SERIOUS INCIDENT

Aircraft Type and Registration:	Airbus A321-231, G-EUXM
No & Type of Engines:	2 International Aero Engine V2533-A5 turbofan engines
Year of Manufacture:	2007 (Serial no: 3290)
Date & Time (UTC):	20 April 2012 at 1230 hrs
Location:	Lambourne Hold, near London Heathrow Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 7 Passengers - 182
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	13,735 hours (of which 1,500 were on type) Last 90 days - 100 hours Last 28 days - 5 hours
Information Source:	AAIB Field Investigation

Synopsis

On two separate flights air speed indications became temporarily unreliable. On both occasions the flight crews retained control of the aircraft flight path and managed the situation while remaining in compliance with their ATC clearance. On one of the flights a simultaneous TCAS RA was caused by unreliable vertical speed data. In both cases the aircraft diverted to an airfield clear of adverse weather where it landed without further incident. During the investigation of the first incident the CVR was found to have been deleted by maintenance actions.

History of the flight

The aircraft was operating a passenger service from Stockholm Arlanda to London Heathrow. The flight had been unremarkable, although thunderstorms were forecast for the London area. At around 1230 hrs the aircraft joined the Lambourne hold with the co-pilot as Pilot Flying (PF). The aircraft was descending in light turbulence to FL140, the indicated Total Air Temperature (TAT) was +3°C and the pilots did not see any indication of airframe icing. St Elmo's fire was visible, however, and shortly after the aircraft entered cloud tops there was a white flash of lightning, without any associated noise.

Both pilot's recalled that about one second after the flash the air speed indications on their Primary Flying Displays (PFDs) fluctuated, with both the high and the low speed ends of the scale alternately visible. The standby air speed indicator was also fluctuating, and although neither pilot could recall the extent of its fluctuations, they thought it was not by as much as the primary instruments. The commander remembered that at one stage his PFD speed indication briefly appeared to be blank. The pilots estimated that the instrument disruption lasted for between 10 seconds and 2 minutes. Neither recalled seeing fluctuation of vertical speed or altitude indications.

The pilots recalled that coincident with the ASI fluctuations the master warning sounded repeatedly, an Electronic Centralised Aircraft Monitor (ECAM) message appeared, the autopilot disconnected without its associated audio caution, and the flight controls changed to Alternate Law. The pilots commenced the procedure for '*Unreliable Speed Indication*' and turned off the Flight Directors. PF checked the thrust setting and decided to leave the autothrottle engaged while monitoring the engine N_1 indications for any significant variation. A TCAS Resolution Advisory (RA) appeared on the PFDs though the crew did not hear its associated audio. This RA was depicted on the VSIs as green below 500 ft/min rate of climb, and red above 500 ft/min, indicating that a climb at less than 500 ft/min or a descent was appropriate. The lack of audio resulted in neither pilot being certain they had seen the RA immediately. The navigation display showed conflicting traffic 2,500 ft above and flying level. G-EUXM was in a gentle descent and thus already in compliance with the RA. The commander informed ATC which, based on radar, was unable to identify any conflicting traffic.

The audio voice callout "clear of conflict" sounded and the crew levelled the aircraft at FL140, in compliance with the earlier clearance. With ATC agreement the aircraft was turned away from a storm cell, towards better conditions in the Bovingdon hold. The flight instruments had now stopped fluctuating. The pilots crosschecked the pitch versus power tables in the Quick Reference Handbook (QRH) and confirmed the speed indications now appeared to be correct at 240 KIAS. PF re-engaged the autopilot.

The pilots noted the ECAM message NAV-ADR DISAGREE and carried out the associated actions. They agreed to follow the optional IF NO SPD DISAGREE branch of the procedure, as all indications were now normal. This directed the crew to land with FLAP 3 (the operator's normal landing setting) use V_{REF} +10 kt (5 kt faster than normal) and noted that the flight controls would enter Direct Law when the landing gear was selected DOWN. The ECAM then displayed AOA DISCREPANCY, suggesting the problem had been caused by a mismatch between the aircraft's three Angle Of Attack (AOA) probes. No further procedures were presented or required.

The commander checked the aircraft electronic maintenance pages for the status of the AOA probes and noted that all three AOA outputs were within 0.5° of each other.

The pilots established the aircraft in the hold at Bovingdon in VMC. The commander referred to the company Abnormal Procedures manual (PRO–ABN) and noted that an AOA fault might cause spurious stall warnings. The crew discussed the implications of the failures and considered various scenarios, utilising the company's decision making tool T-DODAR[1], and decided to divert to London Stansted airport, which was clear of adverse weather. A PAN was declared and on ATC request 7700 was set on the transponder.

Footnote

[1] T-DODAR, Time- Diagnose Options Decide Assign Review; a method of adding structure to decision making.

Direct Law landings are rare and the commander sought supplemental information from the company manuals to confirm his understanding of it. However, with additional storm cells developing near London Stansted he decided to prioritise the landing. The flight controls remained in Alternate Law until the autopilot was disengaged, after which an uneventful landing was accomplished in Direct Law, using autothrust.

Operating information

The pilots commented that company training in unreliable airspeed indications had made the incident straightforward. They noted, however, that the '*Unreliable Speed Indication/ADR Check Proc*' QRH procedure spanned four pages of the QRH. Pitch and power settings for a 'clean' aircraft, at minimum speed, were shown in a table on the fourth page, which had delayed them in finding the appropriate settings. They noted that as aircraft may spend considerable time operating at minimum clean airspeed in holding patterns, earlier presentation of these figures would be helpful. The operator informed the AAIB that it will discuss this with the manufacturer, and the manufacturer commented that the procedure referred to memory items that could be actioned immediately.

Subsequent incident

A second unreliable airspeed event occurred to G-EUXM on 16 June 2012. The aircraft was operating from Edinburgh to London Heathrow Airport when, while climbing through FL265 having been in VMC, the aircraft flew through the top of a "dome" of cloud. The commander's airspeed indication reduced towards zero, returned to normal, then reduced again. The co-pilot's indications were similarly affected, with a red 'SPD' caption visible. The autopilot disconnected and the pilots commenced the actions for unreliable airspeed, disconnecting the autothrust and turning off the flight directors. When the initial actions had been completed the airspeed indications appeared to have returned to normal. As in the first event the aircraft was now in Alternate Law and the pilots were aware that it would revert to Direct Law for the landing. Considering the destination weather, including wind from 230° at 24 kt gusting to 39 kt, they decided to divert to London Stansted where the wind of 210° at 22 kt was more favourable.

