SERIOUS INCIDENT

Aircraft Type and Registration:	DHC-8-402 Dash 8 Q400, G-JECR
No & Type of Engines:	2 Pratt & Whitney Canada PW150A turboprop engines
Year of Manufacture:	2006 (Serial no: 4139)
Date & Time (UTC):	15 November 2018 at 0807 hrs
Location:	Exeter Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 35
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	7,200 hours (of which 5,800 were on type) Last 90 days - 156 hours Last 28 days - 49 hours
Information Source:	AAIB Field Investigation

Synopsis

Whilst climbing to FL190 en-route to Charles De Gaulle Airport, Paris the pilots received an ALT MISMATCH message and they elected to return to Exeter Airport. Following an inspection after landing, a small white crystalline deposit was found covering three of the four static pressure holes on the left primary pitot static probe. It is probable that the use of a non-approved product, to improve the seal between a test adaptor and the pitot static probe during maintenance immediately prior to this flight, may have resulted in the blockage of the static holes and led to the ALT MISMATCH message. Two Safety Recommendations have been made; one to the air data accessory kit manufacturer and one to the aircraft manufacturer to improve the instructions for the use of testing kits when carrying out leak tests of the pitot/static system and to only use approved lubricants. The maintenance organisation has taken Safety Action to introduce tighter controls on the test kit equipment.

History of the flight

Prior to the incident flight, the aircraft had been undergoing a standard maintenance check at the operator's maintenance facility at Exeter Airport. This activity included cleaning and leak checks of the pitot static system. The aircraft was released for service on the morning of 15 November 2018.

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The first flight, on that morning, was planned from Exeter to Charles de Gaulle Airport, Paris. The weather conditions were benign with a temperature of approximately 9°C. The commander completed a pre-flight walkaround of the aircraft and did not observe anything unusual. The aircraft pushed back from the stand at 0706 hrs. The pushback, engine start, and taxi were all normal. The pitot heat was selected ON as the aircraft entered the runway in accordance with the operator's standard procedures. The takeoff roll was uneventful and the 80 kt airspeed cross check did not reveal any discrepancy.

At approximately 500 ft aal, an ALT MISMATCH message briefly appeared on the primary flight display. The flight crew reduced the rate of climb whilst they discussed the message. The mismatch message reappeared intermittently throughout the climb. The aircraft levelled off at FL190, where the flight crew recall the commander's altimeter showed 18,860 ft, the co-pilot's altimeter showed 19,000 ft and the standby altimeter showed 18,920 ft. The airspeed was consistent with the aircraft's pitch and power setting but, the two primary airspeed indications showed a 3 to 4 kt difference.

The ALT MISMATCH message continued to appear intermittently at FL190. The flight crew actioned the appropriate QRH drill and decided, in consultation with the operator, to return to Exeter Airport. The subsequent descent, approach and landing were uneventful.

Recorded information

The aircraft was equipped with a two-hour CVR, a 25-hour FDR and a wireless Quick Access Recorder (QAR) system. The QAR recorded the same data as the FDR. Significant parameters recorded by the FDR included the altitude and airspeed parameters from Air Data Unit 1 (ADU1) and Air Data Unit 2 (ADU2). Information from the standby altitude and standby airspeed indicator was not recorded.

The FDR and QAR provided a complete recording of the incident flight. However, by the time the operator became aware that the CVR was required by the AAIB, the incident flight had been overwritten. The CVR recording provided some useful information on the post incident ground inspections to diagnose the fault.

Analysis of flight data for the incident flight indicated that shortly after takeoff the altitude from ADU1 under-read the altitude from ADU2 by about 50 to 60 ft, but as the aircraft climbed the altitude difference varied between 20 and 70 ft. During this same period the airspeed from the ADU1 under-read the airspeed from the ADU2 by about 3 kt.

When the aircraft levelled off at FL190, the altitude from ADU1 under-read the altitude from ADU2 by about 140 ft, and the difference between the ADU1 and ADU2 airspeeds remained at approximately 3 kt. The cruise airspeed was then reduced from about 230 to 190 kt, at which point the ADU1 and ADU2 altitude difference reduced to about 100 ft.

As the aircraft descended for the approach, the altitude difference between ADU1 and ADU2 reduced to about 20 ft and the airspeed difference increased briefly to 5 kt.

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A review of previous flights of G-JECR, and data from other aircraft of the same type, indicated that during the climb it was normal to see a difference in altitude between ADU1 and ADU2 of 20 to 30 ft. This then reduced to less than a few feet in the cruise and to an average of about 5 ft during the approach. The difference between ADU1 and ADU2 airspeed during the climb and cruise was about 1 kt and during the approach, this could increase to about 3 kt.

