with the centre hydraulic system. He said that when the aircraft was stabilised he handed back control of the aircraft to the Co-Pilot and spoke with the FAs, who advised him that some passengers had been injured. He stated that “we accomplished the loss of centre hydraulic checklist in the QRH¹⁰”.

In his initial interview and first written statement, the Commander made no mention that he was aware that the Co-Pilot was of the belief that the aircraft was about to stall, or that this was the reason that the Co-Pilot had pitched the aircraft down and applied engine thrust. The Commander’s first written statement provided very little detail about the event.

In a later statement provided some time after the event, the Commander stated that during the remaining descent, he learned from the Co-Pilot that immediately after encountering the turbulence, the Co-Pilot’s instruments showed a very low airspeed and a potential stall, which prompted the Co-Pilot to carry out the pitch down manoeuvre. The Commander made no mention in any of his reports, of any communications between himself and the Co-Pilot regarding the manoeuvres performed by the Co-Pilot during the event, or of activation of the Stick Shaker. See also **Section 1.6.3.2, Warning System**.

1.5.3 Co-Pilot

During initial interview, the Co-Pilot, who was the PF at the time, said that when the turbulence was encountered, the aircraft experienced a “series of very rapid major jolts”. He said that following this he noticed that his airspeed was showing low, “well into the red warning” and “probably somewhere around 90 knots” so he “initiated a stall recovery procedure”. He stated that following this, within just a few moments, the airspeed went back up into the normal range, so he “pulled the power back” and started to level off but then the aircraft went “back into a stall, the indication of a stall”, leading him to repeat the pitch down manoeuvre. The Co-Pilot stated that at this point, it was realised that the Commander’s instruments and the standby instruments showed that the airspeed was “well above the stall” even though the airspeed as indicated on his instruments was “below [the stall] and the stall warning was still on”. Regarding this “stall warning”, a subsequent report received from the Co-Pilot, stated that it was later realised that the warning heard was an overspeed warning and not a stall warning as initially thought. Control was then passed to the Commander.

¹⁰ QRH: Quick Reference Handbook.

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The Co-Pilot's subsequent written report stated:

"The incident happened about 70 miles from EIDW in decent descending through approximately FL250 while descending to FL170. In the previous few thousand feet on descent, we entered IMC conditions and were getting just a bit of St Elmo's fire, but the radar just showed scattered areas of nothing more than light precipitation. Just prior to the incident, the St. Elmo's fire became very active and the captain turned the ignition switches to flight. The engine anti-ice switches were already on at this point. All of a sudden and very abruptly, we received some rapid and severe turbulence and strong updrafts along with the sound of abruptly entering precipitation. When the turbulence subsided, I noticed that the First Officer's airspeed tape was reading very low and well into the red (just above 125 kts to my recollection), with the yellow slow range at the top of my airspeed tape. At this point, not knowing if we had experienced an upset of some kind from the turbulence, I proceeded to do a high altitude stall recovery manoeuvre, as I believed at that moment that our airspeed was lost in the severe turbulence and the aircraft was in critical danger of entering a stall.

After applying full power and lowering the aircraft nose steeply to attempt to recover flying airspeed. I asked the Captain "are we stalling?" as my airspeed was almost stagnant and not recovering, even as I had lowered the nose and applied full power. After a few moments the airspeed started to recover, but very slowly (just barely re-entering the yellow low speed range as read from the first officer airspeed tape). The Captain advised me that we were in fact very fast as read from his instruments and for me to raise the nose and reduce power.

I returned the throttles back to a normal range and started to raise the aircraft nose and assess the situation. As soon as I started to raise the aircraft nose and reduce power, the airspeed as read from my speed tape, once again plummeted. Still in fear of a stall situation, and not knowing whose instruments were correct, I once again lowered the nose and reapplied power until I could be sure that we were not going to stall. Shortly after doing so, the over-speed warning horn started to sound. At first I thought it was a stall warning as that would match what I was seeing on my speed tape, but then realized that it was indeed an over-speed and the Captain's instruments were correct. I told the Captain that my airspeed was still way low and he responded that his airspeed was still showing that we were very fast and to raise the nose and reduce power. At that point, realizing that my airspeed was incorrect, I gave control of the aircraft to the Captain.

The Captain returned the aircraft to normal flight from the descent/stall recovery that I had initiated using the alternate airspeed indicator and alternate artificial horizon. After a few more moments, my [the Co-Pilot's] airspeed returned to normal and I assumed control of the aircraft again from the Captain. I didn't actually see the instruments return to normal as I was backing up the Captain by watching the Captain's alternate instruments and verifying they were indeed correct but once he had settled the aircraft back to level flight I looked back at my airspeed and saw that it had returned to normal.



Shortly thereafter, we were informed by the flight attendants that we had passengers in need of medical attention due to the abrupt turbulence and we let ATC know that we would require medical assistance upon landing. About this point we got an EICAS message for the Centre Hydraulic System and the Captain proceeded with the 'Abnormal Checklist'. All checklists were accomplished and the flight landed without further incident".

1.5.4 Flight Attendants

The In-Flight Service Manager (ISM) reported that the FAs were in the process of stowing galley equipment and checking the aircraft cabin when the event occurred. The ISM and another FA managed to secure themselves into their crew-seats adjacent to the main passenger door at the front of the aircraft (door 1 left), but four other FAs *"hit the ceiling"*. The ISM stated that *"the drop occurred twice"*.

Prior to landing, the ISM walked through the cabin to check on the passengers. She said that she noticed that two passengers were bleeding from the head and that one of these apologised *"for not having her seatbelt on, that she forgot to put on her seatbelt"*. The ISM also said that the four unsecured FAs *"all complained of neck, back and head pain"*.

One FA reported that during the descent, moderate turbulence was encountered. She said that a FA working in the rear galley area made an announcement for seat belts and that *"All of a sudden, I was completely off my feet. We dropped and a few other passengers were lifted off their feet as well. It felt as though we dropped two times"*. She said that she was assisted by a passenger and managed to secure herself into a crew seat.

Another FA confirmed that the fasten seatbelt sign was illuminated when moderate turbulence was encountered. The FA said that he made a Public Address announcement, urging passengers to return to their seats and fasten their seatbelts. He stated that seconds later *"the turbulence went from moderate to severe"* and that there were *"two abrupt drops that threw everything around that wasn't latched down"*.

1.6 Aircraft Information

1.6.1 General

The aircraft, a Boeing 757-224, was manufactured in 2000 and was operating on a valid Certificate of Airworthiness which was initially issued by the FAA on 25 February 2000. The certified limit load factor envelope of the B757 aircraft with flaps up is +2.5g to -1.0g.

1.6.2 Hydraulic System

Three separate hydraulic systems, left, right and centre, provide fluid at 3,000 psi¹¹ to operate various aircraft systems. In conjunction with the left and right systems, the centre system provides hydraulic power to the flight controls. There is no fluid interconnection between the systems and no aircraft system is solely dependent on the centre hydraulic system.

¹¹psi: Pounds per Square Inch – Unit of pressure.

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The components of the centre system are located in a bay which is situated aft of the left hand wing root. See **Section 1.3, Figure No. 1.**

1.6.3 Air Data System

The air data system consists of the pitot-static system (four pitot probes and six static ports), one total air temperature probe (TAT), two angle of attack (AOA) vanes, two air data computers (ADCs), and electronic flight instruments. The system provides pitot and/or static pressure information to various flight instruments and airplane systems. The pitot-static system consists of the following:

Four Pitot probes:

- One left pitot probe (supplies ADC-L, i.e. the Commander's ADC)
- One right pitot probe (supplies ADC-R, i.e. the Co-Pilot's ADC)
- Two auxiliary pitot probes, one left and one right (right supplies standby airspeed indicator)

Six Static ports:

- One left and one right (supplies ADC-L)
- One left and one right (supplies ADC-R)
- Two alternate ports, one left and one right (both supply the standby instruments)

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The ADCs process the information received from the sensors and send the data, in digital form, to several aircraft systems. Switches for each crew member's ADC selection are located on the flight deck. When the switches are set to NORMAL, the ADC-L provides information, including IAS, to the Commander's instruments, and the ADC-R provides similar information to the Co-Pilot's instruments. IAS is derived by measuring the difference in pressure between the pitot probes and the static ports. As an aircraft's airspeed increases, so the pressure within the pitot probe increases. The ADC converts the difference between pitot probe pressure and static port pressure into airspeed information for display on the flight instruments. Should a pitot probe become blocked, then incorrect pressure will be sensed at the pitot probe, resulting in an erroneous airspeed being sent to the flight instruments. As an example, during descent with a blocked pitot probe, the system will sense a constant pitot probe pressure and an increasing static port pressure and interpret this as a reducing indicated airspeed.

A fault within an ADC will result in warning flags appearing on the air data instruments. However, failure of a pitot probe to send correct pressure information is not recognised by the system as an ADC fault, and therefore will not cause warning flags to appear. The opposite ADC is available to each flight crew member as an alternate air data source if required, by setting the relevant ADC selected from NORMAL to the ALTN (Alternate) position. With the switches in the NORMAL positions, the Flight Data Recorder (FDR) information is taken from the same ADC that is supplying the Commander's instruments. In this case, both ADC switches were set to NORMAL.



1.6.4 Crew Alerting and Warning Systems

1.6.4.1. General

Four warning systems are used to provide alerts and warnings to flight crews. They are as follows:

- Engine Indicating and Crew Alerting System (EICAS)
- Warning System
- Ground Proximity Warning System (GPWS)
- Traffic Alert and Collision Avoidance System (TCAS)

Of these, the two alerting systems pertinent to this event are the EICAS and the Warning System.

1.6.4.2. EICAS

The EICAS consolidates engine and subsystem indications and provides a centrally located crew alerting message display. Messages are displayed on the Primary (upper) EICAS Display located on the centre forward flight deck panel, situated between the two pilot positions. The EICAS also displays some system status and maintenance information.

The EICAS provides the following information:

- System alerts
- Maintenance information
- Status messages
- Communication alerts

‘System alerts’ are messages associated with aircraft system failures or faults. These may require the performance of non-normal procedures, or affect the way the flight crew operates the aircraft. In the case where the system detects a difference in air data between the two ADCs, then the caution messages ALT DISAGREE or IAS DISAGREE are displayed on the EICAS. These messages are inhibited at low altitude or when both pilots have the same air data source selected.

‘System alert’ messages are also accompanied by the illumination of the Master Caution (amber) light which is located on the glare shield in front of each pilot seating position. The Master Caution is intended to draw attention to messages shown on the EICAS display.

1.6.4.3. Warning System

The warning system consists of two flight deck warning speakers, two Master Warning (red) lights and two stick shaker motors. The warning system controls and activates visual, tactile and/or aural alerts for a number of systems, one of which is airspeed. The two airspeed warnings and the aural warning operate as follows:

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Stall Warning: Warning of an impending stall is provided by left and right stick shakers, which independently vibrate the left and right control columns. Both systems are energised in flight and deactivated on the ground through air/ground logic.

Overspeed Warning: An overspeed warning occurs if Vmo/Mmo¹² limits are exceeded. Should an overspeed condition occur, then the following indications are given in the cockpit:

- The Master Warning lights illuminate
- The Overspeed (OVSPD) light illuminates
- The EICAS warning alert message 'OVERSPEED' is displayed
- An aural warning siren sounds

All overspeed warning indications remain active until airspeed is reduced below Vmo/Mmo.

Aural Alerts: Aural alerts are provided for crew attention, recognition, and response. They include synthetic voices and tones. Aural tones are used to alert the crew and to discriminate between the different alert types and levels.

An aural alert consisting of a beeper is used for all system alert, caution-level messages. The beeper produces a tone that sounds four times per second. The beeper automatically silences after one series of four beeps.

1.6.4.4. IAS Disagree Alert

Prior to 2002, the B757/767 aircraft did not provide a specific unreliable airspeed or IAS Disagree alert message to pilots. Following an accident involving a B757, (see **Section 1.12** and **Appendix C**), the NTSB¹³ issued a Safety Recommendation (A-96-16), which requested that the Federal Aviation Administration (FAA) require the Aircraft Manufacturer to modify the B757/767 EICAS to include a caution alert when an erroneous airspeed indication is detected.

Subsequently, a Service Bulletin (SB) SB757-34A0222 was published by the Aircraft Manufacturer in 2002. This SB introduced a modification for an IAS DISAGREE alert to be displayed on the EICAS when there is a difference in indicated airspeed between the Commander's and the Co-Pilot's instruments. The FAA published an Airworthiness Directive, AD2004-10-05, on 18 May 2004 which, *inter-alia*, mandated the completion of this modification. The subject aircraft was fitted with this modification.

For an IAS DISAGREE alert to be generated, a difference of more than 5 kts, lasting for more than 5 seconds, must be detected between the Commander's and the Co-Pilot's Air Speed Indicators. Where an airspeed disagreement is detected, the EICAS will generate the following:

1. An EICAS alert message IAS DISAGREE on the Primary EICAS display on the Centre Forward Panel of the Cockpit.
2. A Master Caution light on the Glare Shield (one in front of each Pilot).
3. A Warning tone, see Aural Alerts above.

Neither Pilot reported seeing the IAS DISAGREE alert message or its associated MASTER CAUTION.

¹² **Vmo/Mmo:** The maximum operating speed limit.

¹³ **NTSB:** The National Transportation Safety Board of the United States of America.



1.6.5 Standby Flight Instruments

In case of failure of any of the primary flight instruments, the following standby instruments are available:

- Standby Attitude Director Indicator
- Standby Altimeter
- Standby Magnetic Compass
- Standby Airspeed Indicator

The standby airspeed indicator provides current airspeed in knots. It is connected directly to the right auxiliary pitot probe and the alternate static ports. Except for the standby magnetic compass, the standby flight instruments are located on the left side of the centre forward panel, beside the Commander's seating position.

1.6.6 Stall Warning System

The stall warning system provides warning of impending stalls, indication and guidance in wind shear conditions, and detection and display of system faults. As part of the system, a stick shaker motor is fitted to each control column which causes the column to vibrate if the aircraft is in danger of stalling. The control system (Stall Warning Computer) for each stick shaker is supplied with angle of attack information from its own vane (angle of attack sensor), i.e. the left hand stick shaker is controlled by the left hand vane and the right hand shaker by the right hand vane.

According to the Aircraft Manufacturer, stick shaker activation occurs when the angle of attack of the vane exceeds a certain value which is determined from the airspeed and wing configuration. The stick shaker is only recorded on the Flight Data Recorder (FDR) when both the left and right stick shakers indicate SHAKE. The Stick Shaker FDR parameter is recorded once every second.

1.6.7 Weather Radar

The weather radar system consists of two transmitter/receivers, an antenna, and a control panel. A switch on the control panel selects which transmitter/receiver is used. The Electronic Flight Instrument System (EFIS) control panel Weather Radar (WXR) switch controls power to the transmitter/receiver and selects the weather radar display on the respective Horizontal Situation Indicator, HSI¹⁴.

The radar display range is set by the HSI range selector, on the EFIS control panel. The transmitter/receiver is activated when either WXR switch is on. The weather radar transmitter sends out directional pulses of microwave radiation.