Neither pilot saw any St Elmo's fire or airframe icing during the second incident. Disruption to the ASIs ceased on or shortly after the aircraft left cloud.

Meteorological information – Incident 1

The UK Met Office provided an aftercast of the weather situation in the London TMA at the time of the first incident. They noted that the general situation was consistent with forecasts. The aftercast showed that the conditions were conducive to the formation of thunderstorms and that there was electrical activity and lightning strikes to the ground in the region of the Lambourne hold. London Heathrow, in common with the other London aerodromes, reported thunderstorms including hail and strong wind gusts at various times throughout the day.

Meteorological information – Incident 2

The UK Met Office provided considerable satellite cloud temperature data for the location of the second incident. Cloud top temperatures were approximately -50°C.

Other Aircraft

No other aircraft in the LAM hold at the time of incident 1 reported any unusual occurrences or TCAS RAs. Several aircraft had been struck by lightning during descent and approach to airports in the London area that day without any reported adverse effects.

System information

Electronic Instrument System

The Electronic Instrument System (EIS) includes the Primary Flying Display (PFD) and Navigation Display (ND), and the Electronic Centralized Aircraft Monitoring (ECAM) functions.

The ECAM uses aircraft system data which has been processed by the System Data Acquisition Concentrators (SDAC), Flight Warning Computers (FWC) and Display Management Computers (DMC). This data is then presented to the flight crew on the Engine/Warning Display (E/WD) and System Display (SD). The E/WD displays the engine and fuel parameters, the checklist and warning messages, and some information relevant to system operation. The SD displays synoptic diagrams giving the configuration and status of various aircraft systems.

Centralised Fault Display System

The Centralised Fault Display System (CFDS) provides a central maintenance aid which allows maintenance information to be extracted, and system and sub-system BITE tests to be initiated from the cockpit. It comprises a Centralized Fault Display Interface Unit (CFDIU), which receives data from other aircraft systems BITE. The CFDIU is accessed from two Multipurpose Control and Display Units (MCDU) located in the cockpit, which can be used initiate tests and to call up other reports such as the Post-Flight Report (PFR).

Air Data and Inertial Reference System

The Air Data and Inertial Reference System (ADIRS) supplies temperature, anemometric, barometric and inertial parameters to the PFD and ND as well as various other systems. The ADIRS includes three identical Air Data and Inertial Reference Units (ADIRU) each of which has two parts: the Air Data Reference (ADR) and the Inertial Reference (IR). The ADR supplies barometric altitude, airspeed, mach, angle of attack, temperature and overspeed warnings. An ADIRS panel, located in the cockpit, allows the crew to select the mode for each ADIRU and provides information on the status of the IR and ADR systems. The normal procedure is for all three ADIRU to be selected ON during flight with ADIRU 1 providing information to the left side (Capt) instruments, ADIRU 2 providing information to the right side (F/O) instruments. In the event of a failure of ADIRU 1 or 2, ADIRU 3 can be selected to provide information to either the Capt or the F/O instruments. In normal operation, all three ADIRU constantly provide air data to a number of systems including flight guidance, autoflight and autothrust.

The air data is provided to the ADIRU from three pitot probes, six static pressure probes, three Angle of Attack (AOA) sensors and two Total Air Temperature (TAT) probes (Figure 1). The data from the AOA and TAT probes is provided directly to the ADIRU as an electrical signal, whereas air pressure from the pitot and static probes is first converted at an Air Data Module (ADM) into an electrical signal. Air pressure is provided directly to the standby airspeed indicator and altimeter from static and pitot probes that are also linked by two ADMs to ADIRU 3. The pitot head probes, static ports, AOA probes and TAT probes are electrically heated by three independent Probe Heat Computers (PHC) that automatically control and monitor the electrical power to the Capt, F/O and standby probes.

Pitot heating

The pitot probes, as well as the other sensors, are heated to counter icing. This heating can only provide a finite amount of energy in a given time. Conditions can be encountered in which the heat removed from the probe due to environmental conditions exceeds the ability of

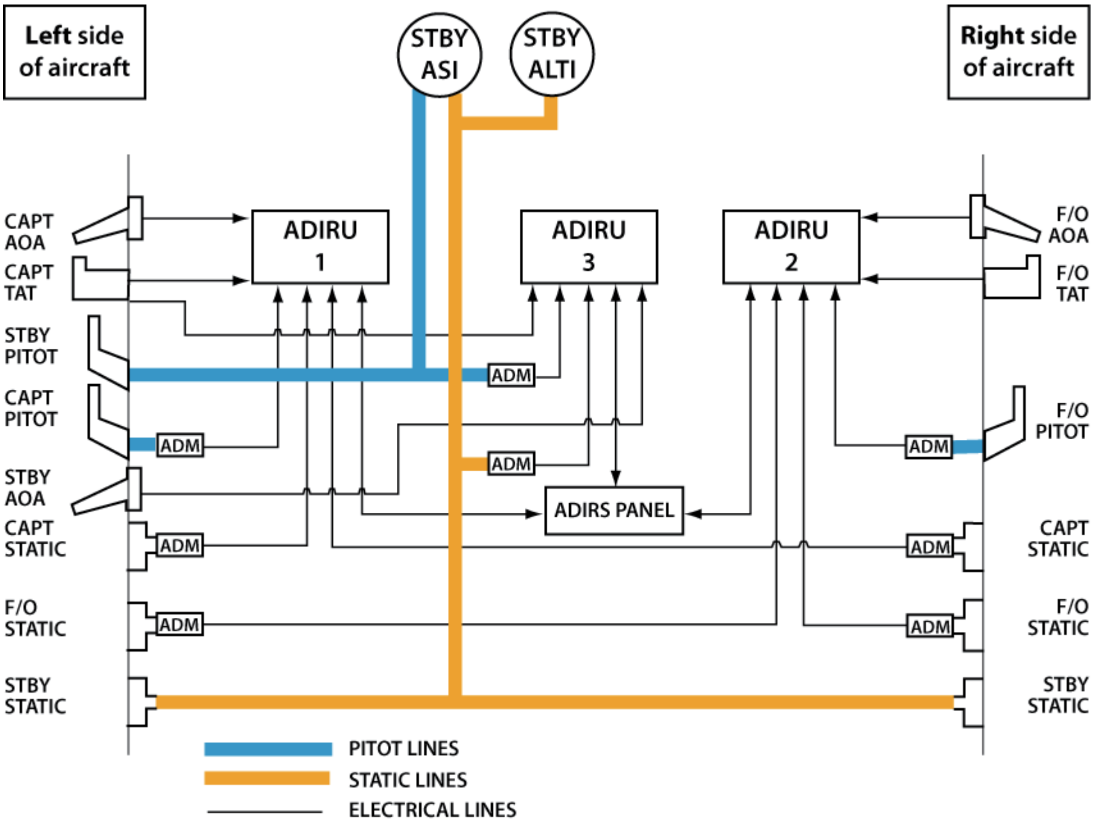

Figure 1

Air data system

the heating system. Ice may then accumulate on the probe. Probe icing can lead to blocking of the pitot probe orifices which results in erroneous airspeed and altitude indications. This will continue until the aircraft enters less severe environmental conditions in which the probe heating system can melt the ice.

