INCIDENT

Aircraft Type and Registration:	DHC-8-402, G-JECG
No & Type of Engines:	2 PW150A turboprop engines
Year of Manufacture:	2004
Date & Time (UTC):	10 December 2006 at 1930 hrs
Location:	Approximately 10 nm east of Prestwick Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 71
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	56 years
Commander's Flying Experience:	9,950 hours (of which 650 were on type) Last 90 days - 173 hours Last 28 days - 50 hours
Information Source:	AAIB Field Investigation

Synopsis

During flight in icing conditions, the flight crew experienced multiple flight instrument failures which were consistent with icing of the pitot/static probes. Recorded flight data indicated that the standby pitot/static probe heat switch had not been selected ON prior to flight, and the investigation concluded that, in all probability, the remaining two pitot/static probe heat switches had also not been selected ON. Non-standard checklist procedures and distractions may have created an environment in which the selection of the probe heat switches to ON was missed before takeoff, and not detected until after the icing encounter.

History of the flight

The aircraft was scheduled to fly two return flights between Edinburgh Airport and Belfast City Airport, to be operated by the same crew. The incident occurred on the third sector, whilst en-route to Belfast. The flight crew reported for duty at 1515 hrs and, as part of their normal pre-flight activities, checked the meteorological conditions. The weather was forecast to remain generally wet and windy, with extensive cloud and in-flight icing. However, temperatures at ground level were well above freezing.

The first two flights were unremarkable; when airframe icing had been detected, the aircraft's ice protection systems had been used and had functioned normally. The co-pilot had flown the sector inbound to Edinburgh, and was also to be the handling pilot for the flight to Belfast. During the 35 minute turn-round at Edinburgh, he carried out an external inspection of the aircraft, which included a check of the pitot/static probes and angle of attack sensors. No anomalies were noted. During the external inspection there was continual drizzle, with a temperature of 12ºC.

The aircraft subsequently taxied for a departure from Runway 24, with four crew and 71 passengers on board. The commander was handling the aircraft during taxi, as it could only be steered from his seat. During the taxi phase, the co-pilot noticed that an expected annunciation on the Engine Display (ED), regarding the engine bleed air system, was not present and brought this to the commander's attention. After a check of the takeoff configuration warning system, the propeller condition levers were found to be incorrectly set for takeoff. The situation was rectified and the correct indications were obtained on the ED.

The commander then called for the taxi checklist. The co-pilot read the checklist, which included a mixture of 'challenge and response' items as well as 'read and do' items. The crew received a takeoff clearance prior to arriving at the runway holding point, ahead of an aircraft which was on final approach. Takeoff commenced at 1913 hrs.

Precipitation was encountered about 1,000 ft after takeoff and propeller anti-ice was selected ON. The autopilot was also engaged. The crew were given a direct routing towards Belfast, and cleared to climb to FL160 (approximately 16,000 ft amsl). The aircraft encountered heavy precipitation during the climb, and a number of visual checks were made for ice. When airframe ice was seen, the crew switched the airframe icing protection system from MANUAL/OFF to FAST. The crew reported that, at FL100, they checked the altimeter indications, which were normal, and carried out a number of other routine check items. As the aircraft continued to climb, the crew received an ICE DETECTED message on the ED, generated by the automatic ice detection system. No action was necessary as airframe, engine and propeller de-ice systems were already on by this time, though it was noted that the ice build-up was exceptionally heavy on a dedicated and lighted spigot.

As the aircraft approached its cruising level, the crew received an "ALT MISMATCH" alert on their Primary Flying Displays (PFDs), warning of a discrepancy in the displayed altitude. A cross-check of the standby flight instrument display showed that the commander's (left-hand) PFD was showing an erroneous altitude of approximately 150 ft below the co-pilot's PFD altitude. As the autopilot was selected to receive its inputs from the right hand (co-pilot's) instrument sources, the crew were content for it to remain engaged.

The aircraft levelled at FL160, just above a cloud layer. Soon after reaching FL160, the crew began to experience further discrepancies between both indicated altitudes and airspeeds, and observed heavy icing on the aircraft structure. The autopilot then disconnected automatically. The commander's indications of altitude and airspeed decayed rapidly, and were replaced by red failure indications. By selecting the right hand instrument sources to feed his own PFD, the commander was able to restore speed and altitude indications to his display. The Air Traffic Controller handling the flight noticed that the aircraft's SSR Mode C altitude had disappeared from his radar display, and queried it with the crew. In response, the commander requested an immediate descent, stating that the crew were experiencing instrument problems and that he required a descent to clear the icing layer. The crew were cleared for a descent to FL80.

As the descent began, the co-pilot's altitude indication (now displayed on both pilots' PFD as a result of the commander's source selection) appeared to read correctly, but the airspeed indication began to show a deceleration at a rate which matched the decreasing altitude. The co-pilot kept the power levers at the cruise setting as the indicated airspeed reduced, concerned that the aircraft was approaching a stall (he recalled seeing an IAS of 134 kt). Recognising that this was an erroneous indication, the commander intervened and directed the co-pilot to reduce power and to select an appropriate pitch attitude for the descent. Both the altitude and airspeed indications subsequently reduced rapidly and were replaced by red failure indications. Both pilots reported that several amber caution lights illuminated on the Caution/Warning Panel (CWP), associated with the instrument failure indications.

The commander made a 'PAN-PAN' call to ATC, stating that the crew had lost all pressure instruments, and initiated the Emergency Checklist. The controller assisted by providing the crew with groundspeed readouts from his display, and Mode C altitude information, when it became available in the later stages of the descent. Both pilots reported that the standby IAS display also showed a red FAIL indication during the descent, though it was uncertain whether the standby altitude display remained valid.

As the aircraft approached FL80, the PFD altitude indication returned and the co-pilot used it to level the aircraft. Subsequently, the remaining airspeed and altitude indications from both left and right sources recovered to normal. The crew considered a diversion, but it was decided that continued flight to Belfast at the lower level was the best option, given the relatively short distance to Belfast and the reported weather. During discussion between the flight crew immediately after the icing encounter, the co-pilot queried the position of the pitot/static probe heat switches with the commander, and said that he thought they may be OFF. Later, neither pilot could be completely certain whether or not the switches were physically moved at this point, but information from the Flight Data Recorder (FDR) was consistent with the standby pitot/static probe heat switch[1] being moved from OFF to ON, about three minutes after levelling at FL80, having been at OFF since the start of the recording (switches for the left and right pitot systems were not monitored by the FDR). The aircraft landed at Belfast at about 1950 hrs, without further incident.

Meteorological information

A broad warm sector was covering the Edinburgh area at 1800 hrs on the evening concerned, giving extensive layer cloud. A tight isobaric gradient gave rise to reasonably strong winds. Upper air soundings showed the freezing level to be at about 8,500 ft, and the -5ºC level at about 12,500 ft. There was likely to have been large amounts of layered cloud to 12,000 ft, and possibly higher in places. Since the surface temperature at Edinburgh was 12ºC, the aircraft was not considered to be in icing conditions for takeoff.

Although icing is most commonly associated with large convective clouds, layers of stratiform clouds can also contain large quantities of supercooled droplets because such clouds include continuous, if limited, convective activity. Temperature ranges in which airframe icing can be expected are from a slightly positive temperature down to -40ºC, though severe icing rarely occurs below about -12ºC.