Part of the energy from these pulses is reflected off atmospheric particles such as water droplets, back in the direction of the weather radar unit, where it is detected by the receiver. The weather radar can detect turbulence only when there is sufficient precipitation. Consequently, clear air turbulence cannot be sensed by weather radar.

¹⁴ **HSI:** Horizontal Situation Indicator. A primary flight instrument on the main instrument panel which displays navigation information to the pilot, including: heading, track, map information, navigation waypoints. It can be used to display weather information from the aircraft's weather radar.

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The control panel also incorporates 'Tilt Control' and 'Gain Control' selectors which allow the pilots to adjust the angle of the radar beam and the sensitivity of the radar receiver. These selectors can be used by pilots to assist in analysing the weather returns.

The Flight Crew informed the Investigation that the weather radar was ON, but that the returns displayed were not significant.

1.6.8 Autothrottle Thrust Lever Operation

The autothrottle system moves both thrust levers together to control speed or thrust, depending on the engaged autoflight mode. For example, if the engaged mode is set to a target speed, the autothrottle system will adjust the thrust levers to maintain that speed. Should the system detect a reduction in airspeed, the autothrottle will adjust the thrust levers accordingly to regain the target speed.

Thrust levers can be manually positioned without disconnecting the autothrottle. After manual positioning, the autothrottle system repositions the thrust levers to comply with the engaged mode. The autothrottle system does not reposition the thrust levers while in THR HLD (Throttle Hold) mode.

1.7 Maintenance Action

Following the occurrence, maintenance personnel performed a functional test of the Air Data System and no defects were found. The aircraft's pitot-static system was tested and no leaks or heating systems faults were identified. The damaged centre hydraulic system components and servicing bay door were replaced and a temporary repair was carried out to the wing to body fairings. The aircraft then operated on a ferry flight to KEWR, USA, where permanent repairs were carried out.

The Operator subsequently generated an 'Engineering Change/Repair Authorisation' (ECRA) as a result of the occurrence. This ECRA included a requirement to carry out the following three tasks:

- 1 *Perform Flight Faults per AMM Task 22-00-02-742-006* (A test to establish if any autoflight faults were present).
- 2 *Perform a Test 30 per AMM 22-11-02* (A test performed from the Maintenance Control and Display panel (MCDP) to display any Flight Management Computer (FMC) faults).
- 3 *Perform an Operational Test of the Air Data Computing System (Both Left and Right) per AMM 34-12-00-715-001.*

All tests were carried out and no faults were found.



1.8 Meteorological Information

1.8.1 Flight Documentation (Meteorological)

Flight documentation obtained from the Flight Crew when the aircraft landed at EIDW, contained the following TAF¹⁵:

DUB 191700Z 1918/2018 190/10KT 9999 SCT020 SCT040 BECMG 1921/1923 15012KT TEMPO 2001/2010 5000 SHRA BKN010 SCT018CB PROB30 TEMPO 2001/2010 3000 TSRA

The above TAF indicates that at EIDW on the morning of the event, between 01.00 and 10.00 hrs, the cloud conditions would temporarily change to cumulonimbus (Cb)¹⁶, with a 30% probability of thunderstorms. The flight arrived at Dublin during this time period.

The Operator provided the Investigation with a copy of a weather chart, which it describes as 'Significant Weather Briefing chart (available to the crew by 19/2105z)'. This is shown in **Figure No. 3**. The chart indicates the possibility of scattered to broken thunderstorms over the south-eastern part of Ireland, and light turbulence forecast for the midlands and northern half of Ireland.

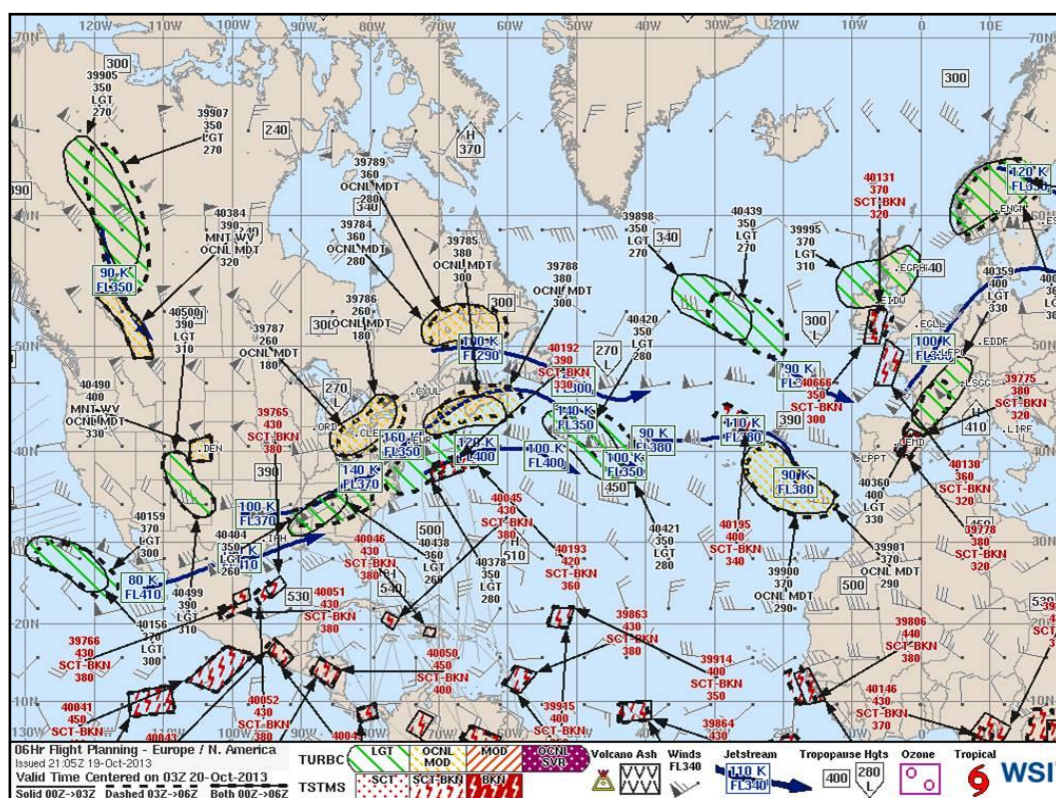


Figure No. 3. Significant Weather Chart, available to Flight Crew of this flight

¹⁵ **TAF:** Terminal Aerodrome Forecast. A concise statement of the expected meteorological conditions at an airport during a specified period (usually 24 hours).

¹⁶ **Cumulonimbus:** Dense towering vertical clouds associated with thunderstorms and atmospheric instability, often abbreviated to 'Cb'.

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1.8.2 Atmospheric Conditions at time of Occurrence

The Investigation requested Met Éireann¹⁷ to provide details of the weather conditions present in the area at the time of the event. They stated that: “Low pressure with a centre of 988 hPa¹⁸ at the mouth of the Shannon estuary maintained an unstable south easterly flow across the country. A well-defined showery trough was moving through the region at the time of the incident with embedded cumulonimbus cloud present. Archived radar echoes indicate some heavier embedded showers were also present”. It was also stated that: “The radar and satellite evidence clearly shows that there was a high possibility of significant (moderate to severe) turbulence associated with cumulonimbus cloud that was present in the area at the time the incident occurred” (Figure No. 4).

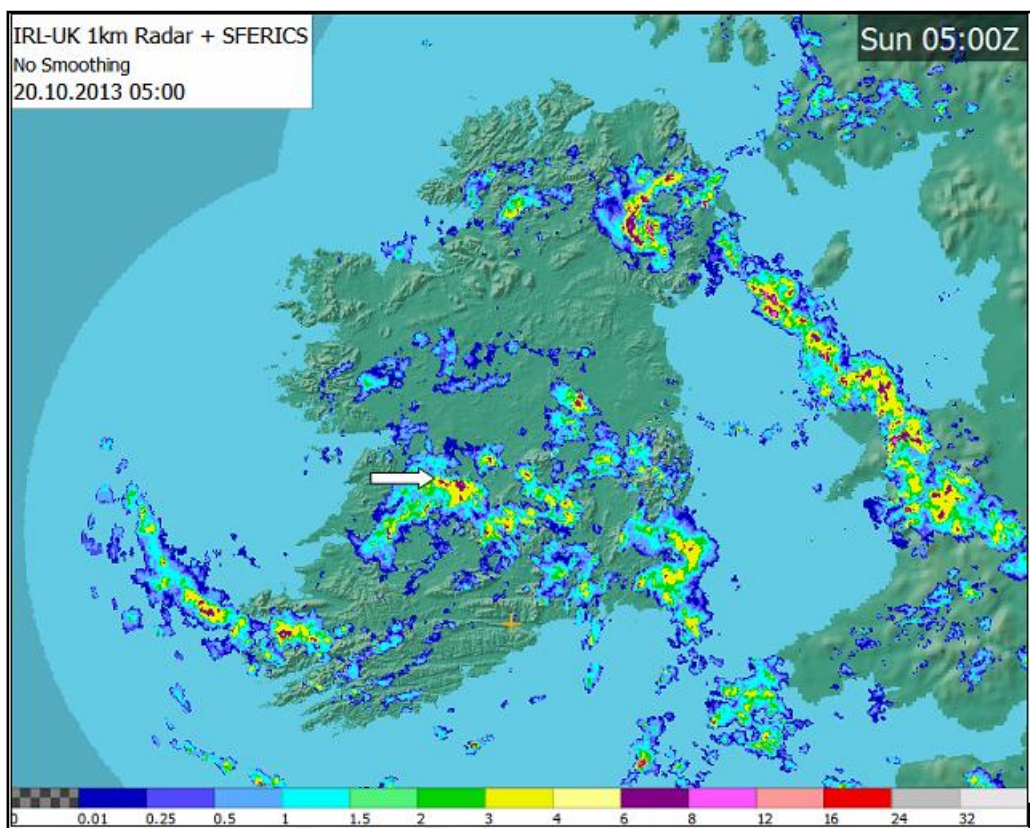


Figure No. 4: Radar image for 0500UTC 20/10/2013. The white arrow shows approximate position of occurrence (Met Éireann)

A Sigmet¹⁹ issued shortly after the occurrence stated; “*embedded thunderstorm activity suggests that the cumulonimbus clouds were topped out at FL320*”.

¹⁷ **Met Éireann:** The Irish Meteorological Service.

¹⁸ **hPa:** Hecopascals – A unit of pressure.

¹⁹ **SIGMET:** Meteorological information issued concerning the occurrence or expected occurrence of specified en-route weather phenomena which may affect the safety of aircraft operations.



Met Éireann also provided the following analysis of the upper air profiles and forecast upper temperatures for the part of the atmosphere through which the aircraft travelled (between 18,000 and 23,000 ft.). The findings are as follows:

“The temperature profile within this layer ranged from, approximately, -22°C at the lower level to -35°C at the upper level. Accepted criteria for water phase in cloud for such a temperature range is that the water phase would be predominately ice. So, and given the proximity of significant cloud masses in the area in which the incident occurred as viewed on satellite imagery, it would suggest that ice crystals were likely to have been present at the time the incident occurred – and at the levels at which the incident occurred. Also, ice crystals would have been the predominant water phase”.

Met Éireann was asked to comment on water droplet size within the Cb, with respect to its reflectivity and detection by aircraft weather radar equipment. Met Éireann stated the following:

*“The remote sensed data (**Figure No. 4**) clearly show well developed Cb cloud and associated intense precipitation patterns. Water droplet sizes would be large [...]. These hydrometeors²⁰ have high reflectivity and it is extremely likely that any on-board RADAR (if live) would have the capability of detecting them”.*

1.8.3 Aircraft Manufacturer’s Atmospheric Analysis

The Aircraft Manufacturer also carried out an atmospheric analysis of the area through which the aircraft tracked. Its findings correlate closely with those of Met Éireann. The Aircraft Manufacturer stated that the key points were:

- *Depending on the exact track, probable flight through a small cold core thunderstorm*
- *Significant ice crystals were present in the core of this storm*
- *FL235 temperature was -37°C*

1.8.4 Ice Crystals

Convective cloud such as cumulonimbus can raise large quantities of moisture within its core. At lower levels within the convective cloud, water content will consist mostly of large water drops, which can be detected by weather radar. However, if conditions are suitable, at higher altitudes within the cloud, this water content may occur as ice crystals. The crystals are usually extremely small, possibly as small as $40\text{ }\mu\text{m}$ ²¹ in diameter. Ice crystals have a radar reflectivity of approximately 5% of that of average-sized water drops, and as a result may not appear on airborne weather radar displays. Ice crystals bounce off cold surfaces such as the airframe, which makes visual detection of ice crystals difficult.

²⁰ **Hydrometeor:** Any water or ice particles that have formed in the atmosphere or at the Earth's surface as a result of condensation or sublimation.

²¹ **μm :** micrometre, also known as a micron, is an SI unit of length equalling 1×10^{-6} of a metre.

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During flight through ice crystals there may be no ice accretion on the exterior or nose of a pitot probe, since the crystals bounce off these surfaces. However, the ice crystals can enter the probe intake itself. If the concentration of crystals is greater than the capacity of the heating element for de-icing and drainage by the purge holes, then ice crystals may accumulate in large numbers in the probe's tube, resulting in temporary blockage of the probe, giving rise to erroneous airspeed indications.

1.8.5 Pitot Probe Airworthiness Standards

The certification basis for the B757-200 was established in 1982. The B757 FAA Type Certificate Data Sheet A2NM included Code of Federal Regulations (CFR) 25.1323 at amendment level 25-1, which stated:

"(e) each [airspeed indicating] system must have a heated pitot tube or an equivalent means of preventing malfunction due to icing".

At the time of the B757 certification, the atmospheric conditions understood and used for design, analysis and demonstration of compliance were defined in CFR Part 25 Appendix C and did not include consideration of ice crystals.

The Appendix D icing envelope definitions were added to Section 33 of the CFR at amendment level 33-34, effective 5 January 2015. At the time of incorporation of Part 33 Appendix D, it was identified that this rule, along with other changes, including changes to CFR Part 25 Appendix C, would;

"Expand the engine and engine installation certification, and some airplane component certification regulations (for example, angle of attack and airspeed indicating systems) to include freezing drizzle, freezing rain, mixed phase, and ice crystal icing conditions".

Thus, CFR, Title 14, Part 25—Airworthiness Standards: Transport Category Airplanes, Subpart F, Instruments: Installation, Section 25.1323, Airspeed indicating system now states:

"(i) Each system must have a heated pitot tube or an equivalent means of preventing malfunction in the heavy rain conditions defined in Table 1 of this section; mixed phase and ice crystal conditions as defined in part 33, Appendix D, of this chapter".

Part 33, Appendix D of the regulation, referred to above, defines the convective cloud ice crystal icing envelope in graph format (**Figure No. 5**). The shaded area of the graph shows the conditions in which ice crystal icing is most likely to occur in association with convective cloud activity.