The three Probe Heat Computers (PHC) monitor and control the electrical power to the heating elements in the probes, ports and AOA sensors. If the electrical current consumption is outside limits, ECAM warnings are generated by the FWS, using discrete signals sent by the PHC through the ADIRU (Figure 2). BITE messages are generated directly by the PHC and recorded in non-volatile memory (NVM) as well as being sent to the CFDIU on two ARINC channels (data buses). In the event that the data communication between the PHC and CFDIU is lost, ECAM warnings will still be displayed providing the discrete outputs from the PHC are still available, but the associated BITE fault message will not be recorded by the CFDIU.

The NVM in the PHC, in which the BITE messages are stored, is cleared during each ground/flight transition as computed by the Landing Gear Control and Interface Unit (LGCIU). Opening the Circuit Breaker (CB) on the power supply to at least one of the two LGCIU will also clear the PHC BITE messages even if the aircraft has not flown.

Flight control laws

The fly-by-wire flying control system can operate in Normal Law, Alternate Law or Direct Law. In Normal Law the system automatically protects the aircraft

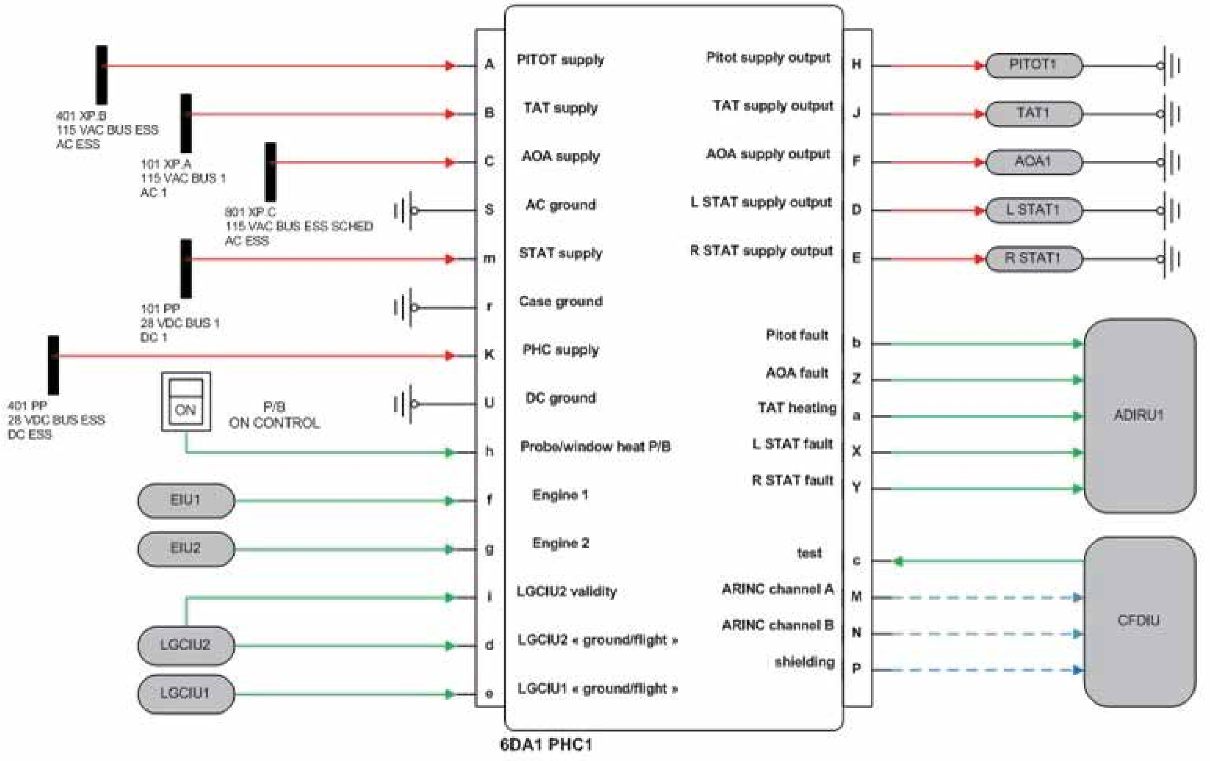

Figure 2

PHC, input and output signals

throughout the flight envelope for load factor limitation, pitch attitude, high AOA, high speed and bank angle protection. In the event of a loss of inputs, such as air data, the system will degrade into Alternate Law where some of the protection is either lost or altered. When the landing gear is selected DOWN in Alternate Law, the system degrades further to Direct Law, in which all protections are lost.

Recorded data

Recorded data was recovered relating to two separate events on G-EUXM and a subsequent event on G-EUXC.

First erroneous air data event

Recordings were recovered from the Flight Data Recorder (FDR), Cockpit Voice Recorder (CVR), a Digital AIDS Recorder (DAR) and Traffic Collision Avoidance System (TCAS) after the first event, on 20 April 2012. Radar recordings of the track and Mode S downlinked parameters of both the aircraft under investigation and the other aircraft involved in the TCAS RA were also obtained.

The recorded data showed problems associated with the air data of all three related systems on the aircraft, and a TCAS event. Pertinent parameters are shown in Figure 3.

The problems occurred whilst descending to a selected altitude of 14,000 ft within a hold north of London. Soon after passing 14,800 ft there was a period of approximately 27 seconds during which all three sources of altitude and airspeed data intermittently and independently jumped to either unreasonable but valid values or values indicating invalid data. This was associated with jumps in recorded air temperature and Mach number.