Footnote

1 For ease of reading, the term *"pitot/static probe heat switch"* is reduced to *"pitot heat switch"* for the remainder of this report, unless required in full.

Recorded information

Flight data

The aircraft was fitted with a 128 word per second Solid State FDR and Solid State Cockpit Voice Recorder (CVR). The FDR recorded just over 26 hours of operation and was downloaded at the AAIB. By the time the order was made for the preservation of the CVR, data for the incident flight had been over-written.

Engine start was at 1902 hrs. Prior to taxi, the engine condition levers were advanced from the 'START/ FEATHER' position to the '900' position (this commanded a constant propeller speed of 900 rpm). Two and a half minutes later, the Condition Levers were then advanced to 95 degrees (corresponding to the '1020' or 'MAX' position). Analysis of the previous three flights showed that the condition levers were advanced directly from the 'START / FEATHER' position to the 'MAX' position after engine start without an intermediate stop at the '900' position.

Recorded information showed that, just prior to takeoff, the pneumatic de-icing system switch was either in the SLOW, FAST or MANUAL position (individual positions were not recorded). The standby pitot heat switch was OFF, as it had been from commencement of the flight recording[2]. The pitot heater has an associated pitot heat caution light which is illuminated on the CWP based on actual heater current measurement. When there is little or no heater current, the caution light will be on, independent from the switch selection. The previous 21 flights on the recording were checked and in each case the standby pitot switch was recorded ON just after engine start.

Footnote

[2] The FDR records switch position as an open circuit or grounded electrical signal. This signal is also wired to both the Ice and Rain Protection System Timer and Monitoring Unit and the relay which supplies power to the standby pitot heater.

No further parameters from the ice protection system were recorded so that pitot heat caution lights for the No 1, No 2 and standby systems, the position of the No 1 and No 2 pitot heat switches and propeller de-icing were not recorded.

At 1913 hrs takeoff power was applied. As the aircraft was passing 12,200 ft, the ice detection system detected ice, at which point, the Static Air Temperature (SAT) sensor recorded a temperature of -3ºC. Around 20 seconds later, the barometric altitude from the left and right Air Data Computers (ADCs) began to diverge, reaching a difference of 218 ft. According to the aircraft manufacturer, the trigger threshold for the ALT MISMATCH alert is a function of the altitude recorded by the left and right ADCs. At the time of maximum altitude mismatch, the threshold for this alert was 123 ft.

The aircraft levelled at 16,000 ft (FL160), at which time the difference between the two recorded altitudes had reduced to around 50 ft, which was below the ALT MISMATCH threshold. The aircraft was established in cruise flight with the autopilot ALTITUDE HOLD mode engaged. About 50 seconds later, the recorded altitude dropped around 200 ft within 1 second, to 15,800 ft. This then slowly recovered to 16,000 ft.

Just under four minutes after levelling off, the ice detection system again detected the presence of ice. Around 30 seconds later, both left and right ADC altitudes began to fluctuate again. As this occurred, the left ADC calibrated airspeed (CAS) dropped to zero and the autopilot disengaged. About 20 seconds after this, the recorded altitude data from the left ADC dropped to zero ft (Figure 1). The remaining altitude information from the right ADC indicated that the fluctuations then ceased and the altitude recovered to 16,000 ft.

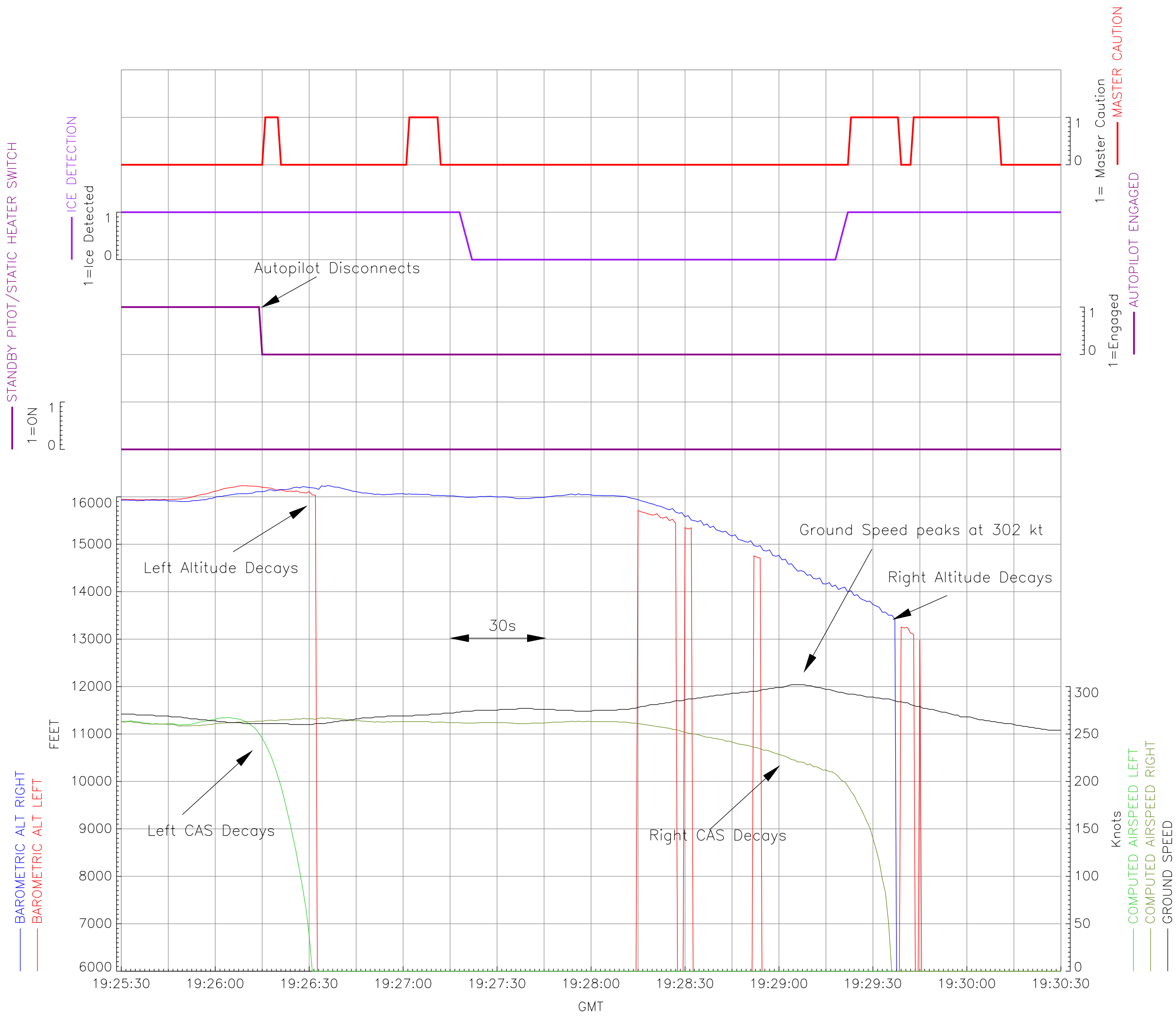

Figure 1

Loss of flight data and aircraft descent

At 1928 hrs, about 6 minutes after levelling at FL160, a descent commenced with a CAS of 263 kt and ground speed of 270 kt. During the descent, the airspeed from the right ADC decreased but the groundspeed increased. Maximum ground speed achieved was 302 kt whilst the airspeed indicated 220 kt. During this descent, altitude data from the left ADC appeared to recover, but for no more than 6 seconds. About a minute after the descent had begun, the CAS from the right ADC decreased further, over a period of 16 seconds, to read zero kt. Two seconds after this, altitude data from the right ADC recovered briefly to read 13,428 ft, but dropped to zero immediately afterwards. Two further recoveries of the left ADC altitude were noted, but again were only temporary.