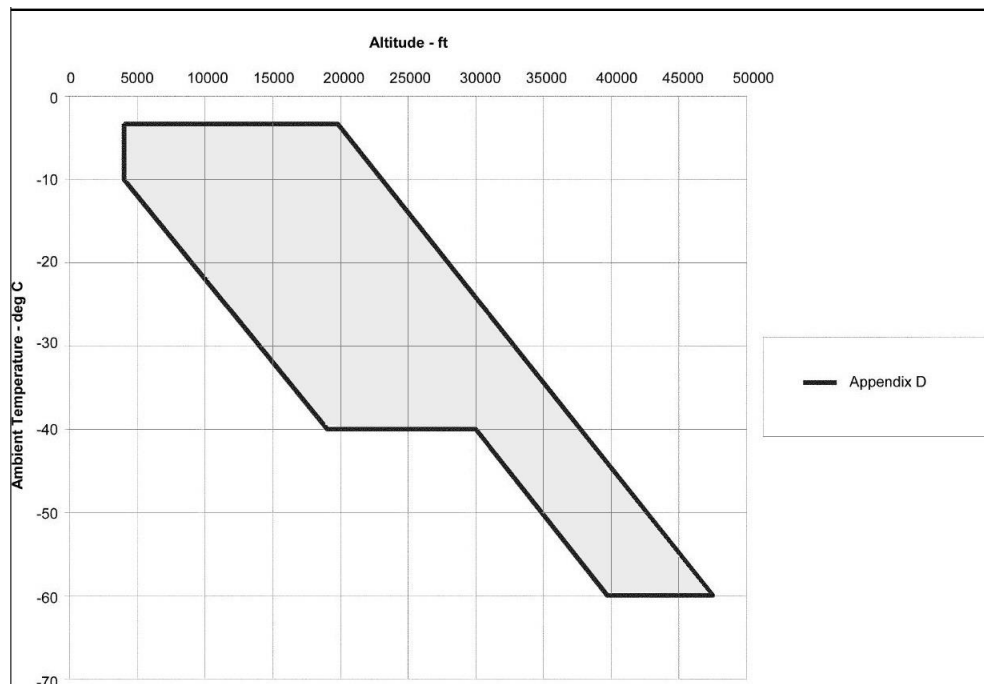


Figure No. 5: The Convective Cloud Ice Crystal Envelope as depicted in FAR Part 33, Appendix D

EASA is responsible for developing aircraft Certification Specifications (CS) within Europe. CS-25 at amendment 16 (issued March 2015), now includes requirements for protection from ice crystal icing, similar to those contained in United States CFRs.

1.9 Flight Recorders

1.9.1 General

Following the event, and on notification that the aircraft had landed without further incident and had positioned to a remote stand, the AAIU's Inspector on Call (IOC) requested the Airport Duty Manager (ADM) to advise the Flight Crew to pull the Cockpit Voice Recorder (CVR) and the Flight Data Recorder (FDR) circuit breakers, to ensure that all recordings were preserved. The ADM later confirmed to the IOC that the Flight Crew had stated that they had pulled the circuit breakers for both recorders.

1.9.2 Cockpit Voice Recorder (CVR)

When the AAIU subsequently removed the recorders from the aircraft, it was determined that while the FDR had been preserved, the circuit breakers for the CVR were not pulled. The download of the CVR confirmed that the relevant cockpit recordings were overwritten and the CVR was of no use to the Investigation.

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In his written report to the AAIU, the Co-Pilot advised, *inter alia*, that:

“A lady from Dublin (I assume she was an agent) came to the cockpit and asked us to pull the CVR and FDR circuit breakers. As there was other personnel in the cockpit speaking to the captain who was on the phone with dispatch at the time, I proceeded to locate and pull the breakers. At this time there were at least four persons in the cramped cockpit and with difficulty I tried to locate the breakers to be pulled.

It was late and just getting light and we were tired and very busy attempting to manage all of the duties placed upon us at that moment with coordinating with the company, the medical personnel, the maintenance staff, the flight attendants and the Irish Safety Authorities. I finally located the FDR breakers but apparently I had completely missed the CVR breakers. I advised the Agent and the Captain that I had pulled the breakers thinking that I had pulled all of the breakers asked of me. I didn’t even realize this mistake until the next day when the agent present on our outgoing flight mentioned that the CVR tapes were not usable due to the breakers not being pulled. At that time I searched the circuit breaker panel and found the CVR breakers and realized that I missed them the night before. This was not done intentionally”.

1.9.3 Flight Data Recorder (FDR)

The Investigation successfully downloaded the FDR data for analysis. The data was also provided to the Aircraft Manufacturer for review.

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1.9.3.1 FDR Recorded Parameters

The Investigation had to take into account certain limitations of the recorded data:

Recorded Computed Airspeed: The source of this parameter is determined by the ADC selector switches. In this case, with both switches set to NORMAL, the source of the recorded Computed Airspeed is the Commander’s ADC-L. Airspeed, as indicated on the Co-Pilot’s instruments, was not recorded.

Recorded Wind Data: The wind data recorded by the FDR is dependent on the primary ADC. In this case, the primary ADC was the ADC-R (Co-Pilot’s) and was determined by the engaged autopilot channel, which was the right autopilot channel. The primary Flight Management Computer (FMC), computes wind data from true airspeed which originates from the primary ADC, which was ADC-R.

Recorded Stick Shake Discrete: This discrete is created exclusively for the FDR and is a combination of both the left and right stick shaker sensors. It only activates when both the left and right stick shakers indicate SHAKE, and is recorded once every second.

Recorded Airspeed Disagree Discrete: The recorded airspeed disagree discrete, ‘EICASIASDISAGREE,’ did not change state during the flight. This discrete is recorded every 64 seconds, with samples taken just before and just after the event.



1.9.3.2. FDR Data Overview

Figure No. 6 shows FDR parameters leading up to, during, and after the event, from 19,640 seconds to 19,740 seconds, a period of 1 minute and 40 seconds. **Figure No. 7** covers the time of the event itself, and shows FDR parameters from time 19,676 seconds to 19,696 seconds, a period of 20 seconds.

The FDR data indicated that the right autopilot channel and the autothrottle were engaged, and remained engaged throughout the event. Prior to the event, the data shows that the aircraft was in a steady descent at approximately 1,500 feet per minute (fpm) and at a computed airspeed of 300 kts (**Figure No. 6, Point 1**).

At 19,560 seconds, descending through approximately 25,500 ft, the atmospheric conditions became turbulent, as indicated by the fluctuations in certain parameters including computed airspeed, acceleration and control wheel deflection. The level of turbulence increased at 19,645 seconds (**Figure No. 6, Point 2**) and beginning at approximately 19,678 seconds, a series of control column commands were recorded with corresponding elevator deflections (**Figure No. 6, Point 6**).

The first control column command, at 19,678 seconds (**Figure No. 6, Point 3**, and **Figure No. 7 Point 1**) was a nose-down command that caused the airplane to pitch down to -9.1 degrees at 19,683 seconds (**Figure No. 6, Point 4**). This was accompanied by an increase in engine thrust (100% N1). As a result, airspeed started to increase. When aircraft pitch reached -9.1 degrees, the control column was pulled back and thrust was reduced towards idle. This resulted in a reduction in nose-down pitch from -9.1 degrees to -8.2 degrees. Consequently, airspeed continued to increase. At 19,684 seconds there was another control column nose-down command, which resulted in aircraft nose-down pitch increasing to -16.2 degrees at 19,689 seconds (**Figure No. 6, Point 5**). Airspeed continued to increase with a computed airspeed of 340 kts being recorded at 19,689 seconds.

During the initial part of the event, the normal load factor reached minimum values of -0.18, -0.36 and -0.22 g between 19,680 and 19,689 seconds (**Figure No. 7, Point 2**). At 19,689 seconds there was a marked pull back on the control column to -4.5 degrees, and a corresponding increase in normal acceleration from -0.22 g to +1.62 g over a period of 2.4 seconds (**Figure No. 7, Point 3**). The aircraft pitch-down attitude started to recover at this time from -16.2 degrees. However, the data showed that the pitch recovery was interrupted at approximately 19,690 seconds.

This corresponds to the time when the data showed the aircraft exceeded the Vmo (350 kts) (**Figure No. 6, Point 7**), at which point a Master Warning occurred (**Figure No. 6, Point 8**, and **Figure No. 7, Point 4**). Recorded data showed a reduction in control column pull at this point and that aircraft pitch remained at between -13.0 and -11.5 degrees nose down for approximately 5 seconds. Aircraft speed continued to increase; peaking at 380 kts computed airspeed (**Figure No. 6, Point 9**). Aircraft descent continued, peaking briefly at 12,000 fpm.

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During the recovery, the normal load factor reached peak values of 1.62, 1.65 and 1.72 g between 19,690 and 19,708 seconds.

FDR data indicate that the speed-brake remained stowed throughout the event.

Prior to the first column push, the FDR data shows two separate thrust (or power) lever movements, described in terms of Power Lever Angle (PLA), and measured in degrees. The first is a small movement from approximately 70° to 73°, which corresponds to a slight decay in computed airspeed at approximate 19,655 seconds. There is a second, faster, thrust lever movement from 72° to 95°, which occurs between 19,674 and 19,678 seconds (i.e. prior to the first column push) (**Figure No. 6, Point 10**).

A third, very rapid thrust lever movement occurs at 19,678 seconds, which corresponds to the time of the first control column push (**Figure No. 6, Point 11**).

The Aircraft Manufacturer provided additional information on autothrottle function, and how thrust lever movement can be determined from the FDR data:

“At times it can be determined whether throttle movement is likely to have been manual by the shape of the plots (graphs of FDR data). The autothrottle generally ramps up the rate while manual movement is more abrupt. With manual control there tends to be throttle movement and then a period where the throttles remain in one position. The autothrottle tends to provide more continuous movement. There tends to be higher rates seen with manual movement. The autothrottle limits the rate to 13 degrees per second with the RB211”.

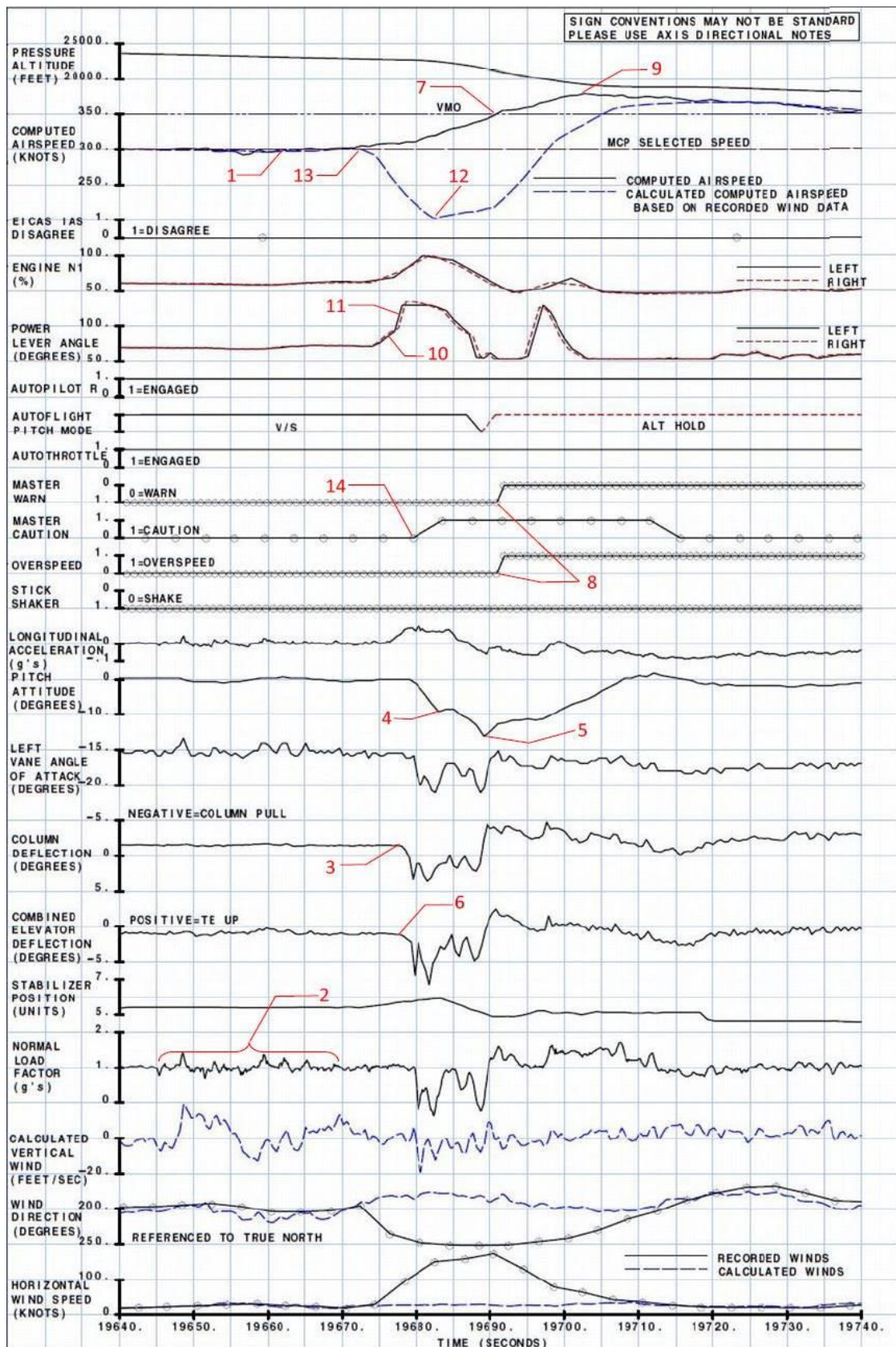


Figure No. 6: FDR data from 19,640 seconds to 19,740 seconds
Numbered labels refer to text in 1.9.3.2 (Courtesy of Boeing Aircraft Co.)