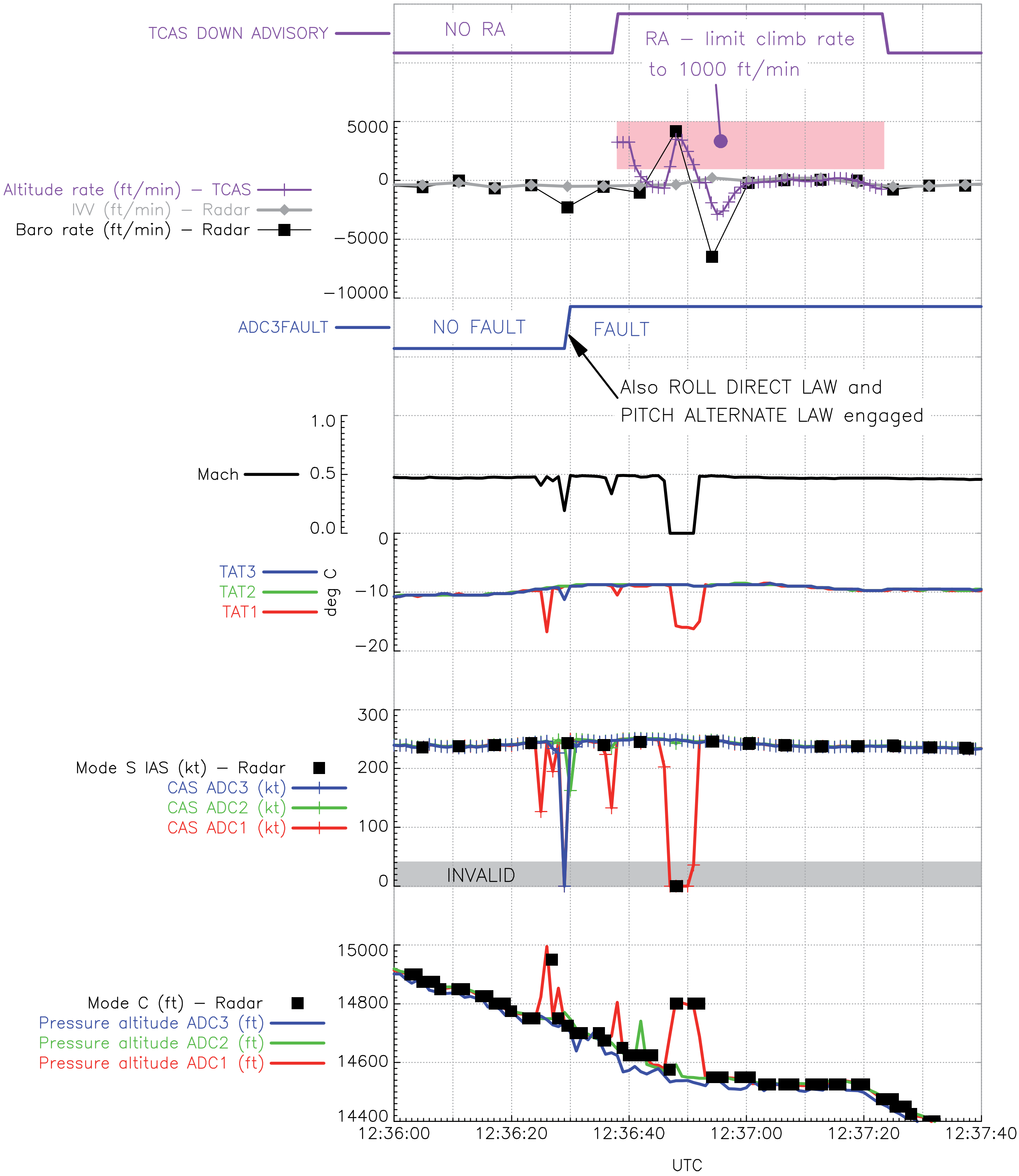

Figure 3

Pertinent parameters from the FDR, ACMS, TCAS and radar recordings

During this 27 second period, Air Data Computer (ADC) number 3 indicated a fault that was latched for the rest of the flight but the other two ADCs did not indicate any faults and no other system problems were apparent in the FDR data. Afterwards, and for the rest of the flight, all three sources of temperature, altitude and airspeed remained reasonable.

Barometric rate was not recorded by the FDR or DAR but was recorded as a Mode S downlink parameter along with Inertial Vertical Velocity (IVV). The IVV showed that the aircraft was in a stable descent but the barometric rate parameter was reacting to the erroneous altitude readings, initially indicating a climb.

During this period another aircraft joined the hold at FL170. The TCAS recording showed an RA advising not to climb at more than 1,000 ft/min. At the same time TCAS recorded the aircraft climbing at 3,250 ft/min and another aircraft at a relative altitude corresponding to FL170. The altitude rate varied as the erroneous ADC 1 altitude parameter varied. The RA cleared 30 seconds after the erroneous air data behaviour ceased.

The TCAS of the other aircraft did not issue an RA. This was in accordance with the TCAS manufacturer's expectations given the separation and relative motion.

The control laws switched from Normal to Alternate law (ROLL DIRECT LAW and PITCH ALTERNATE LAW) when the ADC 3 FAULT became active, closely followed by autopilot 2 disengaging. Autopilot 2 was re-engaged 80 seconds later and remained engaged until passing through 1,000 ft agl on the final approach to Stansted airport, at which point the PITCH DIRECT LAW engaged.

The DAR recorded Static Air Temperature (SAT) of -21°C leading up to the period of erroneous air data.

Second event

A second event occurred on the same aircraft on 16 June 2012, this time during the climb. The relevant data from the DAR and FDR are given in Figure 4. There was a similar period of disrupted air data during which no ADC faults were recorded; later in the flight faults with ADCs 2 and 3 were recorded as the result of crew actions.

The DAR recorded a Static Air Temperature of -41°C leading up to the second event.

CVR recording problem

During both G-EUXM events the CVR Cockpit Area Microphone (CAM) channel recorded a number of periods during which large audio pulses were recorded, often resulting in a recorded waveform using the full amplitude capability of the recording. The time between pulses varied during the affected periods. The air data problems on both flights occurred during a part of one such period during each flight.

The pulses and their effect on the automatic gain control of the CAM channel amplifier resulted in the loss of the cockpit area ambient audio from the recording during intense periods of pulsing and significant degradation during the less intense periods.

The recordings of the crew audio channels did not record any such sounds or indicate that the crew could hear such sounds at the time. Also, there was no adverse effect on the VHF channels being used by the crew during these pulsing periods.