The FDR also provided a recording of the post incident ground tests. This showed that when the altitude was set to about 10,000 ft, ADU1 overread ADU2 by 40 ft, at about 20,000 ft, the difference increased to 100 ft, and at about 30,000 ft the difference was 120 ft.

Aircraft information

The De Havilland Aircraft of Canada Ltd Dash 8 Q400 is a high wing regional airliner powered by two turboprop Pratt & Whitney Canada PW150A engines.

Pitot static system

The two functionally independent ADUs use inputs from a variety of sources to calculate parameters such as altitude, indicated and true airspeed, and temperature. Two such inputs are static and total pressure which are sensed by the pitot static probes installed on the front of the aircraft. There are two primary pitot static probes located on the left and right side of the nose fuselage, linked to ADU1 and ADU2 respectively, and a third pitot static probe on the right side of the nose fuselage linked to the standby instruments (Figure 1).

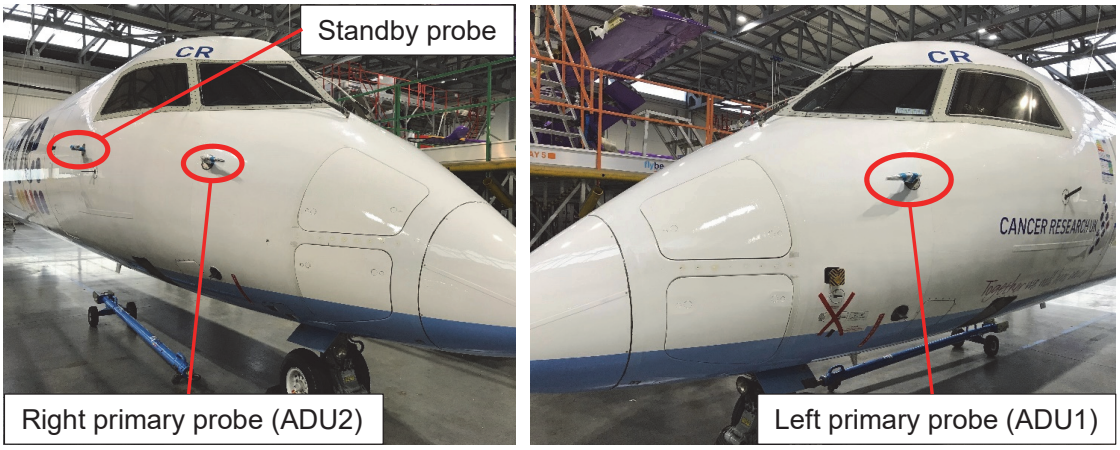

Figure 1
Pitot static probe locations

Pitot, or total pressure, is measured by the forward-facing hole, and static pressure by four 1.5 mm diameter holes on the side of the probe (Figure 2).

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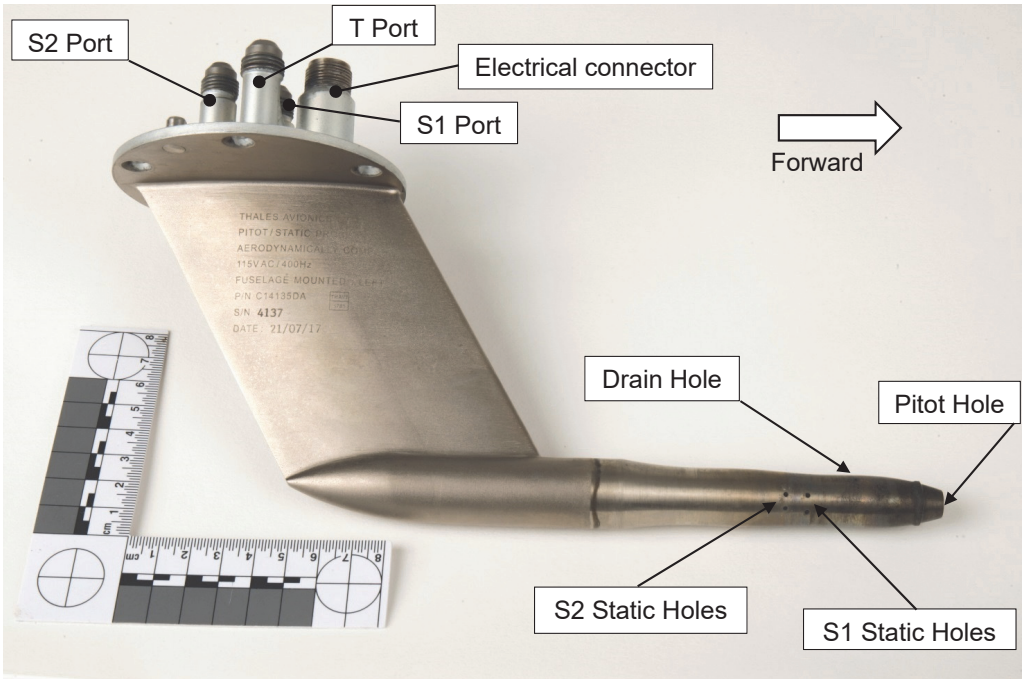