Altitude data from the left and right ADC was absent from the recording for the next two minutes. The left

ADC altitude data returned at 8,914 ft and, 17 seconds later, the right ADC altitude also returned at the same value as the left ADC (Figure 2). CAS did not recover until nearly three minutes after being lost, as the aircraft was levelling at FL80, with an SAT of 2.75ºC. Both CAS values recovered to within 3 kt of each other and within 30 kt of the ground speed. No further anomalous behaviour was observed with altitude or airspeed for the remainder of the flight.

At 1935 hrs, about 2 minutes after levelling at FL 80, the standby pitot heat switch was selected ON (Figure 2). No parameters from the standby instrumentation were recorded. Stall system outputs remained valid, with no stick shaker or stick push events recorded during the flight. Output from both Angle of Attack (AOA) vanes continued to vary within expected values for the flight conditions.

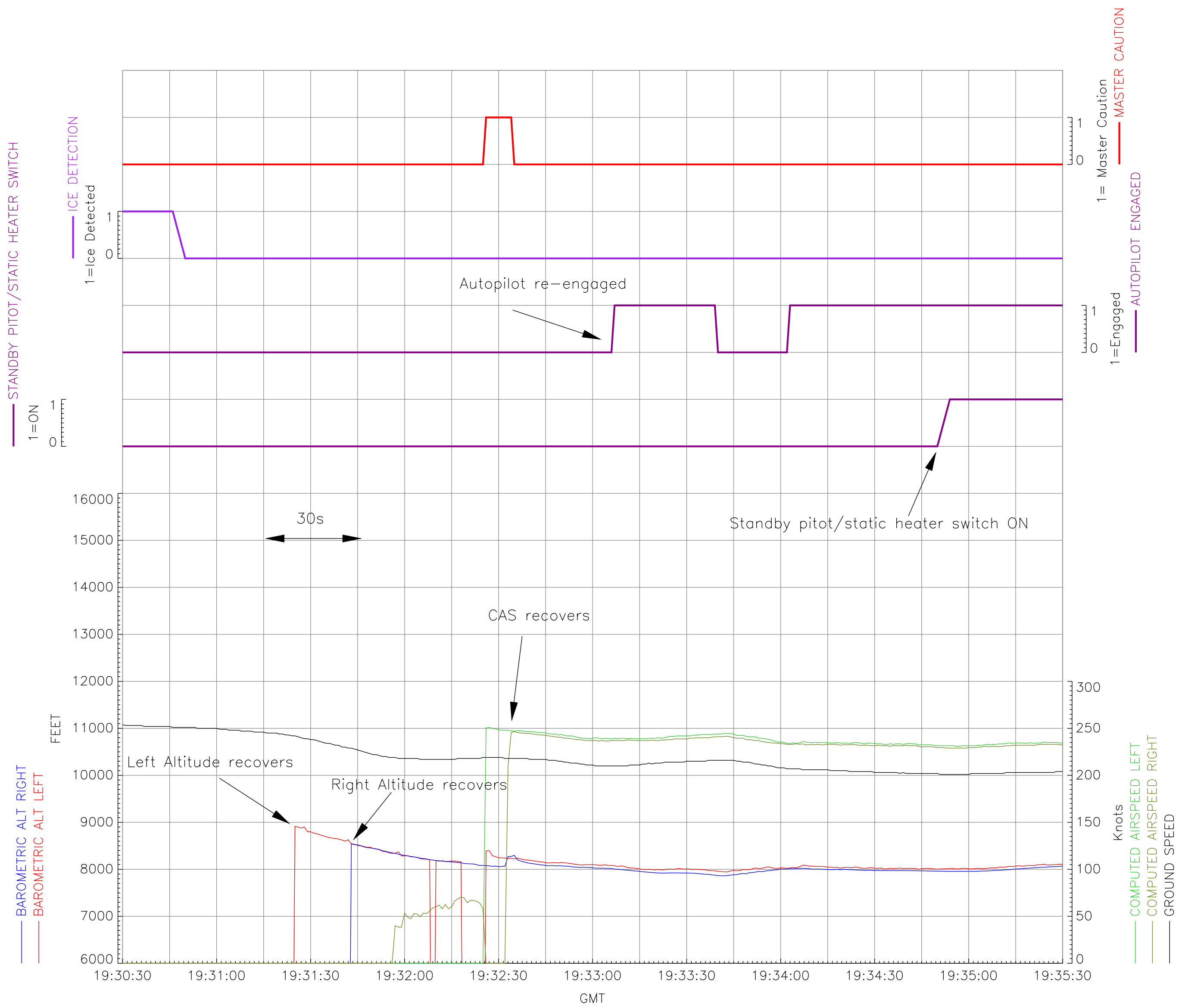

Figure 2

Aircraft level-off, flight data recovery and standby pitot heat switch position

Radiotelephony data

Recorded radio transmissions showed that the crew of G-JECG contacted the Edinburgh Tower controller whilst taxiing as instructed, and were asked to report passing holding point Delta 3 (a short distance before the runway). Forty seconds later the crew reported that they were approaching Delta 3 and were given clearance to line up and take off. There was one aircraft on final approach at this time, which had made an "EIGHT MILE" call before G-JECG was on frequency. Immediately after the co-pilot's acknowledgment of the takeoff clearance, the controller instructed the aircraft on final approach to "CONTINUE THE APPROACH ONE TO DEPART". From the timing of the approaching aircraft's radio call, and assuming it had reduced to minimum approach speed when G-JECG was issued takeoff clearance, it would have been less than 4 nm from the runway as G-JECG lined up for takeoff.

Crew interviews

Initial interviews

The commander and co-pilot were interviewed individually by the AAIB, two days after the incident. Information from the FDR, which indicated that the standby pitot heat switch had been selected to OFF for the majority of the flight, was not available until after the initial crew interviews. However, the co-pilot had already considered the possibility that the pitot heat switches may inadvertently been left off for takeoff, and he raised this at interview.

The co-pilot said that he had developed a routine of completing two checklist items from memory before the taxi checklist was called for by the commander. These were: selection of pitot heat switches to ON and selection of reduced torque for takeoff. The pitot heat switches were an item which the co-pilot was required to action in response to the checklist, and did not require a response from the commander.

The co-pilot said that the issue of the ED indications associated with the incorrectly set condition levers may have presented a distraction, which could have led to the pitot heat switches being left off. Immediately after the engine condition levers had been corrected, the commander called for the taxi checklist, by which time the co-pilot would normally have turned the pitot heat switches ON. There was therefore the possibility that the switches were at OFF on this occasion when the co-pilot read the taxi checklist.