An Airbus A319, registration G-EUPO, experienced an unreliable airspeed indication event in December 2010 (AAIB Bulletin 4/2012). The G-EUPO event differs from the G-EUXM events in relation to the air data

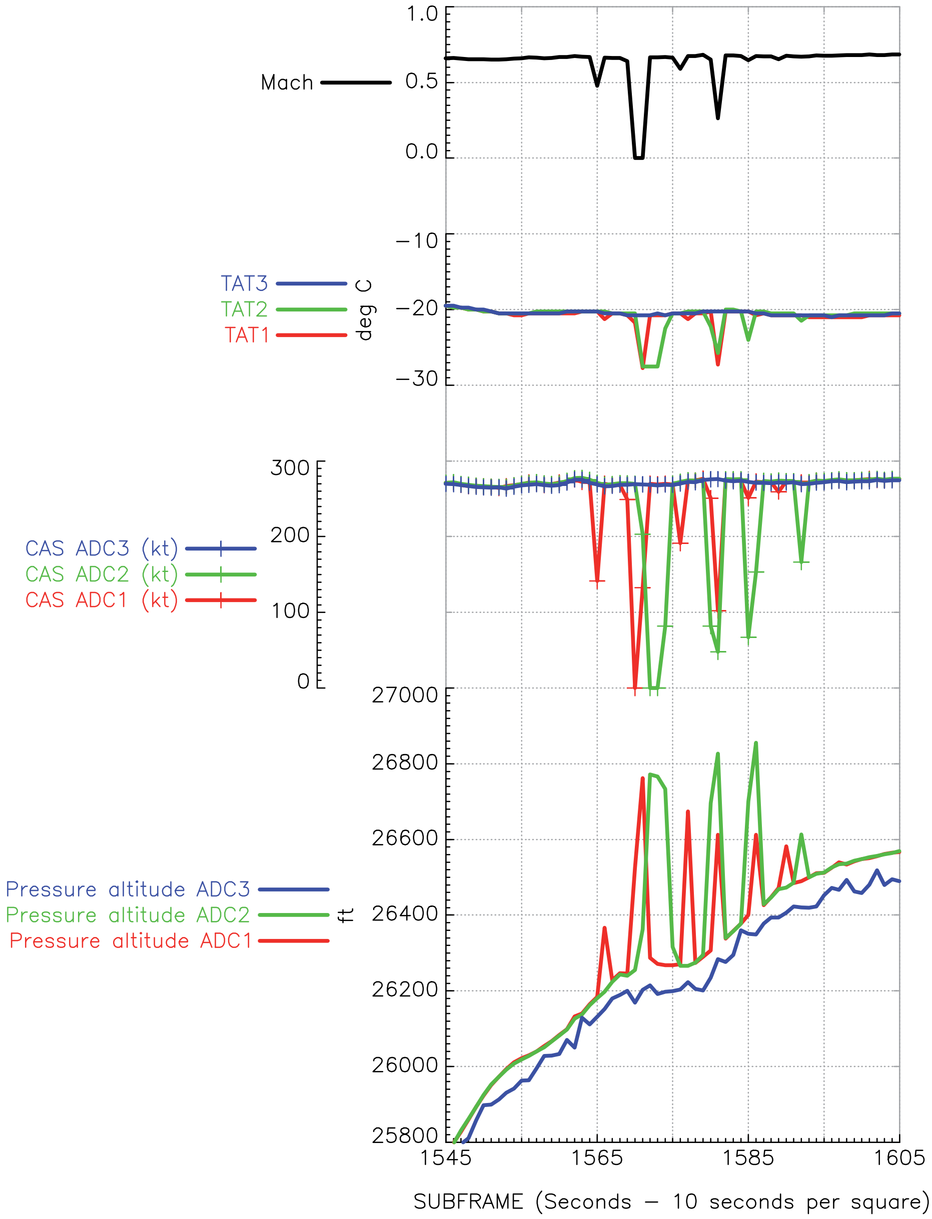

Figure 4

Pertinent parameters from the FDR, ACMS, TCAS and radar recordings

system warnings and parameter behaviour and so the air data problems are not likely to be common between the aircraft. However, the investigation did find similar pulsing on the CAM, not heard by the crew and not evident on the other CVR channels. The investigation found that the effect on the CAM could be replicated with an electrostatic discharge applied to the connector of the CAM control panel.

The airframe manufacturer and associated national investigation body have not observed this problem other than on aircraft subject to this investigation and the G-EUPO event.

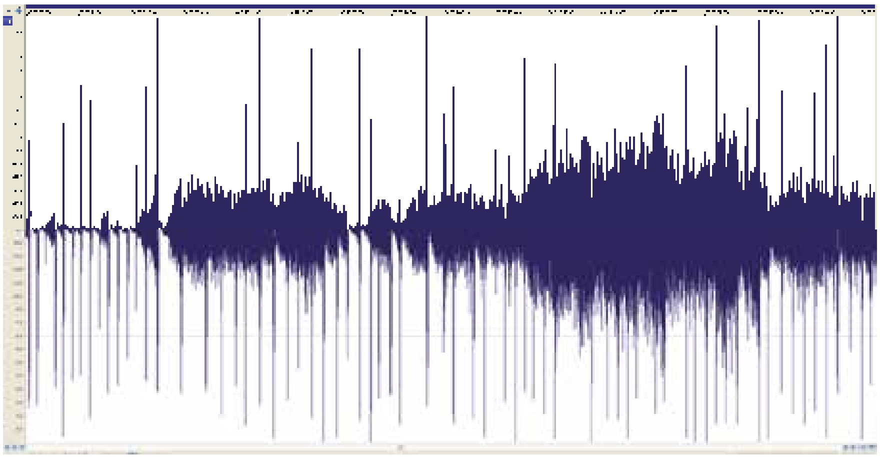

Figure 5

Sample period of the CAM recording showing recorded pulses that were not heard by the crew

Aircraft examination

First incident

An inspection of the aircraft was carried out by the operator in the presence of the AAIB on 21 April 2012. Several areas of damage were identified on the fuselage skin above and below the cockpit windows which were consistent with multiple lightning strikes. No other evidence of lightning strikes was found. Examination of the aircraft's Technical Log showed that the aircraft had been subjected to a lightning strike on 19 April and a number of 'strike points' had been identified above and below the cockpit windows. It was not possible to confirm that all the damage observed had been caused prior to the 20 April incident.

The post-flight report recorded faults with ADIRU 3, the two ADMs associated with ADIRU 3 and the Capt AOA sensor. After restoration of electrical power to the aircraft, interrogation of the CFDS identified the fault messages which had been associated with the systems failures reported by the flight crew and printed on the post-flight report. No additional fault reports were recorded. Further tests of the aircraft's flight control and air data systems confirmed that the previously reported faults were no longer displayed. As a result of the fault messages generated during the incident, ADIRU 3 and its two associated ADMs were replaced together with the Capt AOA sensor and the TCAS computer. A test of the aircraft's pitot-static system indicated that no faults were present.