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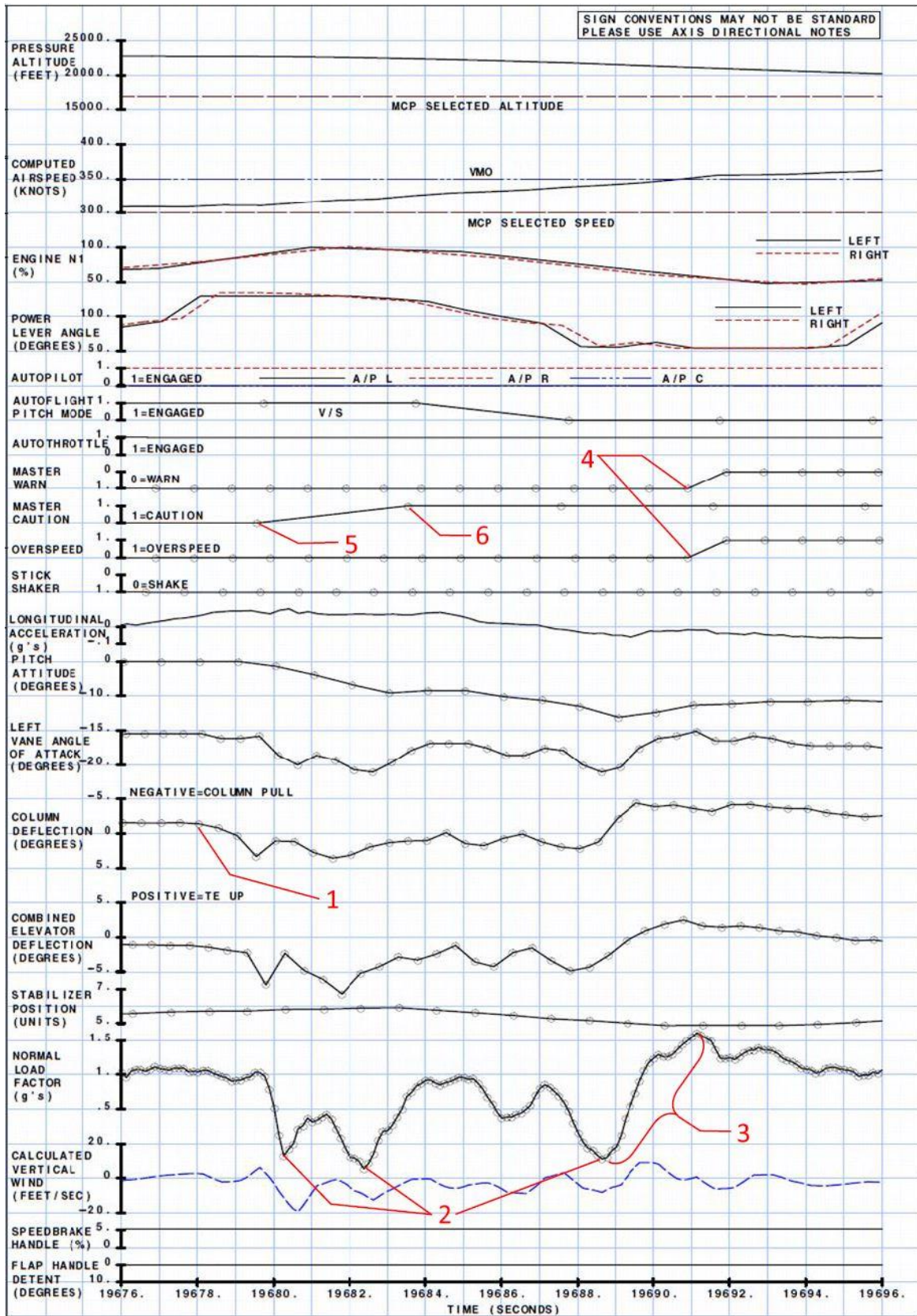


Figure No. 7: Close-up of FDR data from 19,676 seconds to 19,696 seconds
Numbered labels refer to text in 1.9.3.2 (Courtesy of Boeing Aircraft Co.)



1.9.3.3. Aircraft Manufacturer's FDR Review

Due to the fact that the airspeed, as displayed on the Co-Pilot's flight instruments, was not recorded on the FDR, the Investigation asked the Aircraft Manufacturer for assistance in calculating, from the FDR data, the likely computed airspeed indicated on the Co-Pilot's instruments.

The Aircraft Manufacturer determined a calculated computed airspeed, which it stated, represented *"what may have been displayed on the First Officer's instruments"*. However, the calculation was based on the recorded wind data which has a low sample rate of one sample every four seconds and consequently, as stated by the Aircraft Manufacturer, *"large, sudden changes in wind direction and wind speed may not have been captured"*. Nevertheless, it was identified that at time 19,682.5 seconds, the calculated computed airspeed decreased by nearly 100 kts when compared with the recorded computed airspeed (as displayed on the Commander's instruments) (**Figure No. 6, Point 12**). The Aircraft Manufacturer stated that the cause of this airspeed disagreement could not be determined from the FDR data, but *"most likely occurred from a temporary blockage of a pitot probe that supplies pressure to the ADC-R"*.

During their review, the Aircraft Manufacturer used a desktop engineering simulation to recreate the event conditions. Part of the simulation involved an attempt to isolate the contribution of the nose-down column input and the effect of vertical winds. The Aircraft Manufacturer found that with the winds held at zero, the nose-down input resulted in a normal load factor of 0.47 g at the onset of the pitch-down. The effect of the vertical wind, with the elevator held constant, resulted in a normal load factor of 0.45 g at the onset of the pitch-down. The Aircraft Manufacturer stated that *"the simulation results show that both the column input and wind profile contributed to the upset"*.

Regarding the reported differences in IAS between the Commander's and the Co-Pilot's instruments, the Aircraft Manufacturer noted that the relevant FDR discrete 'EICAS-IAS-DISAGREE' did not change state during the flight. However, it is also noted that this discrete is only sampled once every 64 seconds and the data was sampled just before and just after the event. The recorded data indicated that the 'Master Caution' discrete was triggered twice during the event, firstly at 19,680 seconds, (**Figure No. 6, Point 14** and **Figure No. 7, Points 5 and 6**), which lasted for approximately 30 seconds, and again at 19,820 seconds which lasted for a maximum of four seconds (the sampling rate of the 'Master Caution' alert is once every four seconds). The Aircraft Manufacturer stated that the first 'Master Caution' was *"most likely the result of an Indicated Airspeed (IAS) disagree alert, which was not captured by the FDR"*.

The Aircraft Manufacturer also noted that the 'Master Warn' discrete indicated 'Warn' around 19,690 seconds which lasted for 55 seconds followed by a second momentary 'Warn' shortly afterwards and that these warnings corresponded to an 'Overspeed' warning, (**Figure No. 6, Point 8** and **Figure No. 7, Point 4**).

In relation to the stick shaker, the Aircraft Manufacturer stated that the stick shaker discrete as recorded by the FDR, which requires both left and right stick shakers to simultaneously indicate SHAKE, did not change state during the event.

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The following conclusions were provided by the Aircraft Manufacturer:

“The nose-down column and elevator deflections preceded the normal load factor excursion and contributed to the severity of the event.

A combination of nose-down elevator deflections and vertical wind changes resulted in the changes in pitch attitude, vane AOA and normal load factor observed in the FDR data.

During the pitch down manoeuvres, the computed airspeed exceeded Vmo by 30 knots.

The inconsistency between the recorded computed airspeed data and wind speed data was attributed to the source of the data. It is suspected that a pitot probe that supplied pressure information to the First officer’s ADC had a temporary blockage which caused the inconsistent wind data and most likely an airspeed disagree indication between the Captain’s [Commander’s] and First Officer’s [Co-Pilot’s] instruments.

The autopilot and autothrottle remained engaged throughout the event. At the realization of an unreliable airspeed indication, the Airspeed Unreliable procedures listed in the QRH should have been executed. The airplane behaved as expected to the control inputs and control surface deflections.

The crew report stated that stick shaker activated twice during the event²²; however, stick shaker activation could not be validated with FDR data”.

²⁹1.9.3.4. Operator’s Data Review

The Operator informed the Investigation that it utilises a “flight data analytics system”. The flight data received by the system for the occurrence flight was analysed by the Operator. The following details relate to this analysis.

The Operator noted the rapid change in altitude and stated that “*accompanying this change in altitude was a large change in wind speed and direction that is not typical of a gust or wave activity*”. Before the rapid altitude loss and wind shift, the average rate of descent was 1,500 fpm with the average airspeed recorded as 300 kts. There was an increase in vertical acceleration to a maximum value of 1.44g, which the Operator stated was indicative of light to moderate turbulence.

The Operator noted that shortly after this, the aircraft pitched down 16 degrees with a corresponding increase in the rate of descent to 12,000 fpm. The airspeed increased to 379 kts. The Operator’s report stated that the maximum negative vertical ‘g’ loading reached was -0.36g. It also noted that the wind speed increased from 18.5 kts to 174 kts over an 18 second time period and that the wind changed direction from 195 degrees to 236 degrees in four seconds and reached 252 degrees at the maximum wind speed.

²² **Note:** Other than the Co-Pilot’s statement that the overspeed warning may have been confused with a “stall warning”, the Flight Crew made no mention of stick shake activation to the Investigation.



The Operator made the following observations:

“When autopilot is engaged, the aircraft flies using the air data information from that side of the aircraft and uses the data from that side to calculate wind speeds using information from the Inertial Reference Unit (IRU). The IRU uses accelerometers and GPS to determine the speed and orientation of the aircraft and is therefore independent of the air data systems. Based on these assumptions, the change in airspeed is unrealistic and most likely occurred due to an error in the air data system. When the aircraft computer combines erroneous air data airspeed with the IRU ground speed, it calculates a wind speed that is large and inaccurate”.

The Operator concluded that:

“The rapid wind shift is not realistic, but is an artefact of the combination of accurate INS [Inertial Navigation System] data and inaccurate airspeed data from the system where the autopilot was engaged [On the subject aircraft, the autopilot on the Co-Pilot’s side was engaged]. On [the subject aircraft], the First Officer most likely saw a large decrease in airspeed that led him/her to pitch the aircraft downward to attempt to recover what they believed was a stalled aircraft”.

1.9.4 Operator’s Documentation relating to Flight Recorders

The Operator provided the Investigation with a copy of the procedures for operation and removal of Flight Recorders. These are contained in a document called ‘*Emergency/Non-Normals, Section 2.50.1*’. This document states that use of the Flight Deck Voice Recorder “*is limited to accident investigation*”. It also states that the Flight Data Recorder may be used for both “*accident or incident investigation*”.

The same documents contain the following instructions:

- *“If an incident or accident occurs, notify dispatch as soon as practical so that arrangements may be made for removal of the recorder or action taken to protect the recording (e.g., pulling of the recorder circuit Breaker). Under no other circumstances will recorders be deactivated to preserve recorded information, unless directed by Company officials.*
- *Authorization to remove a specific recorder may be given only by Company officials”.*

1.9.5 ICAO Requirement for the Operation of Flight Recorders

ICAO Annex 6, Operation of Aircraft, requires, *inter alia*, the following:

6.3.4.2: Flight recorders — Operation

6.3.4.2.1: Flight recorders shall not be switched off during flight time.

6.10.8.2: To preserve flight recorder records, flight recorders shall be deactivated upon completion of flight time following an accident or incident. The flight recorders shall not be reactivated before their disposition as determined in accordance with Annex 13.

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Note 1. — The need for removal of the flight recorder records from the aircraft will be determined by the investigation authority in the State conducting the investigation with due regard to the seriousness of an occurrence and the circumstances, including the impact on the operation.

Note 2. — The operator's responsibilities regarding the retention of flight recorder records are contained in 11.6.

11.6: Flight recorder records

The operator shall ensure, to the extent possible, in the event the aeroplane becomes involved in an accident or incident, the preservation of all related flight recorder records, and, if necessary, the associated flight recorders, and their retention in safe custody pending their disposition as determined in accordance with Annex 13.

1.10 Aircraft Manufacturer's Publication related to Unreliable Airspeed

The Aircraft Manufacturer issued a Fleet Team Digest (FTD), reference 757-FTD-34-10005, on 13 September 2010, entitled "*Recognition and response to erroneous airspeed by flight crew and airplane systems*". This was revised on 2 April 2012. (Further revisions were issued on 11 February 2014, and 14 August 2014, subsequent to the occurrence). This digest states the following:

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"Erroneous airspeed events can be the result of a variety of contributing factors related to environmental conditions, human factors, and/or hardware failures". It also stated: "The rate of occurrence for multi-channel unreliable airspeed events combined with the probability of inability to recognize and/or respond appropriately in a timely manner may impact the ability to ensure continued safe flight and landing. Boeing has determined this to be an airplane safety issue and has initiated the referenced Service Related Problem (SRP) to address the issue".

The FTD refers to SRP 757-SRP-34-0119 which was initiated to analyse the issue. Further to this and as outlined in the FTD, the Aircraft Manufacturer concluded that there is no single root cause for erroneous airspeed indications. However, the Aircraft Manufacturer identified the following solutions, *inter-alia*, to mitigate the issue:

- 1. Enhanced flight crew training curriculum in reaction to unreliable airspeed.*
- 2. Develop consistent cross-model flight crew procedures (non-normal checklist) for unreliable airspeed.*

In the FTD dated 11 February 2014, the Aircraft Manufacturer classified the issue as "*closed*", stating that the supplemental flight crew training curriculum publication with regard to the unreliable airspeed issue and other related changes were implemented in the Flight Crew Training Manual (FCTM), dated 30 June 2013, and again in the 30 June 2014 revision.



It was also stated that updates to the non-normal checklist for unreliable airspeed were incorporated into the Flight Crew Operating Manual (FCOM), dated 23 October 2012 and again in the 15 May 2014 revision, and that a Flight Operations Technical Bulletin on the subject of unreliable airspeed was issued on 4 June 2013.

1.11 Operator Procedures and Training

1.11.1 Unreliable Airspeed

The Operator's Quick Reference Handbook (QRH) includes a checklist for an Indicated Airspeed (IAS) Disagree message, which instructs the Flight Crew to "Go to the Airspeed Unreliable Checklist". Extracts from the checklist valid at the time of the event are shown in **Appendix A**.

The Operator confirmed that 'Unreliable Airspeed' training had been covered in the ground school portion of a prior year's Continuing Qualification Program.

1.11.2 Unreliable Airspeed Training

The Operator was asked for details of training for Unreliable Airspeed and provided the following information:

"While Qualification, Requalification and Continuing Qualification Training programs include significant stall recovery and upset recovery simulator training, unreliable airspeed training was most recently conducted via the self-study portion of the Operator's Continuing Qualification training program. This training most recently occurred throughout calendar year 2013".

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The Operator also informed the Investigation that a new training program, which includes Unreliable Airspeed objectives, is planned for implementation in 2016.

1.11.3 Stall Recovery

Stall recovery guidance documentation received from the Aircraft Manufacturer directs pilots to "Initiate the Approach to Stall or Stall Recovery maneuver as published in the QRH". The Aircraft Manufacturer's approved stall recovery procedures are given in **Appendix B**. These procedures require, *inter alia*, the following:

- *Hold the control column firmly*
- *Disconnect autopilot and autothrottle*

The Operator was asked for a copy of their Stall Recovery procedures, as published in their QRH. The Investigation was informed by the Operator that their QRH did not contain Stall Recovery procedures. However, the Operator's Flight Manual²³ does give the following guidance for stall recovery: "This is accomplished by disconnecting the autopilot and autothrottles, pushing the throttles to their furthest forward position, calling "Max thrust, stow speed brake," and levelling the wings if in a turn."

²³Supplementary Procedures, Flight Maneuvers 4.70.6 dated 15 Feb 13.

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The document goes on to state, “At intermediate altitudes when terrain contact is not a factor, the pitch attitude should be reduced until acceptable acceleration is achieved”.

1.12 Previous Events involving Unreliable Airspeed and/or Ice Crystal Icing

A review of unreliable airspeed events on several aircraft types highlights that there is a risk of accident or serious incident if crews do not respond appropriately to such events. The review also indicates a number of events where the cause of the airspeed anomaly was due to flight through Ice Crystal Icing. The following table includes a summary of several accidents and incidents involving pitot-static anomalies and/or Ice Crystal Icing. More details of the events in this table may be found at **Appendix B**.