Furthermore, the line-up checklist was carried out as the aircraft was entering the runway, as was usual practice. With another aircraft on approach to land, the co-pilot sensed a degree of urgency to commence the takeoff without undue delay possibly pressurising him to complete the pre-takeoff checklist as soon as possible.

The co-pilot reported that he made the standard call "ALTIMETERS" as the aircraft passed FL100. On this cue, the commander, as "Pilot Not Flying" (PNF), should have carried out certain actions (see '*Checklists and procedures*' section). These would have included turning off the landing lights. However, the co-pilot reported that he turned the landing lights off himself a short while later, and was not certain whether or not the rest of the checks were done, although the commander stated that they were.

Concerning the discussion on the flight deck immediately after the descent to FL80, the co-pilot said that he expressed some doubt as to whether the pitot heat switches were physically selected ON. However, he did not think the associated CWP cautions were illuminated then, or at takeoff.

The commander recalled the issue of the engine condition lever settings, although he thought it had occurred on a previous sector. At initial interview he did not mention the post-descent discussion regarding the pitot heat switches, but did state that he was sure the pitot heat cautions lights were not illuminated at takeoff.

Both pilots reported seeing a number of CWP cautions during the incident, though neither reported seeing the pitot heat system cautions. The co-pilot described "several" cautions, and the captain described between six and ten. They both identified ELEV FEEL plus one or two others on the left side of the CWP, with the bulk of the captions being on the centre/right of the panel. Both mentioned that the majority of the captions were in the general area of the three stall warning system captions, towards the right of the panel; the co-pilot mentioned that stall warning captions may have been among those he saw. However, the crew's Air Safety Report on the incident stated that cautions seen included 'STALL SYSTEM' and 'PUSHER' cautions.

Subsequent interviews

When the FDR data was analysed and the history of the standby pitot heat switch became known, both pilots were asked for further clarification about the discussion immediately after the icing encounter.

The co-pilot felt that the distractions during taxiing could have accounted for missed switch selections. After the incident, he voiced his concern to the commander about the pitot heat switch positions, as they were small and not easy to see at night under reduced flight deck lighting. The commander agreed that there had been some discussion, and that the co-pilot thought the switches might have been off, but the commander thought the switches appeared to be on. Both recalled that the co-pilot had put his hand up to the vicinity of the switches, but the co-pilot was not sure if he had actually moved the switches, and the commander thought that the co-pilot had not done so. Neither pilot thought that any of the associated three pitot heat caution lights had been illuminated on the CWP, though the co-pilot observed that the cautions were on the far left of the panel, furthest from him.

During discussion after landing, the co-pilot had offered the possibility that the pitot heat switches may have been turned off inadvertently by the commander at FL100, instead of the landing lights (which had been left on). The commander rejected this, pointing out that the master caution light would have alerted the pilots if the switches had been turned off in flight.

Engineering investigation

The commander placed the aircraft unserviceable on arrival in Belfast, by making an entry in the aircraft Technical Log. The operator's engineering personnel conducted a water drains inspection, checks of the pitot head heaters, an operational test of the Air Data Computers, a sense and leak test of the pitot/static system and also a complete check of the Central Warning System but no fault was found.

The aircraft was subsequently returned to service and has not suffered any similar or related occurrences, and no other related Air Safety Reports (ASR) or CAA Mandatory Occurrence Reports (MOR) have been raised for this aircraft, either before or since.

There have, however, been a number of occurrences on other DHC-8s within the operator's fleet, involving suspected icing of the pitot/static system. Between 22 October 2006 and 29 December 2006, six ASRs were raised, including one for this incident. Four of these ASRs were raised for incidents on the same day, 29 December 2006, all involving company DHC-8s in the same general area and at the same time. Between 18 August 2006 and 8 December 2007, 13 MORs were raised by the operator, concerning related events.

Bombardier has introduced a set of modifications to improve the drainage of the pitot/static system and reduce the risk of icing of the pitot heads. At the time of the incident G-JECG was fitted with the redesigned pitot/static lines but did not have the modified pitot heads.

Aircraft information

General

The Dash 8-Q400 is a high-wing, twin-turboprop aeroplane manufactured by Bombardier Inc. It is a two-pilot transport category aircraft approved for instrument flight and for flight into known icing conditions. G-JECG carried the manufacturer's Production Serial Number 4098.

Ice protection

Aircraft ice and rain protection includes ice detection, de-icing, anti-icing, and rain removal systems. The de-icing system uses engine bleed air to operate conventional inflatable boot sections installed on the leading edges of the wings, horizontal and vertical stabilizers, and to protect the engine nacelle inlet lips. The anti-icing systems use electrical heating elements to prevent ice formation. The system heats the leading edges of the propeller blades, the three pitot/static probes, two Angle of Attack (AOA) vanes, engine intake flanges, windshields and both the pilot's side windows.

An Ice Detection System (IDS) uses two ice detector probes to actively detect icing conditions. If one or both probes detect more than 0.5 mm of clear ice, an ICE DETECTED message appears on the ED, which remains displayed until icing is no longer detected. There is no flight deck control for the Ice Detection System (IDS), which operates automatically as soon as electrical power is available.

The No 1, No 2 and standby pitot/static probes incorporate integral, electrically powered heaters which are switched on by the flight crew before flight to prevent ice build up. All three pitot/static probes and the AOA vanes are controlled and monitored by separate modules of a Timer and Monitor Unit (TMU). Pitot/static probe heat is controlled by the pitot/static probe heat switches on the ice protection panel on the flight deck overhead panel (Figure 3). The PITOT HEAT STBY, 1, and 2 caution lights on the CWP are illuminated based on the heater current measurement. Normally the switch selection and the heater current will agree. In the case of a heater or wire failure causing an open circuit, the caution light will accurately indicate the status of the heater, ie not being powered, even though the switch may be selected.

The AOA vanes are electrically heated automatically during flight; they do not require pilot selection. There are no CWP caution lights for AOA heater failures. However, if the Stall Protection Module (SPM) senses an AOA heater failure, it causes the PUSHER SYS FAIL caution light to come on, and the applicable STALL SYST FAIL caution light.