Second incident

A physical inspection of the aircraft confirmed that there was no evidence of additional lightning strikes of damage to the aircraft. All the air data and flight control systems operated normally and a test of the pitot-static system confirmed that it was serviceable. As a precaution, all three of the aircraft's pitot probes were replaced and the removed units dispatched to the AAIB for further examination.

Component examination

The ADIRU removed after the first event was tested at the operator's approved test facility and no faults were identified with the unit.

The two ADMs and the AOA sensor were subjected testing at the manufacturer's facility. No faults were found.

The three pitot probes removed after the second incident on 16 June were Thales units, part number C16195BA. These probes had been introduced on the A320 family of aircraft to provide improved airspeed indication behaviour in heavy rain conditions when compared with an earlier Thales probe, part number C16195AA. A visual examination of the probes showed no evidence of corrosion or mechanical damage. The probe manufacturer conducted a series of tests which found no defects within the probe heating system.

Flight crew training

The operator had identified several possible events as having a high priority for training within its Advanced Training and Qualification Package (ATQP), based on a Task Analysis and Training Needs Analysis of its Airbus operation. Unreliable airspeed was among them, and was included in one of the Line Orientated Evaluation (LOE) scenarios conducted in 2009-10. Three different evaluation scenarios had been developed, so about 33% of the operator's Airbus pilots were evaluated on this item.

The number of crews required to re-fly the exercise was above the trigger level for a training intervention. Therefore, in the 2010 recurrent training sessions, a package covering unreliable airspeed, including presentations, group discussion and simulator time, was provided for all pilots. An unreliable airspeed event in December 2010 (G-EUPO, published in AAIB Bulletin 4/2012) helped to validate the package and a video was created, with the crew from that incident, providing tips about what they thought went well and what to look out for. This video was incorporated into the online version of the 2010 training package remained available to all company pilots remotely via the operator's training intranet. The commander during the first incident had had this training; the co-pilot was new to the company and had not.

The operator's training cycle envisaged revisiting an unreliable airspeed scenario towards the end of 2012. The re-fly rate on such exercises will be used to evaluate the effectiveness of the training package and close the feedback loop regarding further training.

Abnormal procedures manual (PRO-ABN)

The PRO-ABN-34 procedure '*NAV ADR disagree*' cross-refers to PRO-ABN-27 which describes the various flight control laws. This was the information the commander of incident 1 was intending to review when he decided instead to prioritise the landing. In his subsequent post-flight review, the commander commented that the only information in PRO-ABN-27 of which he was unaware was that manual thrust is advised during Direct Law landings.

CVR preservation

The operator put in place engineering instructions to preserve the FDR but not initially the CVR. In the time between the crew leaving the aircraft and the AAIB arriving, the CVR erase button had been pressed. The purpose of the CVR is to assist in accident investigation and the purpose of the CVR erase function is to protect staff from routine management monitoring; both serve their purpose and are not mutually exclusive. In accordance with CVR standards, erased audio can be recovered using special techniques, but this is a time-consuming and costly activity. Consequently, the recovery of CVR evidence took longer than usual, delaying the investigation. No systemic issues were found relating to the act of the CVR erasure that would constitute a risk to further investigations.

The operator's recorder preservation procedures are predicated on an engineering function. The rationale is that if there is a hazard, the crew should not be subjected to risk for the purpose of recorder preservation. In this case, like many others before, there was no hazard after landing and a procedural requirement for the crew to take an active part in the preservation of the recordings would have resulted in a more robust approach to flight recorder preservation requirements. The lack of crew action in an operator's recorder preservation process is not unique to this operator.

Similar events

The same operator reported a similar occurrence on G-EUXC, the same aircraft type, which occurred on 20 August 2012. The data shows similar air data behaviour, with a slightly longer period and without any faults recorded. The entry condition was pressure altitude of approximately 26,800 ft with a SAT of -23°C. The CVR was not removed (and not required to be).

Other national accident investigation bodies have reported erroneous air data events with recommendations for further action. These include:

> Australian Transport Safety Bureau (ATSB) report AO-2009-065 "*Unreliable airspeed indication 710 kn south of Guam, 28 October 2009, VH-EBA, Airbus A330-202*". This report also refers to three unreliable airspeed events on A320 aircraft which occurred in Australian airspace between 2008 and 2010;

> Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA) report into the loss of Airbus A330-203 registration F-GZCP (AF447) on 1 June 2009.

Icing certification standards

Current icing certification standards, detailed under EASA Certification Specifications for Large Aeroplanes CS-25, Appendix C, define altitude and temperature envelopes for continuous and intermittent maximum icing conditions for supercooled liquid droplets. Ice crystals, not considered to be as hazardous as liquid, are not covered.

Airbus has its own standards relating to ice crystal icing and supercooled droplet icing that extend beyond the EASA CS-25 requirements. Both G-EUXM events involved combinations of altitude and SAT that fall outside their current requirements. Airbus testing has shown that the probe designs meet all current requirements.

Figure 6 shows the EASA CS-25 requirement envelopes and Airbus requirements; the two events are plotted on SAT v Altitude graph.

Airbus has conducted studies including investigating reported airspeed indication problems, icing wind tunnel testing and instrumented flights tests. The results have been shared with the aviation community and Airbus is working in partnership with other organisations on better understanding of icing problems. As a result of their studies, Airbus considers that the current EASA and Airbus requirements need to be improved to better address pitot probe icing. Airbus is in the process of developing expanded envelopes for inclusion in the EASA requirements, which address ice crystal issues. When the revised standards are approved, work can begin with the pitot probe manufacturers to develop designs that reflect the new understanding of pitot probe icing issues. The proposed standards are also given in Figure 6.

There is also a new requirement, currently related to engines, that specifies the total water content associated with SAT and Altitude. Work is being done to apply these to other aircraft equipment, including air data probes.