Date	Aircraft	Event	Event Factors Identified
February 1996	B757	Fatal Crash	Blocked pitot probe. <u>Crew confusion</u> . Did not respond to Stall warning.
October 1996	B757	Fatal Crash	Blocked Static ports. Erroneous airspeed and altitude indications. <u>Crew confusion</u> .
October 2002	B757	High Altitude Stall	Partially blocked pitot probe. <u>Crew Confusion</u> . The flight crew's improper decisions regarding their use of inaccurate airspeed indications.
May 2005	B717	High Altitude loss of control	Blocked pitot probes (anti-ice systems not on). Improper response to erroneous airspeed indications.
January 2009	B757	High Altitude pitch up due erroneous over-speed	Left pitot probe blocked. <u>Crew confusion</u> and misunderstanding of ADC and Autopilot and Flight Director switching.
June 2009	A330	Fatal Crash	Blocked pitot probes from <u>Ice Crystal Icing</u> . <u>Crew confusion and Startle Effect</u> . Lack of clear display in cockpit of airspeed inconsistencies.
June 2009	B767	Significant Airspeed and Altitude deviations in cruise	Temporary fault of Left ADC resulting in erroneous indications on Captain's instruments. Inappropriate response to erroneous airspeed indications. Displayed caution messages on EICAS, ALT DISAGREE and <u>IAS DISAGREE not noticed by crew</u> .
July 2009	B767	Crew noticed airspeed disagreement. Carried out Unreliable Airspeed checklist	Same aircraft as above. Discrepancy noticed on instruments but crew did <u>not notice EICAS caution message</u> .



Date	Aircraft	Event	Event Factors Identified
April and June 2012	A321	Two events. Temporary Unreliable Airspeed indications	Flight through an area of weather likely to be associated with <u>ice crystals</u> . It is probable that the air data errors were due to the effect of ice crystals on the pitot probes temporarily overcoming the pitot heat system.
No date ²⁴	CL-600	Unreliable air data in cockpit.	An investigation into two recent in-service events determined that the root cause in both events was high altitude icing (<u>ice crystal contamination</u>).

1.13 Human Factors

1.13.1 Crew Resource Management (CRM) and Flight Crew Communications

The FAA has defined CRM as the “*effective utilization of all available resources – equipment and people – to achieve safe, efficient flight operations*”. Two of the key elements of CRM are cooperation and effective communication between pilots.

In essence, communication is the passing of a message (information) from one party (a sender) to another (a receiver). Good cross-crew communications can greatly enhance the ability of a crew to analyse and react to different flight events, including failures and anomalous indications on the flight instruments.

The sharing of information is vital in multi-crew aircraft, particularly for the PM task. The same situation can look quite different to two pilots, depending upon their intentions and awareness of what the other knows. The PM is at a disadvantage if he/she does not have a full picture of what the PF is intending to do. This can be minimised by good communications between the PF and PM.

Crew communications often make use of standard calls. The importance of using standard calls increases during time-critical or high workload situations such as critical flight phases and abnormal situations. In addition to being concise and unambiguous, standard calls should be in line with the design and operating philosophy of the aircraft, airline SOPs²⁵ and applicable regulations.

Material published²⁶ by the FAA on awareness and prevention of aircraft upsets includes guidance on training which states:

“Training must include [...] CRM techniques for the most effective prevention and threat mitigation strategies. Desired goals [...] include the following:

7. Effective verbal and non-verbal communication regarding airplane state.”

²⁴ Subsequent to these two events, Transport Canada issued an Airworthiness Directive (CF-2015-08) on 28/04/2015.

²⁵ **SOPs:** Standard Operating Procedures.

²⁶ FAA Upset Prevention and Recovery Training AC No: 120-111 date 14/04/15.

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The same document includes training elements such as “CRM techniques for working as a crew to return the airplane to normal flight and communicating airplane state between pilots, including CRM callouts to improve situational awareness”. It points out that evidence shows that the PM is often better placed than the PF to recognise adverse trends in aircraft state or flight parameters. The PM should actively monitor the aircraft state and flight parameters and promptly callout any divergence from planned and/or briefed flight path. However, communications can be compromised if the message is omitted, poorly constructed, not transmitted, blocked or lost (not received), or because it is misinterpreted by the receiving party. Causes of communications failure can include distractions in the cockpit such as outside transmissions (ATC), warning sounds (horns) in the cockpit and startle factor (see **Section 1.13.3**).

1.13.2 Human Factors Affecting the Optimal use of Weather Radar

An article published by another aircraft manufacturer titled ‘Adverse Weather Operation – Optimum Use of Weather Radar’, points to the following possible human factors issues that may affect flight crew use of weather radar.

“The weather radar display may be wrongly disregarded by the flight crew (who may decide to enter clouds) in the following conditions:

- *Near the destination airport*
- *When following another aircraft*
- *When more than 15 minutes behind schedule*
- *At night.”*

The article also goes on to point out that,

“The weather radar, if not correctly used or interpreted, may mislead the flight crew when:

- *An area of strong activity is hidden behind heavy rain*
- *A small Navigation Display range is not sufficient for the flight crew to determine if an elected trajectory between clouds is blocked by adverse weather further ahead*
- *Dry hail precipitation returns a weaker echo than water droplets*
- *The antenna tilt is not correctly adjusted*
- *Gain is left in a manual position.”*



1.13.3 Startle Factor and Surprise

The FAA has defined²⁷ 'Startle' as *"uncontrollable, automatic muscle reflex, raised heart rate, blood pressure, etc., elicited by exposure to a sudden, intense event that violates a pilot's expectations"*. It also defines 'Surprise' as *"An unexpected event that violates a pilot's expectations and can affect the mental processes used to respond to the event"*. They go on to state, *"Because upsets that occur in normal flight operations are unplanned and inadvertent, pilots may be startled or surprised, adversely impacting recognition or recovery"*.

The incidence of startle factor in aviation has been linked to improved aircraft reliability. Modern commercial air transport aircraft now routinely perform normally day after day, year after year and pilots are rarely exposed to actual malfunctions. The degree of expectation of novel or critical events may be so low that the level of startle encountered by pilots when such events occur can be high. One effect of the startle response can be the focusing of the individual on the causal stimulus to the exclusion of other verbal, visual, aural and tactile events taking place in the cockpit such as warnings, alerts and communications.

Fear or anxiety, if present, can cause a startle response to become more pronounced and attention to become more focused.

During flights there may be long periods of routine flight management and systems monitoring. In such an environment, if the pilot is confronted with sudden unexpected stimuli, the brain may respond with an instinctive reflex psychomotor action (startle). If the actual event that caused the startle response does not match the pilot's mental model of the system state or aircraft behaviour, then the outcome may be a loss of situational awareness and subsequent inappropriate action.

Startle may occur during an aircraft upset. A reference document titled *'High Altitude Operations, Supplement #1 to the Airplane Upset Recovery Training Aid'*²⁸, recognises that although an aircraft upset is more usually defined as an exceedance of pitch roll or bank, it can also occur when the aircraft is within normal limits of pitch roll and bank, *"but flying at airspeeds inappropriate for the conditions"*. The same document also states: *"the flightcrew may be startled by unexpected low airspeed stall warnings, dynamic buffeting and large changes in airplane attitude (design dependent) especially when the airplane is on autopilot"*.

It goes on to note: *"There can be a tendency for pilots to react before analysing what is happening or to fixate on one indication and fail to properly diagnose the situation. Proper and sufficient training is the best solution for overcoming the startle factor. The pilot must overcome the surprise and quickly shift into analysis of what the airplane is doing and then implement the proper recovery"*.

FAA AC 120-111 published in April 2015 also contains material on upset prevention and recovery training.

²⁷ AC 120-111 published in April 2015

²⁸ Produced by the Industry Airplane Upset Recovery Training Aid Team, October 5, 2008

FINAL REPORT**1.13.4 Circadian Rhythm**

Research suggests that flight crew alertness and performance is most affected during the Window of Circadian Low (WOCL). This generally occurs between the hours of 02.00 and 06.00 with reference to the subject's local time. FAA Advisory Circular (AC 117-3, 'Fitness for Duty', dated 10/11/12), defines the WOCL in paragraph 14, (a), which states: *"Individuals living on a regular 24-hour routine with sleep at night have two periods of maximum sleepiness, known as Windows of Circadian Lows (WOCL). The primary WOCL occurs at night, roughly from 2 a.m. to 6 a.m., a time when physiological sleepiness is greatest and performance capabilities are lowest. The secondary WOCL occurs in the afternoon, roughly from 3 p.m. to 5 p.m. For the purpose of this AC, part 117 defines the primary WOCL as a timeframe of 0200 to 0559. During this timeframe, flightcrew members may find their performance degraded as a result of the body requiring sleep"*.

The Flight Crew's local time for the subject occurrence was 01.00 hours.

1.14 Tests and Research

In an effort to understand the factors leading up to, and during the event, the Investigation carried out simulator trials under conditions as close as possible to those encountered by the occurrence flight.

Whilst the simulation closely resembled the occurrence flight in a number of areas, the following anomalies during the trial were noted:

- The right autopilot channel could not be maintained. The trial could only be flown on centre autopilot.
- The EICAS message Airspeed Disagree did not display.

These anomalies are believed to be limitations associated with the simulator and may not reflect the behaviour of an actual B757 aircraft.

The simulated flight was set up with the aircraft established in a descent at approximately 1,500 fpm, and at an IAS of 300 kts. The trial commenced with a simulated blockage of the Co-Pilot's pitot at 29,000 ft. It was noted that the IAS on the Co-Pilot's instruments reduced slowly, with an IAS of 180 kts being displayed on the Co-Pilot's ASI after approximately 200 seconds. 180 kts equates to the top of the Amber Band on the IAS Speed-tape.

At an IAS of 180 kts on the Co-Pilot's ASI, a stall recovery was commenced. With an indicated rate of descent in excess of 6,000 fpm, the IAS on the Co-Pilot's ASI reduced from 180 kts to 90 kts in approximately 20 seconds.



2. ANALYSIS

2.1 General

Shortly before the event, the aircraft was in a stable descent towards EIDW at 300 kts and descending at approximately 1,500 fpm. The Seat Belt sign was reported as being on. The aircraft then entered IMC and encountered turbulent atmospheric conditions, which the Co-Pilot described as “severe”. There was a marked increase in the intensity of St. Elmo’s Fire. The Co-Pilot, who was PF, then noticed that his ASI indicated a low airspeed. Fearing that the aircraft was in danger of stalling, he initiated what he termed “a high altitude stall recovery manoeuvre”. During this action, the Co-pilot stated that his indicated airspeed started to increase, but then dropped again. As a result the Co-pilot repeated the actions.

During these manoeuvres the actual airspeed of the aircraft increased, eventually reaching 380 kts, 30 kts above the Vmo. Shortly after the second pitch down manoeuvre, the overspeed audio warning activated. This was initially considered and reported by the Co-Pilot to be a “stall warning” and likely compounded his belief that he was responding to a stalling condition.

Following the second pitch down manoeuvre, there was a realisation that the Commander’s airspeed agreed with the Standby ASI, and control of the aircraft was transferred to the Commander.

During these manoeuvres, the aircraft experienced negative ‘g’ loads, followed rapidly by positive ‘g’ loads. During the negative ‘g’ manoeuvres some unrestrained persons, and items not secured within the aircraft, impacted parts of the aircraft interior such as the ceiling. The sudden return to positive ‘g’ conditions resulted in persons and objects falling back down. It is likely that the injuries sustained by the passengers and cabin crew occurred during these rapid changes in ‘g’ load.

FDR data shows that the hydraulic quantity decreased sometime after 19,685 seconds. At this time the aircraft was undergoing the second pitch down manoeuvre, after which the aircraft underwent a rapid change in normal load factor from -0.22 g to + 1.62 g, as the airspeed increased through the Vmo of 350 kts. The computed airspeed remained above 350 kts for the next 50 seconds, peaking at 380 kts. It was likely that the centre hydraulic access panel became detached during this period, causing the damage that resulted in loss of centre hydraulic system fluid and pressure.

The normal acceleration forces recorded on the FDR during the event did not exceed the certified limit load factor envelope of the B757 aircraft.

2.2 Meteorology

Aftercast and meteorological analysis received by the Investigation for the weather conditions present in the area at the time of the event indicated that there was a high possibility of significant turbulence associated with cumulonimbus cloud that was present. It is probable that the aircraft tracked through, or close to and downwind of, an area of convective cloud activity.

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The Flight Crew had received meteorological information that forecast the possibility of both convective cloud and turbulent conditions close to EIDW.

The Flight Crew stated that during the descent they had the aircraft's weather radar ON. However, both pilots informed the Investigation that they observed no significant weather radar returns, "*just light precipitation*". The Co-Pilot also stated that he did not see any vertical development of convective cloud above the layer they passed through during their descent.

It has been shown that on-board weather radar systems might not be operated optimally when near the destination airport. Analysis of the weather over Ireland at the time of the event shows the presence of convective activity close to the track of the aircraft. This should have been visible to the Flight Crew on the aircraft's weather radar display, subject to it being appropriately adjusted.

The Flight Crew stated that they also saw St. Elmo's Fire after the aircraft had entered IMC, and the Co-Pilot reported that the St. Elmo's Fire intensity increased just prior to the event. St. Elmo's Fire is an indicator that the atmosphere in which an aircraft is flying is highly electrostatically charged and is often associated with nearby convective cloud such as cumulonimbus or thunderstorm activity. It may also be an indication of the presence of ice crystals. This, and the other meteorological evidence, is consistent with the likely presence of ice crystals in the area through which the subject aircraft tracked.

At temperatures below freezing, near convective weather, the airplane can encounter moisture made up of high concentrations of small ice crystals. Ice crystals are difficult to detect because they do not cause significant weather radar returns. However, the convective cloud that gives rise to the ice crystal should be visible on airborne weather radar, if appropriately adjusted.

Therefore, the following Safety Recommendation is made to the Operator:

Safety Recommendation No. 1

United Airlines should review its guidance material to Flight Crew on the optimal use of Airborne Weather Radar during flight in or near areas of actual or forecast convective cloud activity (IRLD2016-004).

2.3 Blocked Pitot Probe

Analysis of the atmospheric conditions through which the aircraft flew indicated the presence of ice crystals. This is supported by flight crew statements of increasing St. Elmo's Fire.

Similar to other events outlined in this Report (**Section 1.12** and **Appendix C**), the airspeed discrepancy on the subject aircraft was most likely due to a temporary blockage of a pitot probe. The Aircraft Manufacturer stated that: "*It is suspected that a pitot probe that supplied pressure information to the First officer's [Co-Pilot's] ADC had a temporary blockage which caused the inconsistent wind data and most likely an airspeed disagree indication between Captain's [Commander's] and First Officer's instruments*".



Following the event, the Operator performed a check on the Pitot-Static, Air Data, and Probe Heat Systems. No faults were found. The Investigation is therefore of the opinion that the most likely cause of the temporary blockage of the Co-Pilot's Pitot probe was ice crystal icing.

The altitude and temperature at which the event took place were plotted on the Convective Cloud Ice Crystal Envelope chart, from the latest certification standards contained in CFR Part 25.1323 (amendment level 33-34, effective from 5 January 2015). The graph shows that the event occurred within the envelope now specified (**Figure No. 8**).