Flight deck displays

An Electronic Instrument System (EIS) displays primary flight data, navigation, engine and system parameters on five display units on the flight deck, including both pilots' PFDs and the ED. Critical air data is supplied to the flight instruments by the Air Data System (ADS). In normal operation each pilot receives air data from his own data source: ADC 1 for the commander and ADC 2 for the co-pilot. An ADC source reversion selector

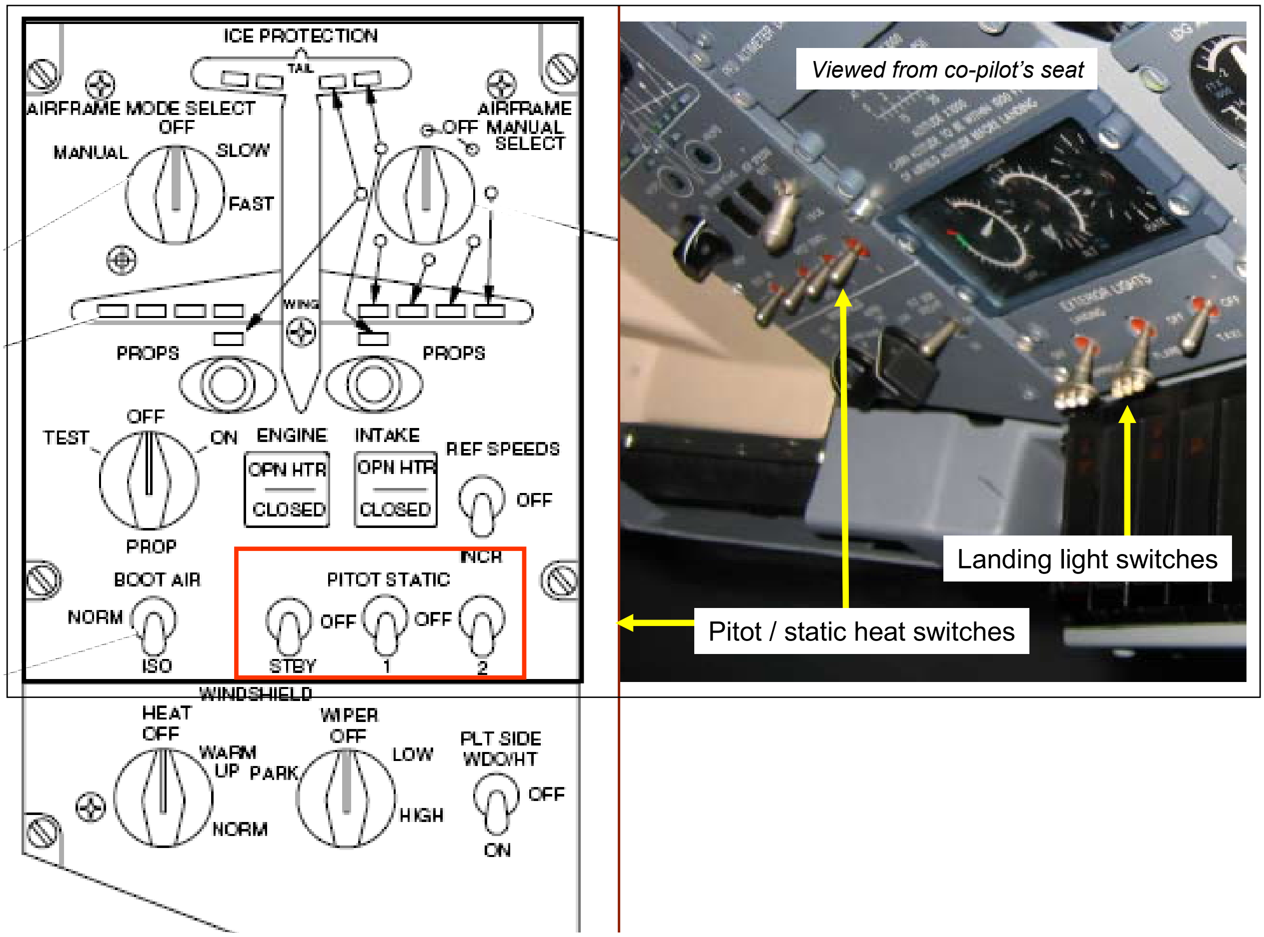

Figure 3

Pitot/Static probe heat switches – panel layout and cockpit view

allows either pilot to select the opposite side air data source to feed his PFD.

Airspeed is indicated on a vertical scale and digital readout on the PFD. A yellow IAS MISMATCH message on the PFD indicates that the two ADC sources are providing IAS values that differ by 10 kt or more. If the airspeed parameter malfunctions, the scale and digital readout are removed and replaced by a red IAS FAIL message.

Altitude is similarly indicated on the PFD by a scale and digital readout. A yellow ALT MISMATCH message appears on the PFD when ADC sources are providing different barometric altitude values. The message appears at a variable threshold, ranging from a difference of 60 ft at sea level to 180 ft at 27,000 ft. In the case of an altitude parameter failure, the indications are removed and replaced by a red ALT FAIL message.

An integrated electronic standby instrument presents airspeed and altitude information in a similar, though simplified, format to that of the PFDs. The instrument operates independently and does not interface with other systems. The standby airspeed and altitude functions are independent of the primary ADS, and receive data from pressure sensors which utilize pressure from the standby pitot/static probe. If a failure in either function is detected by internal monitors, the relevant information is removed from display and replaced by a red failure message.

Central Warning System

The Central Warning System (CWS) monitors aeroplane equipment malfunctions and unsafe operating conditions. Caution and warning lights provide a visual indication to the flight crew of a non-normal condition, and are housed in a Caution/Warning Panel (CWP) forward of the overhead panel. If one on these illuminates, it is accompanied by a MASTER WARNING or MASTER CAUTION light, located at eye-level on the center glareshield, alerting the crew to the non-normal situation. The MASTER CAUTION light is accompanied by a single chime, and the MASTER WARNING light by three chimes. When either the MASTER CAUTION or MASTER WARNING light is pressed, it extinguishes and is reset; if a subsequent fault occurs, the MASTER CAUTION or MASTER WARNING light flashes with the new caution or warning, until either is pressed again. A caution/warning light on the CWP remains on for as long as the non-normal condition exists.

In the case of an IAS mismatch, when the discrepancy reaches 17 kt, the following amber cautions should illuminate:

a) RUD CNTRL (rudder control)
b) ELEVATOR FEEL
c) SPLR OUTBD (spoiler outboard)
d) PITCH TRIM

Each of the three pitot heat switches has an associated caution light on the CWP which illuminates if the systems fails or is switched off (Figure 4).

Documentation supplied by the aircraft manufacturer described failure indications for the aircraft's stall warning system. In general terms, the three cautions associated with the system, NO 1 STALL SYST FAIL, NO 2 STALL SYST FAIL and PUSHER SYST FAIL, illuminated in flight only for failures which inhibited the Stall Protection System (SPS) from computing stick-shaker and stick-pusher commands, such as failures