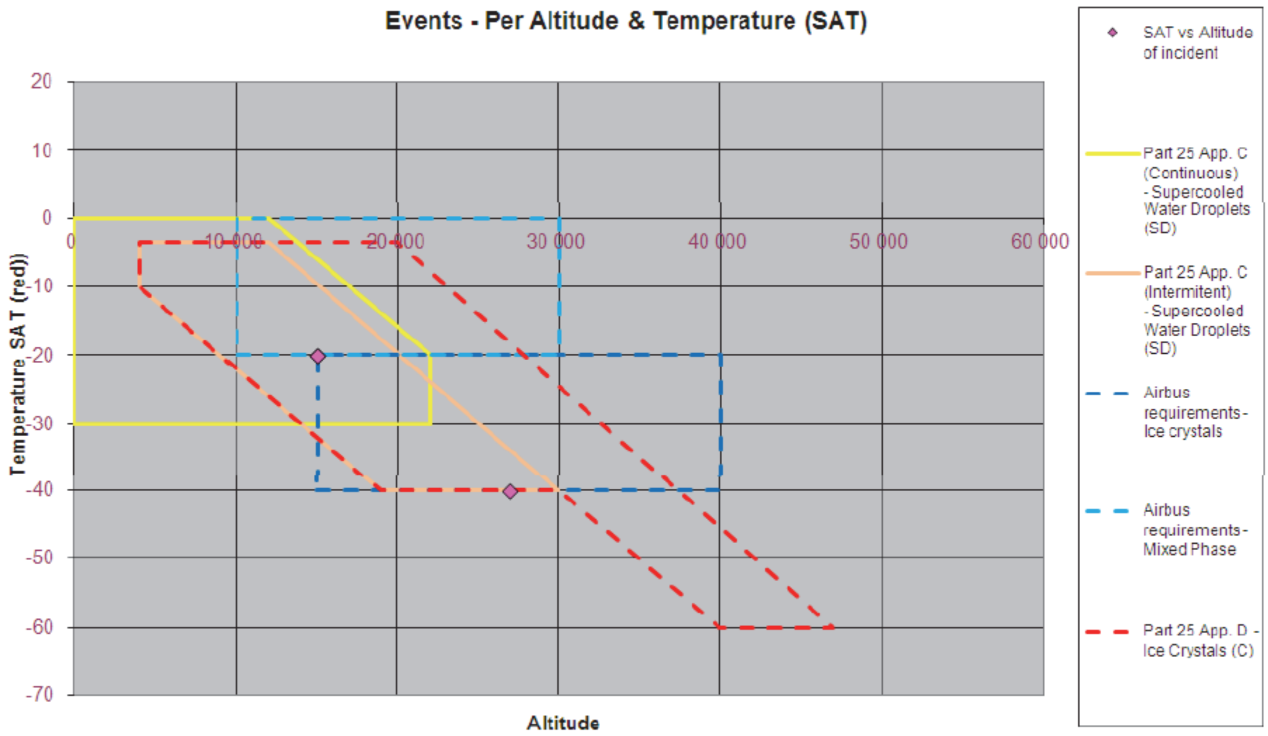

Figure 6

Altitude v SAT envelopes for the current and proposed requirements and the G-EUXM events.
The diamonds are the G-EUXM events

Airbus considers that even though the two G-EUXM airspeed indication problem events occurred on the same aircraft, albeit months apart, and on only one other of the operator's fleet during the same period, the events are not associated with any fault on the aircraft. They consider that the problems were consistent with their studies linking these events to obstruction of at least two pitot probes by ice crystals, and not any airframe-specific problem.

Airbus reported that the failure of two or more probes to perform their function is certified as a "Major" event and as such should not occur more than once every 10^5 flight hours. Its statistics indicate that the actual occurrence rate is in the order of 100 times less frequent.

Weather

The Met Office supplied colour-coded and time-stamped images depicting the temperature of the tops of the clouds over the UK covering the periods of both flights where pulsing on the CAM channel was recorded. Comparing these to the recorded location of the aircraft during the periods of CAM interference showed an approximate correlation with localised colder patches of cloud tops, between -51°C and -62°C. This indicates higher altitude cloud, more likely to contain ice crystals.

Electrostatic discharge

The environment through which an aircraft flies provides a number of mechanisms for electrically charging it. Airbus identified the more common sources of charging as triboelectric charging (flying through snow, ice, hail, rain or sand), ionic engine exhaust charging (exhaust particles charged during combustion) and flying through intense electric fields (such as those required to generate lightning).

The main mechanisms for discharging are arcing, corona discharge and streamering.

Arcing involves an electrically isolated metal component on the aircraft developing a sufficient charge to cause a spark to jump the gap to the rest of the aircraft. Conductive parts are electrically bonded to the primary structure to prevent this, but a failure in the bonding mechanism can cause arcing. Arcing can create an electromagnetic interference that can induce a current in unshielded wiring.

Corona discharge is a luminous and audible discharge, usually from parts of the aircraft such as the antennas, wing tips and windshields to the atmosphere. The windshield discharge is the St Elmo's fire seen by pilots. Static dischargers are installed to control the location and effect of this.

Streamering, also a luminous effect, often involves the charge jumping from one part of the airframe to another due to a change in properties of the surface creating a difference in charge. This is mitigated using conductive coatings, under the thin painted surfaces, bonded to the structure to drain any build-up.

The CVR manufacturer has recreated a pulsing effect, similar to that recorded by the CVR, by applying electrostatic discharges to the CAM system components, suitably interconnected, in a workshop environment. This supports the theory that the source of the problem is outside of the CVR CAM components.

Airframe manufacturer experience with problems associated with static build-up and discharge does not include any previous effect on the CVR and is most commonly associated with an effect on the VHF antenna closest to the problem area. They have committed to working with the equipment manufacturer and the operator to resolve this problem.

TCAS

The Traffic Collision Avoidance System (TCAS) works in association with a Mode S transponder to detect aircraft in the vicinity and assess whether their closure rate constitutes a hazard. TCAS can only assess relative altitudes by comparing the altitude of the onboard air data system with the altitude data which the other aircraft transmits via Mode S. Jumps in altitude translate to increases in calculated altitude rates; TCAS projects this forward in time to assess whether an aircraft conflict is likely. If necessary, TCAS will issue an appropriate instruction to the pilots, known as a Resolution Advisory (RA), to improve the separation between conflicting aircraft.

Two sources of air data are supplied to the Mode S transponders, but only one source is used at a time and they are not compared. TCAS derives its own aircraft altitude from the Mode S transponder. Problems can occur when erroneous data reaches the Mode S transponder due to sensing or data transmission problems.

Analysis

The April 2012 incident began shortly after a bright flash of light, generally associated with lightning. There was no noise that is often associated with lightning strikes and identifiable damage was not found on the airframe. Existing aircraft skin damage may have masked any new lightning damage. Coincidence with the bright flash does not prove causation and it was impossible to be certain that a lightning strike occurred as there are other explanations for unreliable air data indication.