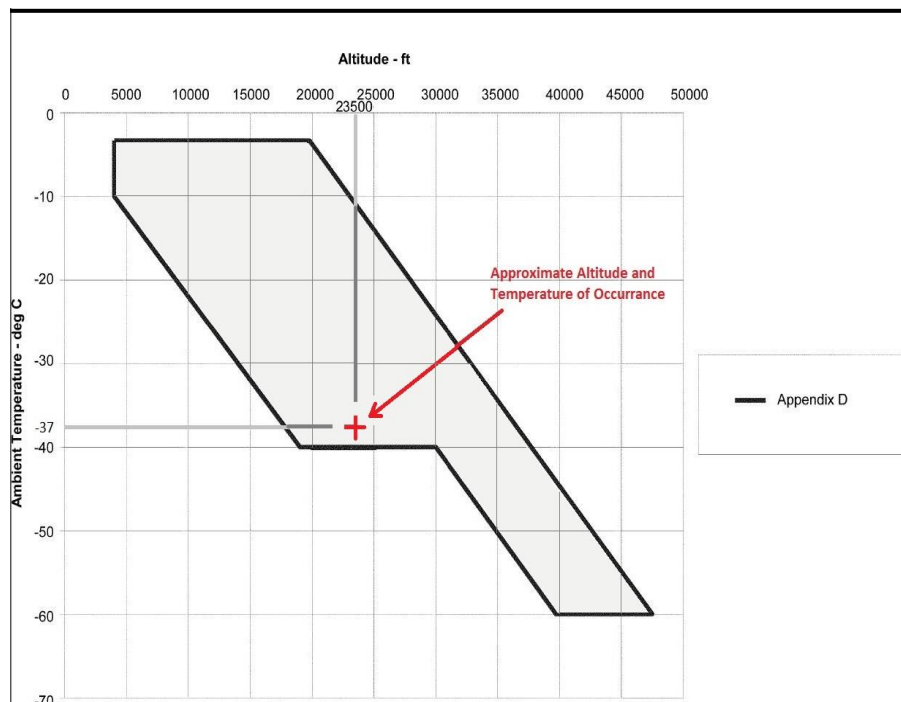


Figure No. 8: FAR Part 33, Appendix D, ice crystal icing envelope with event plotted.

The B757 aircraft type was certified in 1982, under the icing certification criteria requirements in existence at that time. Those criteria did not account for ice crystal icing. This event shows that the B757 aircraft pitot probes may be susceptible to ice crystal icing under certain conditions. The Investigation recognises the industry's understanding of the effects of ice crystal icing is improving, as reflected in the changes to icing certification requirements. The Investigation considers that further study could lead to safety benefits in relation to protection from ice crystal icing for aircraft types certified prior to the introduction of CFR Part 25.1323 (amendment level 33-34).

Therefore, the following Safety Recommendation is made to the FAA, as the regulatory authority of the state of design/manufacture:

Safety Recommendation No. 2

The FAA should conduct a study to establish whether a safety deficiency exists in pitot probe icing protection for aircraft certified under CFR Part 25 prior to 5 January 2015, and address any deficiencies that may be identified (**IRLD2016-005**).

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2.4 Airspeed Discrepancies

The computed airspeed recorded on the FDR was that which was displayed on the Commander's instruments. The Co-Pilot's computed airspeed as indicated on his flight instruments was not recorded. However, data for wind speed and direction from the Co-Pilot's ADC was recorded. This data has a low sample rate of one sample every four seconds. Nevertheless, in order to gain an understanding of the event, the data was used during the Aircraft Manufacturer's analysis, to calculate the airspeed that may have been indicated on the Co-Pilot's instruments. The Aircraft Manufacturer estimated that the computed airspeed as indicated on the Co-Pilot's instruments was likely to be 100 kts less than the value of 300 kts displayed on the Commander's instruments at the time (**Figure No. 6, Point 12**).

The Operator also analysed the data for the flight, as received through their *'flight data analytics system'*. Again, the wind speed and direction from the First Officer's ADC was used to attempt to understand the airspeed that may have been displayed on the Co-Pilot's instruments. The Operator did not put a figure on this but noted that *"the First Officer [Co-Pilot] most likely saw a large decrease in airspeed that lead him/her to pitch the aircraft downward to attempt to recover what they believed was a stalled aircraft"*.

Previous accident and incident reports have shown that:

1. Pitot probes can become temporarily blocked by ice crystal icing.
2. Blocked pitot probes, leading to unreliable airspeed indications in the cockpit, can result in flight crew confusion and inappropriate flight crew actions.
3. In some instances this has led to fatal accidents.
4. The EICAS message and Master Caution alert, introduced on this aircraft type to alert flight crew to an unreliable airspeed, may go unnoticed.

In the case of the subject event, it is suspected that the pitot probe became temporarily blocked by ice crystal icing, leading to unreliable airspeed indications in the cockpit. The Aircraft Manufacturer's FDR analysis indicated that a Master Caution IAS DISAGREE was displayed on the EICAS, and annunciated to the Flight Crew. However, the Flight Crew did not report seeing this warning.

Just prior to encountering the turbulence, the aircraft was in a steady state of flight, descending at 1,500 fpm, 300 kts, wings level, and a pitch attitude of approximately zero degrees.

As the turbulence decreased, the aircraft's rate of descent, airspeed, pitch and roll, had not altered significantly. Thus, the change in airspeed indicated on the Co-Pilot's ASI should have been recognised as an unreliable airspeed by the Flight Crew. If this had been recognised, the first action required by the Airspeed Unreliable checklist in the Operator's QRH, is to *"Check the Pitch and Thrust"*. The checklist goes on to tell flight crew, if pitch and thrust are not normal for the phase of flight, to disconnect the autopilot and autothrottle.



These actions were not carried out by the Flight Crew during the initial stage of the event. Furthermore, when it was recognised that the Co-Pilot's indicated airspeed was unreliable, these actions were not carried out.

The Operator informed the Investigation that Unreliable Airspeed training was most recently conducted via the self-study portion of the Operator's Continuing Qualification training program. Whilst the Operator informed the Investigation that a new training program, which includes Unreliable Airspeed objectives, is planned for implementation in 2016, it is the opinion of the Investigation that such training should provide flight crews with a thorough, practical understanding of unreliable airspeed indications and the correct responses required during all flight phases. The Investigation believes that this is best achieved through simulator training and therefore, the following Safety Recommendation is made to the Operator:

Safety Recommendation No. 3

United Airlines should review its Unreliable Airspeed Training, including theoretical and simulator training, for all phases of flight **(IRLD2016-006)**.

2.5 IAS DISAGREE Alert

The IAS DISAGREE alert is one of the parameters recorded on the FDR. It has a low sample rate of one sample per 64 seconds. During this event the FDR data shows that it was sampled just before and just after the in-flight event and on both occasions was found to be 'off' (not displayed).

However, analysis of the FDR data also indicates that a MASTER CAUTION alert, which is sampled at a greater rate, was generated twice during the event, and that the first MASTER CAUTION was most likely the result of an Indicated Airspeed (IAS) disagree alert, which was not captured by the FDR.

FDR data shows that at 19,679.5 seconds, the MASTER CAUTION alert was 'off', **Figure No. 7, Point 5 and Figure No. 6, Point 14**. When it was next sampled at 19,683.5 seconds, the MASTER CAUTION alert was 'on', **Figure No. 7, Point 6**, which, as stated above, was most likely due to the IAS DISAGREE alert. The FDR data indicates that the control column was moved in the forward direction (nose down) for the first time commencing at 19,678 seconds which was followed by a rearward movement (nose up) just over one second later, i.e. before the MASTER CAUTION alert was generated.

The IAS DISAGREE and its associated MASTER CAUTION alert does not operate unless there is a discrepancy of more than 5 kts between the Co-Pilot's and the Commander's airspeed for more than 5 seconds. Analysis of the FDR data suggests that the discrepancy between the two airspeed sources started to develop approximately 5 seconds before the Co-Pilot pushed the control column forward for the first time. Therefore, when the control column was moved forward for the first time, it is likely that the IAS DISAGREE and the MASTER CAUTION alert were not 'on'. It is possible that when the IAS DISAGREE alert was eventually displayed, it was not noticed/recognised due to the Co-Pilot's belief that the aircraft was stalling, the possible effects of startle factor, and his focus was on trying to recover the aircraft.

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At no stage during their interviews, or subsequent statements, did the Pilots mention seeing or commenting on, the presence of an IAS DISAGREE alert (or an associated MASTER CAUTION). The Investigation found that in two previous events involving IAS DISAGREE on a similar aircraft (B767) investigated by the TSB Canada (see **Section 1.12** and **Appendix C, item 7**), the flight crew did not notice the EICAS alert. The Investigation is therefore of the opinion that the EICAS IAS DISAGREE alert may not provide a sufficient level of warning to flight crews in the event of an Unreliable Airspeed occurrence.

Therefore, the following Safety Recommendation is made to the Aircraft Manufacturer:

Safety Recommendation No. 4

The Boeing Aircraft Company should review the effectiveness of the current IAS DISAGREE warning as a means of alerting Flight Crews to an unreliable airspeed condition (**IRLD2016-007**).

2.6 Fleet Team Digest

The '*Fleet Team Digest*' (FTD) produced by the Aircraft Manufacturer in relation to erroneous airspeed indications acknowledged that this subject is an "*airplane safety issue*" resulting in the Aircraft Manufacturer introducing improvements to flight crew training. The FTD stated, *inter-alia*, that the curriculum was updated in the Flight Crew Training Manual (FCTM), dated 30 June 2013, and that a Flight Operational Technical Bulletin on the subject of unreliable airspeed was issued on 4 June 2013. The FTD classifies the issue as "*closed*". However, the subject event indicates that erroneous airspeed indications and the non-recognition of unreliable airspeed continue to be safety issues.

Therefore, the following Safety Recommendation is made to the Aircraft Manufacturer:

Safety Recommendation No. 5

The Boeing Aircraft Company should review the status of the Boeing Fleet Team Digest relating to erroneous airspeed with a view to reissuing the guidance material (**IRLD2016-008**).



2.7 Human Factors

2.7.1 General

Analysis of the data and review of the Flight Crew's statements indicate that in the initial stages of the event, each pilot likely had a different perception of what was occurring.

The Co-Pilot believed that an aircraft upset had occurred, that this had resulted in a loss of airspeed and that the aircraft was about to stall. This perception may have been compounded by the sensation of the turbulence, the sight of a very low indicated airspeed, and the advancing of the power levers by the Autothrottle.

In contrast, the Commander referred to the aircraft experiencing "*two drops*" that he initially thought were caused by windshear. This perception may have been compounded by the negative 'g' forces he experienced and the increase in airspeed he saw.

As a result of the two different perceptions of the same event, it took approximately 20 seconds before appropriate corrective action commenced, and approximately 30 seconds before aircraft pitch attitude was returned to zero degrees.

2.7.2 Factors that may have Reinforced the Co-Pilot's Belief in the Stall Condition

The Co-Pilot believed the aircraft had suffered an upset and was in danger of stalling due to the very low indicated airspeed he observed, and the turbulence encountered. Other factors that may have reinforced the Co-Pilots belief in the stall condition are described below.

The Autothrottle remained engaged throughout the event. Given the modes selected on the Mode Control Panel, it is likely that any decay in airspeed on the Co-Pilot's instruments would have resulted in an increase in PLA and a corresponding movement of the power levers and increase in engine thrust. A PLA increase from 72° to 95° occurred between 19,674 seconds and 19,678 seconds, prior to the start of the first control column push (**Figure No. 6, Point 10**). This PLA increase is within the autothrottle maximum rate.

From the Calculated Computed Airspeed analysis, indications are that an erroneous decaying airspeed began to occur on the Co-Pilot's ASI approximately 5 seconds prior to the first control column push by the Co-Pilot (**Figure No. 6, Point 13**). During this time, the PLA increased from 72° to 95° . Thus, with the autothrottle engaged, the Power Lever movement was likely an autothrottle response to the (erroneous) reducing airspeed on the Co-Pilot's ASI. This increase in thrust and change in PLA may have been noticed by the Co-Pilot and contributed to his belief that the reduced airspeed was genuine.

During the second pitch down manoeuvre the overspeed warning horn sounded, which the Co-Pilot initially believed was a stall warning as this corresponded with the low airspeed that he was seeing on his instruments. This likely further reinforced his belief that the aircraft was stalling, and as a result delayed the recovery of the excessive nose-down attitude of the aircraft, which resulted in the Vmo exceedance.

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2.7.3 Startle Factor

Given the reliability of modern aircraft and their systems, pilots are rarely exposed to failures and malfunctions, and may become conditioned to an expectation of normalcy during everyday operations. Thus, sudden, serious events may elicit a startle response. Furthermore, during a startle response, pilots' perception and reaction to certain sudden failures or instrument displays may not be appropriate. One effect of the startle response can be the focusing of the individual on the causal stimulus to the exclusion of other events taking place in the cockpit such as warnings, alerts and communications.

Upset Prevention and Recovery guidance published by the FAA indicates that, even though an aircraft may be within its normal pitch and roll envelope, airspeeds not appropriate for the conditions may point to an aircraft upset. The Co-Pilot stated that he thought he may have been experiencing some form of upset from the turbulence. The same guidance material states that flight crew may be startled during aircraft upset events.

Therefore, it is possible that the Co-Pilot experienced a startle response due to the sudden onset of the erroneous airspeed indications on his flight instruments, coupled with the turbulent conditions being encountered and the fear that an aircraft upset had taken place. This startle response likely elicited the immediate, reflex actions performed by the Co-Pilot.

Likewise, the Commander may have been startled by the 'g' forces he was experiencing as the Co-Pilot manoeuvred the aircraft in response to what he (the Co-Pilot) thought was a stalled condition. A startle response by the Commander may have resulted in him not perceiving the IAS DISAGREE or its associated MASTER CAUTION and delayed his analysis and crosscheck of the instruments and the action required to return the aircraft to normal flight conditions.

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2.7.4 Pilot Actions during the Perceived Stall

Up to the time of the event, the aircraft had been descending at 1,500 fpm with an indicated airspeed of 300 kts. Other than the Co-Pilot suddenly perceiving a very low indicated airspeed, there were no major changes to the aircraft's angles of pitch, roll or bank. This of itself should have indicated that an airplane upset, and a stall, were unlikely to be occurring, and that an unreliable airspeed indication may have been present.

Notwithstanding this, the Co-Pilot was of the belief that the aircraft was stalling.

The Stall Recovery actions are not outlined in the Operator's QRH, but stall recovery actions are outlined in their Supplementary Procedures Manual, where it states that initial recovery is accomplished by "*disconnecting the autopilot and autothrottles*". The Aircraft Manufacturer's stall recovery procedures (see **Appendix B**) require the control column to be held firmly, and to disconnect the autopilot and autothrottle.

These actions were not performed, as shown by FDR data, which recorded that the autopilot and autothrottle remained engaged throughout the event.



Furthermore, if the Co-Pilot had carried out the first actions of the Aircraft Manufacturer's Stall Recovery Checklist, which are to hold the control column firmly, and disconnect the autopilot and autothrottle, it is likely he would have sensed the control loads on the control column, especially as he applied forward pressure. The control loads and pitch rate become more pronounced as the IAS of the aircraft increases. This would have given some tactile feedback to the Co-Pilot in the initial stages of the manoeuvre and assisted in his analysis of what was occurring.