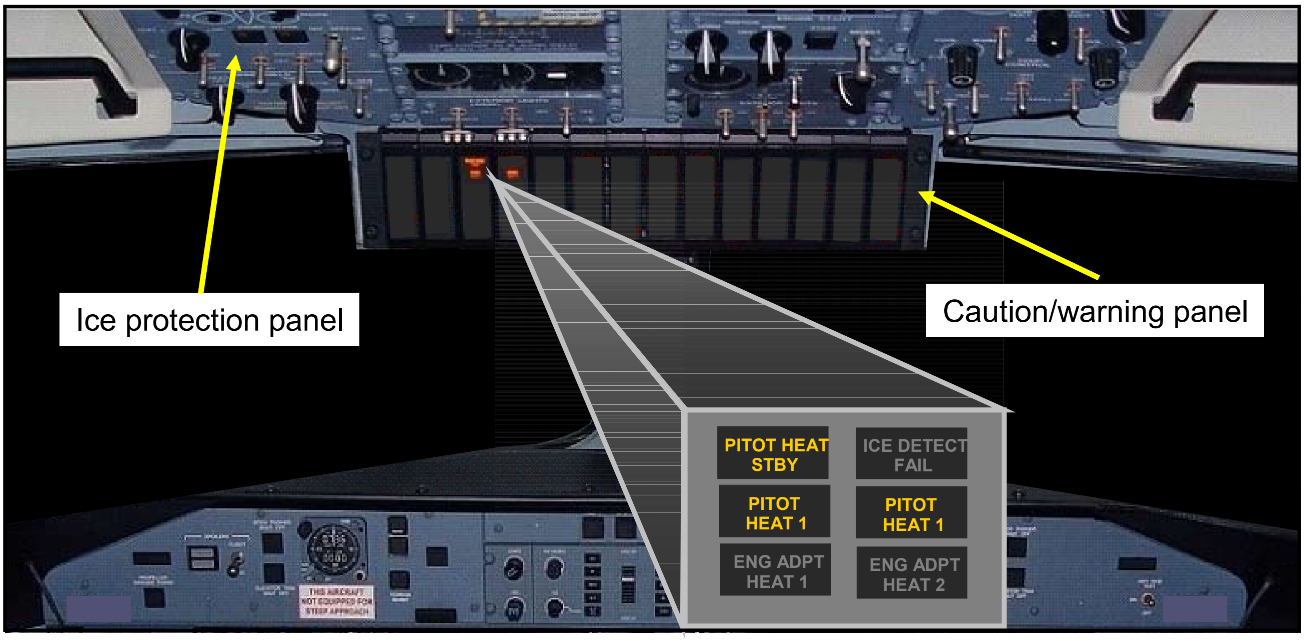

Figure 4

CWP arrangement and pitot/static caution lights

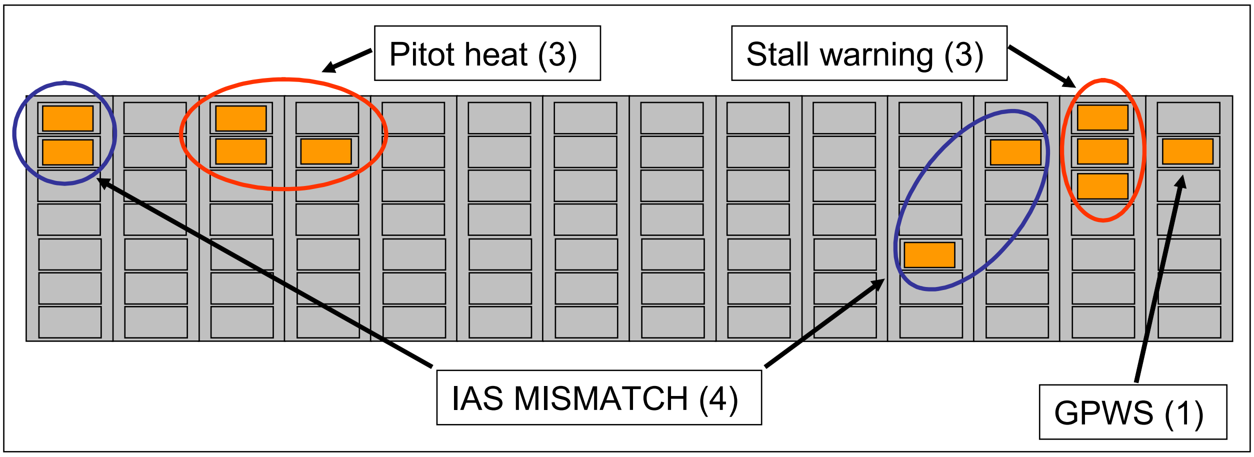

Figure 5

Distribution of CWP caution lights

of the stall protection modules or the AOA vanes. For other, non-critical failures, such as inputs from the ADCs, the SPS would not be prevented from generating a stall warning indication, so the CWP caution lights for such failures would be inhibited until 30 seconds after landing. The failure of both Mach number inputs to the SPS would generate all three cautions only after landing. The distribution of relevant CWP caution lights is shown at Figure 5.

Checklists and procedures

The operator's Operations Manual (OM) included detailed instructions about how various checklist should be completed. In general, checklists were of a 'challenge and response' type, with some exceptions (see below). The 'After Start' checklist included the item:

'Condition Levers……………..MAX'

During taxi, the commander would request the 'taxi' and the 'line-up' checklists, and these were always read aloud by the co-pilot (Figure 6). According to the OM, the co-pilot was required to *'SAY and DO'* the checklist items, with a response only required from the commander for items marked with a '●'. The *'PITOT STATIC'* (taxi checklist) and *'CAUTION WARNING LIGHTS'* (line-up checklist) were among those items not requiring a response from the commander.

Despite the specific instructions that the co-pilot should *'SAY and DO'* the taxi checklist items, the OM also stated that '*set-ups or flows*' preceded certain checklists, including the taxi checklist, and that such flows were performed automatically when the associated trigger was reached. It went on to say that the checklist would then be called for, and that the checklist itself may be the trigger. The trigger for the taxi checklist was not stated, nor was any 'set-up or flow' listed.

The manufacturer's Airplane Flight Manual called for the selection of pitot heat switches in its *'pre-taxi'* checklist only when conditions of slush or wet snow-covered taxiways exist. The switches are normally selected ON as part of the *'pre-take-off'* checklist, a sequence intended to reduce thermal damage of the pitot heads. The manufacturer stated

Taxi Checklist	
• BRAKES................................	CHECK
• TAKE-OFF WARNING TEST.....	TEST
ALTIMETERS..........................	QNH SET
PITOT STATIC........................	ON
•.PWR FOR TAKE-OFF.............	NTOP or RDC..............%
FLT INSTRUMENTS	CHKD
CABIN	SECURE
• ICE PROTECTION..................	AS REQD**
FLYING CONTROLS................	CHECK/ FREE
CABIN CREW.........................	CHIME
• CLEARANCES...........	REVIEWED***
TRANSPONDER/ TCAS...........	ALT/ AUTO/ AS REQD

Figure 6

Taxi and line-up checklists (operator's Operations Manual)

that, at the operator's discretion, in order to standardise procedures, the pitot heat switches may be selected ON in the after-start check for all weather conditions. The operator's OM contained expanded checklists, which contained additional information or guidance regarding checklists. For the taxi checklist item '*Pitot Static Switches*', the expanded checklist included the note:

> *'Under conditions of slush or wet snow covered runways, put on before commencing taxiing'.*

The crew actions required passing FL100 were listed in the OM thus (see Figure 7):

Simulator trial

A full-flight DHC-8-400 simulator was used to study the flight deck environment, and indications experienced by the crew. Areas of particular interest were:

i. Operation and conspicuity of pitot heat switches

ii. Conspicuity of pitot heat caution lights at various stages of flight

iii. Lighting conditions

EVENT	PF	PNF
FL 100	***"Altimeters"***	***"Passing FL … climbing FL …"*** Land / Taxi Lights …. OFF Fasten Belts ……… As reqd by Captain Checks: Pressurisation, Anti-icing, Cabin Temp

Figure 7

Operations Manual crew action required passing Flight Level 100

iv. Flight instrumentation in normal and degraded/failure modes

v. Behaviour of sub-systems after ADC failure/icing events

vi. Ergonomic and human factors considerations

The pitot heat switches were grouped together on the icing panel immediately above the commander's head. The switches were not large, and their throw was not great, such that it was difficult to be certain, when viewing the switches in isolation from either seat, whether they were all ON or all OFF. This was particularly true from the co-pilot's seat, looking up and across the panel (Figure 3), and even more so in low lighting conditions. However, this was only true when all the switches were in the same position: if one switch was in a different position from the other two, the fact was more obvious.