The vertical speed fluctuations shown on the DAR data were not noticed by the pilots. Either this was not displayed on the PFDs or the focus of the crew's attention was elsewhere. The rapid, though spurious, changes in vertical speed triggered a TCAS RA against the aircraft 2,500 ft above. The rapidity of the vertical speed change, without a change in actual altitude, masked the reason for the RA from the air traffic controller. The controller saw G-EUXM as being in compliance with its clearance and clear of other traffic. The pilots verbally acknowledged the TCAS RA within eight seconds of the audio commencing, slightly outside the target for TCAS RA response, but the aircraft remained compliant with the RA at all times.

A TCAS RA is presented both aurally and visually to the crew to give a high probability that they will detect it. This RA did not require the pilots to take any different action and as such the visual aspect may have been less obvious than an RA which required a change of the aircraft's flight path. The RA occurred at a time of high workload and neither pilot detected the digitised "MONITOR VERTICAL SPEED" aural alert. This 'inattentional' deafness is within normal human performance and is why critical alerts should be provided via more than one sense.

In this incident the crew reacted appropriately to a transient unreliable airspeed situation. They maintained the aircraft within known, safe datums which allowed its systems to recover from the initiating event. The crew then made a series of decisions which reduced consequential risk: they selected a hold in VMC, diverted to an aerodrome with better weather than the planned destination and, as the weather changed, prioritised the landing task over supplemental information gathering.

The manufacturer and operator's existing procedures and training worked and the aircraft remained in compliance with its ATC clearance at all times.

The June incident occurred as the aircraft transited the top of developing cloud at a temperature of approximately -50°C. An ice crystal encounter in those conditions seems likely and would have been outside the certification standards for the pitot system, as referred to by the ATSB in 2009. The aircraft remained in a safe condition throughout and the pilots mitigated risk associated with high winds at their planned destination.

Erroneous air data

The data showed periods during which the air data parameters of the three separate systems suffered intermittent errors, but not at precisely the same time. When a system became erroneous, all its main parameters were affected. This indicates errors due to the environment, each system being affected slightly differently.

Problems with the pitot or static probes would affect system Mach calculations, which are used to calculate corrections to other parameters. However, given the altitude errors were small compared to the speed errors, it is likely that the problems were associated with the pitot probes.

The location and time of the problems correspond to weather likely to be associated with ice-crystals, so it is probable that air data errors were due to the affect of ice crystals on the pitot probes temporarily defeating the pitot heat system.

Airbus analysis indicated that for the whole A320 family the current rate of occurrence of two or more pitot probes providing erroneous data is better than that required by the "Major" classification of this failure condition. However, the occurrence rate depends on the period chosen. The operator experienced three temporary erroneous airspeed indication events within a four month period, two on the same aircraft. The previous such event was significantly before this.

Current icing standards are associated with supercooled water droplets and not ice crystals. Airbus testing has shown that the pitot probe designs meet current requirements.

Airbus believed the events were due to ice-crystals and so not covered by the EASA CS-25 icing standards targeted at supercooled water droplets. The only current and relevant requirements that were applicable were the Airbus ice crystal icing requirements.

Ongoing Airbus research, including analysis of other documented events reported by operators, icing wind tunnel testing and flight testing, has highlighted the inadequacies of current icing requirements. When revised standards are agreed, they can inform design discussions with the pitot probe manufacturers.

The first G-EUXM event occurred outside the SAT/Altitude boundary of the Airbus requirement but within the proposed new envelope. The second G-EUXM event occurred at a temperature just outside the proposed revised boundaries for CS-25 and also the total water content boundaries, and so is not addressed by the proposed changes. The fact that there were two occurrences on the same aircraft indicates there may be another unidentified environment, system design or specific aircraft factor.

Testing of the aircraft air data and pitot heat systems found no problems. Airbus did not provide checks other than the AMM tasks for the air data and pitot heat systems, because it associated the two events on this aircraft with the ice crystal issue, not the coincident CVR CAM audio pulsing. At the time of writing, the aircraft has been flying without a recurrence. It is feasible that component removals associated with this investigation resolved an undetected problem, such as component bonding.

The G-EUXC event occurred within the current Airbus requirements relating to ice crystals but also within the boundary of the proposed new requirements relating to both ice-crystals and total water content.

TCAS event

TCAS reacted to the erroneous air data by issuing an RA that was not contrary to the intended flight path and did not create a conflict with another aircraft. The other aircraft did not generate a TCAS RA. However, with different aircraft relative flight paths, a similar error could result in RAs that could induce a genuine traffic conflict.

This consequence of TCAS receiving erroneous altitude data highlights a hazard associated with closely stacked airspace. However, the effect on the altitude data is only temporary, reducing exposure to the hazard.

CVR CAM pulsing

In both events involving G-EUXM, the periods of the CVR CAM pulsing corresponded to weather conducive to electrical charging of an aircraft. In the first event, during the first indication of airspeed upset, the crew observed St Elmo's fire which is a phenomenon caused by build-up of static charge. The crew also observed a nearby lightning flash. These indicate an abundance of electrical charging sources.

Though the aircraft was not reported to have been directly struck by lightning during the reported events, a direct lightning strike had occurred on G-EUXM a few days prior to the first event. However, maintenance action did not reveal any associated problems.

The CVR CAM pulsing effect is not commonly observed, but the circumstances under which it could be observed require that a CVR is removed for replay and that the aircraft has flown through an area of high electrical charge within the recording period (30 minutes or two hours depending on CVR model). This is an uncommon combination.

In this case it is feasible that lightning activity degraded a bonding mechanism resulting in arcing under circumstances of electrical charge build-up, resulting in the CVR CAM pulsing recorded. No evidence of this, or a wider systematic issue, was found.

The airframe manufacturer has undertaken to work with the equipment manufacturer and the operator to resolve this problem, which affects the ability of the CVR to fulfil its intended function.

CVR erasure

CVR erasure is not a common problem associated with accident investigation. No systemic issues were found that required further action to prevent recurrence of CVR erasure.

The most common cause of loss of CVR evidence is over-writing of the recording. In this case the recovery of the CVR recording was significantly delayed but it was not lost or over-written. However, both cases demonstrate that robust CVR preservation procedures are necessary, involving crew when there is no hazard requiring evacuation. The delay to the evidence did not have an airworthiness impact, and these events do not support a further related Safety Recommendation. However, this information has been passed to the CAA for consideration, along with previous AAIB recommendations, when approving operator procedures to meet requirements associated with the preservation of flight recorder recordings.

Conclusion

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.