However, startle and surprise may have resulted in a more reflexive response by the Co-Pilot to the observed sudden decrease in indicated airspeed on his instruments. A reflex response can result in actions that are immediate and automatic, and may not be aligned with specific checklists. Therefore the actions of the Co-Pilot must be considered in this context. It is the opinion of the Investigation that the initial actions of holding the control column and disconnecting the autopilot and autothrottle were likely omitted as a result of startle response.

Both of these issues, the recognition of airplane upset and training for startle factor, are addressed in the recent FAA document AC 120-111. Therefore, the Investigation makes the following Safety Recommendation to the Operator:

Safety Recommendation No. 6

United Airlines should review their guidance material on aircraft upset recognition and startle factor in its recurrent and CRM training programs in the context of the recently published documents, '*High Altitude Operations, Supplement #1 to the Airplane Upset Recovery Training Aid*', and FAA AC 120-111, '*Upset Prevention and Recovery Training*' (IRLD2016-009).

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2.7.5 Communication between the Pilots

Interviews conducted with the Flight Crew and further statements provided by them after the occurrence, suggest that the level of inter-crew communication was such that neither pilot was able to fully assess what had happened to the aircraft, or what action the other pilot was taking. There was no indication that an initial cross-check took place in the cockpit with regard to the low airspeed condition that was indicated on the Co-Pilot's instruments, or the Co-Pilot's belief that the aircraft was in danger of stalling prior to the initial pitch down manoeuvre. In his initial interview and first written report, the Commander made no mention of any communication from the Co-Pilot during the event.

Consequently, there appears to have been no shared picture or shared understanding by the Flight Crew members of what had initiated the event, or what actions were being performed to address it. Following the initial pitch down manoeuvre by the Co-Pilot, in response to a perceived stall condition, it took approximately 30 seconds before the aircraft pitch was restored to approximately zero degrees.

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Standard calls are designed to facilitate timely, effective and efficient crew communication and coordination. The absence of a standard call at the appropriate time, or the omission of an acknowledgement of a standard call, may result in loss of situational awareness. The Operator's stall recovery procedure includes the standard call "*Max thrust, stow speed brake.*" The Investigation found no evidence that this call was made.

The Co-Pilot stated that he used the phrase "*are we stalling?*" after he had commenced the first pitch down manoeuvre. This phrase, as it was a question, would not have imparted any information to the Commander about what the Co-Pilot was seeing on his instruments, or doing with the controls, and therefore may have delayed a crosscheck by the Commander of the airspeed indicators.

The use of standard calls at the commencement of the Co-Pilot's actions should have alerted the Commander to the situation the Co-Pilot was perceiving, and may have improved the Commander's level of situational awareness.

It is understandable that startle factor and surprise may have triggered the initial response of the Pilots to this event. However, flight crew training, especially concerning the use of standard calls, is designed to improve the level of cross-crew coordination, ensuring that each pilot is aware of what the other is perceiving and any actions they are taking as a result. This is particularly relevant during non-normal events. It is the opinion of the Investigation that more timely and accurate communications between the two Pilots may have prevented this occurrence developing to the extent it did. Therefore, the Investigation makes the following Safety Recommendation to the Operator:

Safety Recommendation No. 7

United Airlines should emphasise to flight crew the importance of using Standard Calls, especially during non-normal flight manoeuvres (IRLD2016-010).

2.8 Stall Warning

During his interview and subsequent written reports, the Commander makes no mention of the activation of the stick shaker or a stall warning. The Co-Pilot does not mention the activation of the stick Shaker. However, in his initial interview and second written report, the Co-Pilot mentioned the possibility that the stall warning had activated. In both reports the mention of stall warning activation coincides with the time when the over-speed warning would have activated, which the Co-Pilot subsequently stated he may have confused with the stall warning. During analysis, the Aircraft Manufacturer did not exclude the possibility that the Co-Pilot's stick shaker activated. However, they advised that the stick shaker discrete as recorded by the FDR, which requires both left and right stick shakers to activate, did not change state during the event.



2.9 Injuries

It was reported that the seatbelt sign was ON, as is normal during a descent. The FAs were in the process of stowing galley equipment and securing the aircraft cabin in preparation for arrival. One passenger reported that he was in the aircraft lavatory at the time of the event. FA reports state that several passengers and Crew Members were *“lifted off their feet”* and in some cases, *“hit the ceiling”*.

Reports received from the FAs included the observations that there were *“two abrupt drops”*. This is consistent with the Co-Pilot’s report that a *“stall recovery manoeuvre”* was performed twice. The FDR Data shows that the aircraft pitched nose-down initially to -9.1 degrees at time 19,683 seconds and then further to -16.2 degrees at 19,689 seconds. The minimum values of -0.18 g, -0.36 g and -0.22 g were reached during this period. There were also rapid changes to positive ‘g’ from these negative values. Negative vertical acceleration can result in an unsecured person or object moving towards the aircraft ceiling and returning to positive vertical acceleration can result in objects impacting back towards the floor of the aircraft. The Investigation is therefore of the opinion that the injuries occurred during this time.

As part of the analysis of the ‘g’ forces experienced during the event, the Investigation sought to determine if they were due to control column input alone. The Aircraft Manufacturer attempted to separate the effects of control column input and the weather conditions, through the use of an engineering simulation. It was concluded that *“both the column input and wind profile contributed to the upset”*.

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2.10 Loss of Centre Hydraulic System

Regarding the loss of quantity/pressure in the centre hydraulic system, it is likely that during the event, the hydraulic service door became dislodged and opened, causing the hold open rod to disconnect and strike the dump valve key. The degree of damage to the dump valve key was such that it led to a loss of hydraulic fluid from the centre hydraulic system, which was signalled in the cockpit. As the aircraft continued its descent into EIDW, the hydraulic service door was subjected to further airflow damage resulting in the door bending and breaking in half, but remaining attached to the aircraft. The B757 aircraft has three hydraulic systems. In this case, the loss of the centre system had no bearing on the continued safe operation of the aircraft.

2.11 Lack of CVR Data

The non-availability of the CVR denied the Investigation the opportunity to fully understand the cockpit environment at the time of the occurrence and to accurately account for the communications, discussions and actions of the Flight Crew as they responded to the unfolding events.

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As stated in **Section 1.9.2** of this report, the Investigation notes and accepts the Co-Pilot's statement that he thought the circuit breaker for the CVR had been pulled. The Investigation reviewed the Operator's published guidance on the use of Flight Recorders. The guidance material might lead Commanders to believe that data from CVRs is to be used for accident investigation only, and that only Company officials (other than Flight Crew) may preserve Flight Recorders and authorise their removal. This could be interpreted in a way that is not consistent with the requirements of ICAO Annex 6, Section 6.3.4.2.2, Operation of Flight Recorders, and specifically Section 11.6, preservation of Flight Recorder records (responsibility of the operator).

Therefore, the Investigation makes the following Safety Recommendation to the Operator.

Safety Recommendation No. 8

United Airlines should review its Operations Manual to ensure that the procedures associated with the preservation of Flight Recorders following an Accident or Incident are in accordance with the provisions of ICAO Annex 6 (IRLD2016-011).



3. CONCLUSIONS

(a) Findings

1. Both Flight Crew members were appropriately licensed.
2. The aircraft was operating on a valid Certificate of Airworthiness.
3. During the descent towards Dublin Airport the aircraft flew through, or close to, an area of convective cloud activity, in which ice crystals were the predominant water phase.
4. The Flight Crew reported that they observed nothing more than light precipitation on the weather radar display.
5. The convective weather should have been visible on the cockpit displays if the weather radar had been appropriately adjusted.
6. Turbulent atmospheric conditions were encountered.
7. When the turbulence subsided, the Co-Pilot, who was the Pilot Flying, noticed that the airspeed, as indicated on his instruments, was low.
8. The Co-Pilot initially believed that there was a real loss of airspeed which was caused by the turbulence and that the aircraft was in danger of stalling.
9. It is probable that the loss of airspeed indicated on the Co-Pilot's ASI was caused by a temporary blockage of the right main pitot probe by ice crystals.
10. The Co-Pilot carried out what he termed a "*stall recovery manoeuvre*" of his own volition, by lowering the nose of the aircraft and increasing the engine power.
11. The Co-Pilot did not use the Standard Call "*Max thrust, stow speed brake*", at the commencement of what he termed a "*stall recovery manoeuvre*".
12. During the occurrence the Commander was unaware that the Co-Pilot was carrying out a pitch down recovery manoeuvre in response to his (the Co-Pilot's) belief that the aircraft was stalling.
13. The Co-Pilot observed a second reduction in airspeed, and carried out a second pitch down manoeuvre.
14. During these manoeuvres the aircraft exceeded V_{mo} by 30 kts.
15. Following these manoeuvres, the Flight Crew realised that there was a problem with the Co-Pilot's airspeed indication and control of the aircraft was handed to the Commander.
16. It is probable that an IAS DISAGREE alert was generated through the EICAS system, but the Flight Crew did not report seeing the IAS DISAGREE alert or the associated MASTER CAUTION.

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17. Other unreliable airspeed events have occurred where the flight crew have not recognised an IAS DISAGREE alert.
18. The Operator's '*Stall Recovery*' and '*Unreliable Airspeed*' checklists include the instruction to disconnect the autopilot and the autothrottle.
19. The autopilot and autothrottle remained engaged throughout the event.
20. Disconnecting the autopilot and autothrottle may have assisted the Flight Crew in analysing the status of the aircraft.
21. The initial actions of the Co-Pilot in response to the sight of a low indicated airspeed may be attributed to 'startle effect'.
22. Thirteen passengers and four Flight Attendants received minor injuries as a result of the event.
23. The Seatbelt Sign was switched ON prior to the event, and remained on during the event.
24. Both the control inputs during the pitch down manoeuvres and the turbulent conditions contributed to the normal acceleration forces experienced during the event.
25. The normal acceleration forces recorded on the FDR during the event did not exceed the certified limit load factor envelope of the B757 aircraft.
26. The centre hydraulic system servicing bay door was dislodged and damaged during the event, resulting in damage to other centre hydraulic system components and a loss of hydraulic fluid/pressure in the centre system.
27. The loss of hydraulic fluid/pressure in the centre system had no bearing on the continued safe operation of the aircraft.
28. The Co-Pilot thought that he had isolated both the FDR and CVR. However, only the FDR was successfully isolated.
29. Following the event, ground checks of the Pitot-Static and Air Data Systems found no faults.
30. At the time of the B757 certification, the conditions understood and used for design, analysis and demonstration of compliance were defined in CFR Part 25, Amendment level 25-1, Appendix C, and did not include consideration of ice crystals.
31. The event occurred at an altitude and temperature that falls within the latest FAR Part 33, Appendix D, Ice Crystal Icing envelope, which forms part of FAR 25, Section 25.1323, Airspeed Indicating System requirements.



(b) Probable Cause(s)

- Temporary blockage of the right main pitot probe due to ice crystal icing, leading to an unreliable airspeed indication.
- Non-standard Flight Crew response to a low airspeed indication.

(c) Contributory Cause(s)

Startle effect due to a sudden unexpected indication of low airspeed, following an encounter with turbulence.

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4. SAFETY RECOMMENDATIONS

No.	It is Recommended that:	Recommendation Ref.
1.	United Airlines should review its guidance material to Flight Crew on the optimal use of Airborne Weather Radar during flight in or near areas of actual or forecast convective cloud activity.	IRLD2016004
2.	The FAA should conduct a study to establish whether a safety deficiency exists in pitot probe icing protection for aircraft certified under CFR Part 25 prior to 5 January 2015, and address any deficiencies that may be identified.	IRLD2016005
3.	United Airlines should review its Unreliable Airspeed Training, including theoretical and simulator training, for all phases of flight.	IRLD2016006
4.	The Boeing Aircraft Company should review the effectiveness of the current IAS DISAGREE warning as a means of alerting Flight Crews to an unreliable airspeed condition.	IRLD2016007
5.	The Boeing Aircraft Company should review the status of the Boeing Fleet Team Digest relating to erroneous airspeed with a view to reissuing the guidance material.	IRLD2016008
6.	United Airlines should review their guidance material on aircraft upset recognition and startle factor in its recurrent and CRM training programs in the context of the recently published documents, 'High Altitude Operations, Supplement #1 to the Airplane Upset Recovery Training Aid', and FAA AC 120-111, 'Upset Prevention and Recovery Training'	IRLD2016009
7.	United Airlines should emphasise to flight crew the importance of using Standard Calls, especially during non-normal flight manoeuvres.	IRLD2016010
8.	United Airlines should review its Operations Manual to ensure that the procedures associated with the preservation of Flight Recorders following an Accident or Incident are in accordance with the provisions of ICAO Annex 6.	IRLD2016011
View Safety Recommendations for Report 2016-007		



Appendix A

Operator's Unreliable Airspeed Checklist (pages 1 and 2 of 4)

05.12 **757** **UNITED**
Unannunciated 15 FEB 13

Airspeed Unreliable

Condition: The airspeed or Mach indications are suspected to be unreliable. (Items which may indicate Airspeed Unreliable are listed in the Additional Information section at the end of this checklist).

Objective: Maintain control using manual pitch and thrust.

Notes: *The appearance of airspeed, altimeter, or vertical speed instrument flags may indicate an air data computer problem.*

Unreliable indications without flags generally are caused by a pitot-static system problem, which cannot be fixed in flight.

- 1 Check the pitch attitude and thrust.
- 2 If pitch attitude or thrust is **not** normal for phase of flight:
Autopilot disconnect switch.....Push
A/T ARM switch.....OFF
F/D switches (both).....OFF
Establish normal pitch attitude and thrust setting for phase of flight.

Note: *If pitch attitude and thrust settings are not normal for the phase of flight, refer to the aircraft specific Airspeed Unreliable Table after Additional Information at the end of this checklist.*

- 3 Altitude information, vertical speed information, limit EPR, reference EPR, and EPR bug may be unreliable.
- 4 Cross-check Captain and First Officer airspeed indications and standby airspeed indicator. An airspeed display differing by more than 15 knots from the standby indicator should be considered unreliable.

If pitot-static system icing or blockage is indicated, avoid icing conditions if possible, and consider changing to a warmer/drier altitude.

▼ Continued on next page ▼

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UNITED **757** 05.13
15 FEB 13 Unannunciated

▼ Airspeed Unreliable continued ▼

5 (752) Choose one:

- Reliable airspeed data source **can** be determined:
AIR DATA switch (unreliable side).....ALTN
Invalid overspeed warning and invalid input to AFDS and autothrottle may occur or continue.
Notify ATC that aircraft does not meet RVSM airspace requirements.
■ ■ ■ ■
- Reliable airspeed data source **can not** be determined:
►► Go to step 7

6 (753) Choose one:

- Reliable airspeed data source **can** be determined:
AIR DATA source selector (unreliable side).....ALTN/select other source
Invalid overspeed warning and invalid input to AFDS and autothrottle may occur or continue.
Notify ATC that aircraft does not meet RVSM airspace requirements.
■ ■ ■ ■
- Reliable airspeed data source **can not** be determined:
►► Go to step 7

- 7 Plan to land at nearest suitable airport.
- 8 Maintain normal pitch attitude and thrust setting for phase of flight.
Refer to Airspeed Unreliable Table after Additional Information at the end of this checklist.
- 9 Maintain visual conditions if possible.