The three pitot heat caution lights were grouped together on the left side of the CWP. As expected, the cautions appeared obvious when illuminated together on an otherwise dark panel. However, it was noted that the CWP itself was not naturally in the line of sight of either pilot when seated correctly at the controls looking directly ahead or down at the flight instruments. While taxiing the three pitot heat cautions could be illuminated but not obvious to either pilot. Once airborne, it was felt that the three cautions, if illuminated, would be noticed by the crew as they looked up to action items on the overhead panel, such as turning off the landing lights. The visual impact made by the cautions themselves when the CWP was set to its night DIM setting was, to a limited extent, dependent upon the level of flight deck lighting selected by the crew. Overall, the pitot/static caution lights were generally less noticeable from the co-pilot's (right-hand) seat position.

The level of light returned from the landing lights when flying in cloud was felt to be accurately simulated, and this tended to lessen the impact of CWP cautions at the DIM setting. Switches for the landing lights were just above the left part of the CWP. Although looking at these switches would have brought CWP pitot/static cautions into line of sight, a qualified instructor on type (who was assisting during the detail and who also conducted training for the operator's flight crews), noted that it was common for the light switches to be selected by feel only, being the only switches of that type in that part of the overhead panel. The pressurisation system panel was immediately above the landing lights, and it was noted that, unless the overhead panel lighting was set unusually dim, considerable light escaped from the dials within the indicator panel. When the pitot/static lights were illuminated, their conspicuity was reduced slightly by this effect when viewed from the commander's seat.

A number of instrument and ADS failure/icing scenarios were examined. It was noted that the IAS MISMATCH message appeared at about 10 kt IAS discrepancy, accompanied by autopilot disengagement. When outputs from ADC 1 were failed, the amber cautions RUD CNTRL, ELEVATOR FEEL, SPLR OUTBD and PITCH TRIM illuminated, with the MASTER CAUTION light and chime, as expected. It was not possible to simulate a failure of both ADCs, but a simultaneous ADC 1 failure and simulated icing of the right pitot/static head did not produce additional CWP cautions. The caution lights were spread evenly on the CWP with two on the left and two on the right. If pitot/static cautions were also illuminated, the majority of captions were on the left of the CWP.

No stall system cautions illuminated during the simulator 'flight' until after landing, at which point NO 1 STALL SYST FAIL, NO 2 STALL SYST FAIL and PUSHER

SYST FAIL cautions illuminated (on the right side of the CWP). This was consistent with information from the manufacturer regarding failure of ADC inputs to the stall warning systems.

With the engine condition levers advanced to the "900" detent, the engine rating mode annunciation on the ED showed "MCL" (maximum climb rating) for each engine. The levers were considerably further aft (more vertical) than the fully forward, 'MAX' position. At the 'MAX' position, the ED displayed "NTOP" (normal takeoff power) and "BLEED" annunciations (with engine bleed selected on).

The type rating instructor who assisted with the simulator trial reported that he had encountered instances of crew's omitting anti-icing system selections in error on the ground (particularly the pitot heat switches), and becoming airborne with the system(s) selected off. This was not common, but was usually associated with an abnormal level of pressure or distraction as can be generated in a flight simulator. He commented that he had not seen this happen when crews exercised the correct level of checklist discipline. On the subject of conspicuity of CWP cautions and fields of view, the same instructor reported cases in the simulator of crews taxiing the aircraft with a red engine oil pressure light on the CWP which had failed to extinguish after start, because the warning light was not in their natural field of view during the taxi phase (the MASTER WARNING and MASTER CAUTION 'attention-getting' lights on the glareshield would not illuminate in this case, as the CWP lights had remained on since engine start).

Operator's safety action

The operator conducted an internal investigation into the incident. Whilst it was noted that standard operating procedures had not been followed at all times, the report made a number of internal recommendations, which were under consideration at the time of writing. These included moving the pitot/static probe heat switch selections to the *'After start'* checklist, and requiring that fault diagnosis in the event of a failed takeoff configuration test should be carried out with the aircraft stationary. The second item was intended to eliminate possible distractions and pressures which may have played a part in this incident. The report also recommended making the CWP check before takeoff a 'challenge and response' item.

Analysis

A number of superficially similar events had been recorded in both the company's ASR system and also by the CAA MOR system. These other events probably involved icing of the pitot/static system although the possibility of the pitot/static anti-ice system not being selected ON is not raised in any of them. None of these other events is associated with G-JECG. Although the co-pilot had himself raised the possibility that the pitot heat switches were left OFF for take-off, both pilots thought that they would certainly have noticed if the CWP caution lights had been illuminated before the incident. They must have believed that the cautions were not on, since otherwise they would not have commenced takeoff. However, FDR data showed that the standby pitot heat switch remained OFF until a point in the flight when a discussion about the switch positions occurred, about which point it was selected ON. Although neither pilot reported being certain that the switch was moved, the FDR data showed that it was.

The possibility of an erroneous FDR signal for the standby pitot heat switch was considered, and it is acknowledged that the FDR signal records only either an open or ground circuit based on the switch position. However, FDR data from the 21 previous flights showed the switch being operated at the correct phase of flight, and it continued to show operation in the correct sense after this incident. Additionally, the recorded in-flight switch movement occurred at a point in the flight when the co-pilot raised doubts about the position of the pitot heat switches and, by his own report, may possibly have moved them. Given the generally high level of confidence in FDR data together with the continued correct functioning of the standby pitot heat system on earlier and subsequent flights, it was concluded that the FDR signal relating to the standby pitot heat switch was valid.

The pitot heat switches were normally selected either all ON or all OFF; it would be an unusual event to move a single switch in isolation, either in flight or on the ground. This, combined with the fact that a single switch out of position is more likely to have been noticed, strongly suggests that all three pitot heat switches were OFF for the majority of the flight, and therefore turned ON at the same time, a scenario that is supported by the recorded air data, though not by the crew's accounts. The view of the investigation team was that all three pitot heat switches were in the OFF position from before takeoff until after the descent to FL80.

The fact that neither pilot could be absolutely certain about whether the pitot heat switches had actually been moved after the incident may be due to the stress of the situation. Although the crew did not recall seeing any pitot heat cautions on the CWP, the probability of them all not illuminating with the switches at OFF is extremely low. It would have required independent systems to each have simultaneous undetected faults which did not affect other CWS cautions. Furthermore, the faults would have to be temporary, and affect only the very flight on which at least one of the pitot heat switches was known to have been left OFF for takeoff. Therefore, it was considered that the three pitot heat caution lights were illuminated on the CWP from before take-off until after the descent to FL80.

During the post-incident discussion between the pilots, reference was made to the position of the pitot heat switches, and, from the FDR, at least one was actually moved from OFF to ON. It is unlikely that reference was not made to the CWP cautions at the same time, if there was any doubt about the switch positions. As at least one pilot reported the *possibility* that a switch was moved, and both pilots reported that the associated pitot heat caution lights were not illuminated, it may be expected that a measure of doubt existed at that time about the integrity of the CWP (although neither pilot expressed such a doubt). However, there was no reported attempt to 'troubleshoot' this by, for example, simply cycling a pitot heat switch, nor was any report made by the crew, after landing or since, about the reliability of the CWS.

The co-pilot's routine of selecting the probe heat switches before the checklist called for this action probably contributed to the incident, though it was by no means the only factor. Although he recognised that this was not the correct checklist discipline, it should be noted that the operator's own OM did contain somewhat conflicting guidance in this respect, in that it referred to a *'set-up or flow'* which preceded the taxi checklist, though none was listed. On this occasion the co-pilot was distracted by the incorrect ED indications, such that when the commander called for the taxi checklist, the co-pilot had not completed his own memory items. This created the potential for an act of omission: the co-pilot had become used to responding to the checklist item *'PITOT STATIC'* with the knowledge that he had already moved the switches, and therefore probably did so on this occasion without positively checking the switches or CWP caution lights.

The taxi route to the runway was quite short, and the crew received a line-up and takeoff clearance before reaching the normal runway holding point. With another aircraft on final approach, there was an element of time pressure (at least from the co-pilot's perspective) to become airborne expeditiously. As the commander was taxiing the aircraft, there had to be a hand-over of control on the runway, probably soon after the co-pilot read the last of the line-up checklist items, which was '*CAUTION WARNING LIGHTS.....CHECK*'. This CWP check either did not occur or was ineffective, and this was not noticed by the commander. The handover of control may have interfered in some way with the co-pilot's normal method of checking the CWP, and was probably also influenced by the aircraft on final approach, awaiting a landing clearance.

Simulator trial

The simulator trial showed that it was possible to taxi the aircraft with CWP cautions illuminated but with neither pilot aware of the fact, unless either a deliberate scan was made of the CWP or the pilot's attention was directed to the forward overhead panel area. The position of the probe heat switches in the checklist sequence meant that it was normal on *every* flight (unless taxiways were contaminated) to taxi with the probe heat cautions illuminated (ie probe heat switches OFF). It is difficult to say whether this fact may have had a bearing on this incident, but it is important to stress that a correct and disciplined use of the checklist should alert the flight crew to the fact before takeoff. However, the operator was considering moving the probe heat switches to the after-start checklist as a direct result of this incident.

Central Warning System

Both crew members described a number of CWP cautions illuminating; the commander put the figure at between six and ten, and the co-pilot "several". Out of 84 amber caution lights on the CWP, four are directly associated with an IAS mismatch and three are associated with the stall warning system. Additionally, a GPWS light indicates an invalid or defective ground proximity warning computer; this system receives inputs from ADCs 1 and 2 and generates ground proximity warnings when the aircraft is between 50 ft and 2,450 ft radio altitude. This is the only caution, other than the seven previously mentioned, that monitors a system which receives an IAS or barometric altitude input. However, the GPWS caution does not illuminate for IAS mismatches.

Both pilots indicated that the majority of CWP cautions were toward the right of the panel, but such a spread of cautions appears to be dependent upon illumination of the stall warning cautions. However, the stall warning cautions would not illuminate in the air for an IAS mismatch or loss of ADC inputs, such as associated with this incident. Instead, this would require failures that would render the stall warning systems incapable of generating their respective warnings. In an icing scenario, this would most likely be a loss of information from, or loss of heating of, the AOA probes, although these were heated automatically as long as electrical power was available.

The FDR confirmed that AOA information remained valid throughout the flight and that the stall warning system outputs remained valid. It was therefore the view of the investigation team that the stall warning cautions, if they illuminated at all, did so only after landing at Belfast. There was therefore the possibility that the crew may have noted the cautions on landing and later incorrectly recalled them as having illuminated in flight. It was concluded that only four CWP cautions probably illuminated during the incident, as a direct result of the IAS mismatch (the autopilot disconnect warning light was separate from the CWP). These were spread equally between left and right sides of the CWP panel. If the probe heat cautions are added, this makes a total of seven which matches each pilot's estimate, though the bulk of them would clearly be on the left side, not the centre/right as the crew recalled. It was not possible to reconcile the differences between the crew's reports and the other information available to the investigation, including the recorded data, information from the manufacturer and observations during the simulator trial.

Flight crew effectiveness

The incident would have been disorientating and confusing and the crew were faced with a serious loss of flight instrumentation. However, there are a number of aspects which suggest that the flight crew were, at times, not working together as effectively as possible, although the reasons for this are not obvious. It is quite likely that the crew's workload was one factor in their performance. There were undoubtedly distractions and pressures during the taxi and early takeoff phase, as well as the matter of monitoring the icing and general poor weather situation during the climb.

It is known that the after-start actions were not fully completed at first and that the challenge and response item in the after-start checklist was completed without an effective check by either pilot of the condition levers or the ED indications. Despite the crew's recollections, the probability is that the checklist was completed incorrectly resulting in the probe heat switches being left at OFF. Then, before takeoff, a critical check of the CWP was ineffective and the aircraft subsequently became airborne with flight critical systems not operating.

The check items at FL100 were not fully completed by the commander. As these included a check of the pressurisation and anti-icing systems, and inspection of these panels should also have brought the relevant part of the CWP into view, it may be concluded that the FL 100 items were not carried out by either pilot. One effect of this was that the aircraft continued to climb for a short while further with the landing light glare reflected from the cloud, continuing to reduce the conspicuity of the probe heat lights which were selected to the night 'DIM' setting.

Manufacturer's procedures

It is desirable to minimise a flight crew's workload during the taxi phase, and some other aircraft manufacturers elect to switch on the pitot heat switches prior to taxi. In this case, the manufacturer had a specific reason for delaying the pitot heat switch selections (unless required for environmental considerations), namely the avoidance of thermal damage to the pitot/static probe heads. This procedure was reflected in the operator's OM, and the flight crew had been correctly trained in such procedures. These established procedures provided two formalised opportunities for the pitot heat switches to be checked prior to takeoff.

Contributory factors

A combination of non-standard use of the checklist, distraction on the flight deck and external pressure contributed to the aircraft taking off with the pitot/static probe heat switches incorrectly selected OFF. A high workload during the climb in poor weather and heavy icing conditions probably contributed to further missed checklist actions, such that the aircraft climbed to its cruising level without the omission being noticed. The resulting instrument failure indications and subsequent recovery of information were consistent with the probe heat switches being OFF until after the incident had occurred. The position of the CWP meant that, under specific circumstances, it may not have been readily obvious to the crew that pitot heat caution lights were illuminated.

Flight crew response

Although the crew were consulted during the investigation and the report production process, they expressed concerns about the views contained in the analysis of the facts in this report. In particular they were concerned about reliability of the FDR data in determining the physical position of the standby pitot heat switch. Furthermore, they felt that insufficient weight had been given to their recollection of events. The conclusions in this report however, recognise that anomalies and discrepancies existed in the crew's accounts, which were difficult to reconcile with recorded and other information.