▼ Continued on next page ▼

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Operator's Unreliable Airspeed Checklist (pages 3 and 4 of 4)

05.14

757

Unannunciated

15 FEB 13

UNITED

▼ Airspeed Unreliable continued ▼

10 Checklist complete except Deferred Items.

▼ ▼ ▼ ▼ DEFERRED ITEMS ▼ ▼ ▼ ▼

Review before descent:

- Establish landing configuration early.
- Use electronic and visual glideslope indicators, where available, for approach and landing.
- Refer to IRS groundspeed on the CDU POS REF page and reported wind on approach.

■ ■ ■ ■

Additional Information

One or more of the following may be evidence of unreliable airspeed/Mach indication:

- Speed/altitude information not consistent with pitch attitude and thrust setting
- Speed/airspeed/Mach failure flags
- Blank or fluctuating airspeed displays
- Variation between Captain and First Officer airspeed displays
- Amber line through one or more ADI flight mode annunciations
- Overspeed indications
- Radome damage or loss
- Simultaneous overspeed and stall warnings

Display of one or more of the following EICAS messages may be evidence of unreliable airspeed/Mach indication:

- ALT DISAGREE
- C ADIRU PITOT
- CAPT PITOT
- F/O PITOT
- IAS DISAGREE
- L AUX PITOT
- MACH/SPEED TRIM
- OVERSPEED
- PROBE HEAT
- R AUX PITOT
- RUDDER RATIO
- STBY INST PITOT

▼ Continued on next page ▼

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05.15

757

UNITED

15 FEB 13

Unannunciated

▼ Airspeed Unreliable continued ▼

(752C) Airspeed Unreliable Table

Phase of Flight	Flaps	Altitude	Gross Weight (1000 pounds)	Target Pitch Attitude (approx)	EPR (approx)	Speed Mach/ KIAS (approx)	Rate of Climb/ Descent (approx)
Enroute Climb	Up	FL 300	260.0 180.0	+4.0 +4.0	Max Climb	290	900 1800
		FL 200	260.0 180.0	+6.0 +6.5			1700 2900
		10,000	260.0 180.0	+7.5 +8.5			2400 3800
Level Flight	Up	FL 300	260.0 180.0	+3.0 +2.0	1.52 1.44	290	0
Descent from Cruise	Up	FL 300	260.0 180.0	+0.5 -1.5	Idle	290	-2100 -2500
		10,000	260.0 180.0	+0.5 -1.5			-1700 -2100
		10,000	260.0 180.0	+5.0 +5.0			260 215
Maneuvering or Holding	Up	5000	260.0 180.0	+5.0 +5.0	1.25 1.18	260 215	0
			260.0 180.0	+5.0 +5.0	1.21 1.16	259 215	
			260.0 180.0	+8.0 +7.0	1.24 1.17	215 185	
			260.0 180.0	+8.0 +7.5	1.25 1.18	195 165	
			260.0 180.0	+7.5 +8.0	1.30 1.20	175 145	
			260.0 180.0	+5.0 +5.0	1.31 1.22	175 145	
			260.0 180.0	+2.5 +2.5	1.21 1.15	167 137	
Final App. (3° G/S)		1500	260.0 180.0	+2.5 +1.0	1.26 1.18	165 135	700
			260.0 180.0	+0.5 +1.0	1.26 1.18	165 135	700

(752U) Airspeed Unreliable Table

Phase of Flight	Flaps	Altitude	Gross Weight (1000 pounds)	Target Pitch Attitude (approx)	EPR (approx)	Speed Mach/ KIAS (approx)	Rate of Climb/ Descent (approx)
Enroute Climb	Up	FL 300	220.0 140.0	+4.0	Max Climb	290	1100 2200
		FL 200	200.0 160.0	+5.5 +6.0			2200 3000
		10,000	200.0 160.0	+7.5 +8.5			3000 4000
Level Flight	Up	FL 300	220.0 140.0	+2.5 +1.0	1.13 1.04	290	0
Descent from Cruise	Up	FL 300	200.0 160.0	-0.5 -1.5	Idle	290	2200 2400
		10,000	180.0 160.0	-1.5 -2.0			2000 2200
		10,000	180.0 160.0	+6.0 +5.5	1.02 1.01	205 197	0
Maneuvering or Holding	Up	5000	200.0 160.0	+6.0 +5.5	1.02 1.01	213 197	
			180.0 160.0	+7.0	1.03	185	
			180.0 160.0	+7.0	1.05 1.04	165 157	
			180.0 160.0	+8.0	1.07 1.06	145 137	
			180.0 160.0	+5.0	1.08 1.07	145 137	
			180.0 160.0	+2.0	1.04 1.05	129 137	
			180.0 160.0	0	1.06 1.05	135 127	
Final App. (3° G/S)		1500	180.0 160.0	+2.0 0	1.04 1.05	129 127	700
			180.0 160.0	+0.5 +1.0	1.06 1.05	135 127	700

▼ Continued on next page ▼

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Appendix B

Aircraft Manufacturer's Stall Recovery Procedures

Pilot Flying	Pilot Monitoring
Initiate the Recovery: <ul style="list-style-type: none"> • Hold the control column firmly. • Disconnect autopilot and auto-throttle. • Smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops. Nose down stabiliser trim may be needed. 	<ul style="list-style-type: none"> • Monitor altitude and airspeed. • Verify all required actions have been done and Call out any omissions. • Call out any trend toward terrain contact.
Continue the Recovery: <ul style="list-style-type: none"> • Roll in the shortest direction to wings level if needed. • Advance thrust levers as needed. • Retract the speed brakes. • Do not change gear or flap configuration, except during lift-off, if flaps are up, call for flaps 1. 	<ul style="list-style-type: none"> • Monitor altitude and airspeed. • Verify all required actions have been done and Call out any omissions. • Call out any trend toward terrain contact. • Set the FLAP lever as directed.
Complete the Recovery: <ul style="list-style-type: none"> • Check airspeed and adjust thrust as needed. • Establish pitch attitude. • Return to desired flight path. • Re-engage the autopilot and autothrottle if desired. 	<ul style="list-style-type: none"> • Monitor altitude and airspeed. • Verify all required actions have been done and Call out any omissions. • Call out any trend toward terrain contact.

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Appendix C

Examples of Previous Unreliable Airspeed Events

1. In February 1996 a Boeing 757 crashed after taking off from Puerto Plata, Dominican Republic, with 189 fatalities. The report concluded that the aircraft had a blocked pitot probe and that, although the flight crew were aware of erroneous airspeeds on departure, they became confused by false indications of increasing airspeed during the climb and did not respond to a stall warning.

The NTSB issued several recommendations to the United States' Federal Aviation Administration (FAA), one of which was to *"Require that the Boeing Commercial Airplane Group modify the crew alerting system of the Boeing 757/767 to include a caution alert when an erroneous airspeed indication is detected. (Ref A-96-16)"*.

As outlined in **Section 1.6.4.4**, the FAA issued an AD, 2004-10-05, on 18 May 2004, which contained the requirement to include the Caution alert when an erroneous airspeed indication is detected.

2. In October 1996, shortly after take-off from Lima, Peru, a Boeing 757 crashed as a result of erroneous airspeed and altitude indications, due most likely to partially blocked static ports. The NTSB, in a Safety Recommendation communication stated *"Flightcrew confusion about airspeed and altitude was evident as the airplane continued its final descent. At impact into the Pacific Ocean, the captain's flight instruments were reading approximately 9,500 feet and 450 knots"*. All 70 persons on board were killed.
3. On 19 October 2002, a Boeing 757-200 experienced a stall while climbing from FL 330 to FL 370 en route from Orlando, Florida (MCO) to Keflavik, Iceland (KEF). The flight lost approximately 7,000 ft in altitude during the recovery and then diverted to Baltimore-Washington airport (BWI). There were no injuries. The NTSB investigation noted: *"Evidence from the investigation indicates that anomalies of the captain's airspeed indicator were caused by a partial and intermittent blockage of the captain's pitot probe. The reason for the blockage was not determined"*. The NTSB determined the probable cause of the incident as follows: *"The captain's improper procedures regarding stall avoidance and recovery. Contributing to the incident were the partial blockage of the pitot static system, and the flight crew's improper decisions regarding their use of inaccurate airspeed indications. Contributing to the flight crew's confusion during the flight were the indistinct alerts generated by the airplane's crew alerting system"*.

The report indicated that SB757-34A0222 had not yet been incorporated (it was not yet required) on this aircraft and consequently an IAS Disagree message would not have been generated during the event.



4. On 12 May 2005, a B717 was climbing at night in IMC without the appropriate anti icing systems selected on, and as a result lost control. In the subsequent NTSB investigation report, the probable cause of the event was determined as *“a loss of reliable airspeed indication due to an accumulation of ice on the air data/pitot sensors. Contributing to the incident was the flight crew's improper response to the erroneous airspeed indications, their lack of coordination during the initial recovery of the airplane to controlled flight, and icing conditions”*.
5. On 28 January 2009 a Boeing 757-200 aircraft experienced an airspeed discrepancy during the take-off roll from Accra in Ghana. This was investigated by the UK AAIB and is contained in AAIB Bulletin 12/2009. In this incident, the airspeed as indicated on the Commander's instruments lagged behind the speed as indicated on the Co-Pilot's and it was reported that an associated 'AIRSPEED UNRELIABLE' alert was illuminated during the initial climb. The AAIB's report stated that as the aircraft altitude increased, the Commander's computed airspeed began to rise because the pitot pressure, trapped in a blocked pitot probe, remained constant whilst the static pressure decreased with altitude. This caused the airspeed indicator to initially under-read, then over-read at altitude. When passing FL 180, the Flight Crew selected the left Air Data switch to ALTN, believing this isolated the left ADC from the autopilot and Flight Director system.

In the latter stages of the climb because of the mode selected and because the FMCs were using data from the left FMC, an overspeed condition was sensed which provided a pitch-up command to reduce the airspeed. The aircraft did not appear to be following the correct climb profile which led to the Co-Pilot (PM) pushing the control column forward to *“increase the speed and prevent an increasing ROC (rate of climb)”*. A 'Mayday' was declared and the aircraft commenced a return to Accra. As the aircraft descended, it appeared to be operating normally and the Mayday was downgraded to a Pan. An uneventful approach was flown and an overweight landing was made.

The airspeed discrepancy was caused by a blocked left hand pitot probe.

It was reported that following the incident, the operator *“introduced refresher training for its pilots on the AFDS [Autopilot Flight Director System], its modes and operation. A blocked pitot probe event is also included as a part of their simulator recurrent training”*.

6. 01 June 2009, Air France flight 447 (Airbus A330-203) crashed whilst en route from Rio de Janeiro to Paris – The report indicated that there were airspeed indication discrepancies leading up to and during the sequence of events that culminated in the uncontrolled descent of the aircraft into the Atlantic Ocean with 228 fatalities. Amongst the findings and major factors contained in the final report were the following:
 - Temporary inconsistency between the airspeed measurements, likely following the obstruction of the Pitot probes by ice crystals that, in particular, caused the autopilot disconnection and the reconfiguration to alternate law;
 - Inappropriate control inputs that destabilized the flight path;

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- The lack of any link by the crew between the loss of indicated speeds called out and the appropriate procedure;
 - The crew not identifying the approach to stall;
 - The feedback mechanisms on the part of all those involved made it impossible to identify and remedy the repeated non-application of the loss of airspeed information procedure, and to ensure that the risk model for crews in cruise including icing of the Pitot probes and its consequences;
 - The absence of any training, at high altitude, in manually aeroplane handling and in the procedure for *“flight with loss of IAS”*;
 - Task-sharing was weakened both by incomprehension of the situation when the autopilot disconnection occurred, and by poor management of the Startle effect;
 - The lack of a clear display in the cockpit of the airspeed inconsistencies identified by the computers;
7. On 19 June 2009, a Boeing 767-300 Experienced erroneous instrument indications which resulted in airspeed and altitude deviations. Erroneous captain’s airspeed and altitude indications were not correctly identified. The maintenance crew found no fault in the aircraft’s systems, and the aircraft operated for another month before the difficulty reoccurred on the 21 July 2009. An intermittent fault was found in the left-side air data computer. In their report the TSB Canada noted: *“EICAS data is not recorded on the FDR. Neither flight crew reported the IAS DISAGREE or ALT DISAGREE messages. A functional test confirmed that the IAS DISAGREE and ALT DISAGREE messages would be displayed on the EICAS when the parameters were met. This suggests that the messages were likely displayed on the EICAS but **not noticed by the flight crews of both events**”*²⁹.
8. On 13 March 2011 a Boeing 737-800 was operating from Toronto, Ontario, to Cozumel International Airport, Mexico. During the take-off run, at about 90 knots indicated airspeed, the autothrottle disengaged after take-off thrust was set. As the aircraft approached the critical engine failure recognition speed, the first officer, who was the pilot flying, noticed an AIRSPEED DISAGREE alert and transferred control of the aircraft to the captain, who then continued the take-off. During the initial climb, the aircraft received a stall warning (stick shaker), followed by a flight director command to pitch to a 5° nose-down attitude. The take-off was being conducted in visual conditions, allowing the captain to determine that the flight director commands were erroneous. The captain ignored the flight director commands and maintained a climbing attitude. The TSB Canada, under ‘Findings as to Causes and Contributing Factors’ stated: *“A failure in the right pitot-static system caused the output of erroneous airspeed data from the right air data and inertial reference unit. This resulted in erroneous airspeed indications, stall warnings, and for unknown reasons, misleading flight director commands being displayed on the aircraft instruments during take-off and initial climb”*.

²⁹ AAIU Emphasis added



9. The UK AAIB reported on two events to an Airbus A321 that occurred in 2012 involving unreliable airspeed. Their conclusions state:

“On two occasions the aircraft encountered atmospheric conditions that resulted temporarily in unreliable air data.

The first event occurred within the boundary of current icing certification standards, which only consider supercooled water droplets. The second occurred outside the proposed revised boundaries and may have involved an encounter with ice crystals. Icing certification standards are being reviewed by the manufacturer and EASA.

The hazard of such events persists. However, the safe outcome of these incidents indicates that training to deal with unreliable air data can be effective”.

10. On 28th April 2015 Transport Canada issued an Airworthiness Directive (AD) under the Subject Heading of *“Navigation – Flight Instruments – Unreliable Air Data in the Cockpit”*. The background information given in this AD states:

*“Two in-service incidents have been reported on CL-600-2C10 aeroplanes regarding a loss of all air data information in the cockpit. The air data information was recovered as the aeroplane descended to lower altitudes. **An investigation determined that the root cause in both events was high altitude icing (ice crystal contamination)**³⁰. If not addressed, this condition may affect continued safe flight”.*

- END -

³⁰ AAIU Emphasis added

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

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