Figure 2

Left primary pitot static probe

The two primary pitot pressures (T1 and T2) are fed directly to the respective ADU, whereas the static pressures from the two static holes from each primary probe are averaged (S1 and S2) and fed to each ADU to minimise any sideslip effect (Figure 3).

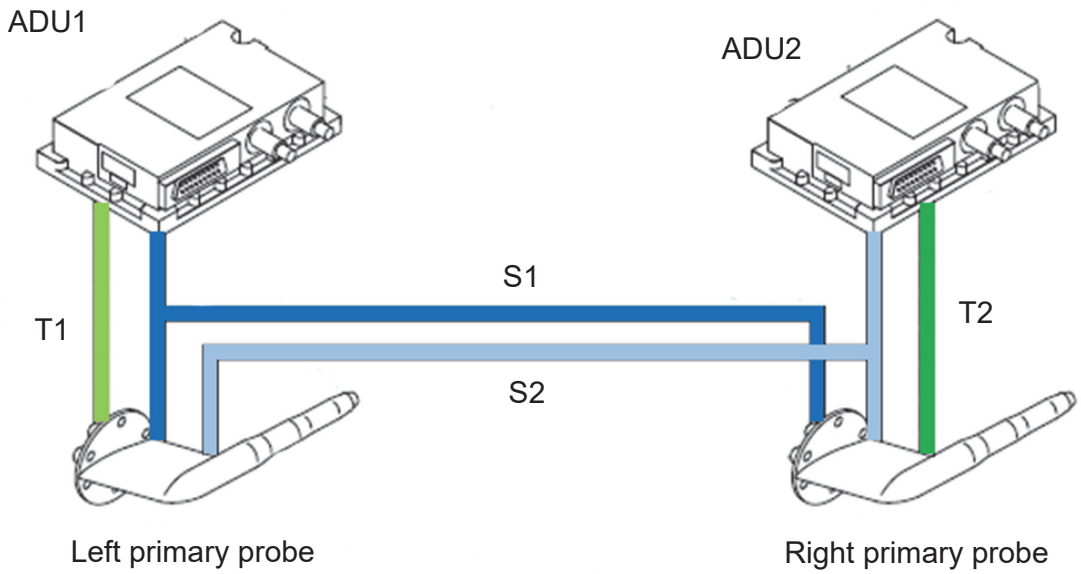

Figure 3

Pitot static system

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In normal operation all three altimeters should read similar values. The aircraft manufacturer defined the tolerances for the difference between the two primary altimeters as 60 ft on the ground, increasing to 180 ft at 27,000 ft (FL270) and is 140 ft at 19,000 ft (FL190). When there is a difference greater than these values between the ADU altitudes for more than one second, the ALT MISMATCH message appears on the PFDs.

Aircraft examination

Post flight troubleshooting

Following the incident flight, the aircraft was inspected on the ground and white '*crystallised deposits*' were reported to be covering three of the four static pressure holes on the left primary pitot static probe (Figure 4). The deposits were lightly adhered to the surface and were removed by a technician but were not retained for further analysis. The right primary and standby pitot static probes were clear of deposits, and the pressure pipes from the probes to the ADUs were cleaned in accordance with the Aircraft Maintenance Manual (AMM) with nothing significant found. Functional and leak checks were also performed with satisfactory results in accordance with the AMM after the deposit had been removed.

Left pitot static probe

The left pitot static probe was removed from the aircraft and inspected under laboratory conditions to characterise any remaining residue. Samples of a range of products available in the maintenance facility were selected as potential candidate materials to aid identification of any residue found (Table 1).

Product	Description	Comments
Lubricating fluid LF5050	Liquid, equal mix of glycol and water. Does not contain fluorine or silicon.	Supplied in the Air Data Accessory kit.
DC4 compound	Semi-solid material, silicone containing grease. SEM-EDX confirms silicon present.	Mentioned during interviews.
Petroleum jelly	Semi-solid material, mix of hydrocarbons. Does not contain silicon or fluorine.	Reported at the time of event notification.
Swagelok Snoop	Liquid, predominantly water with a surfactant[1]. Does not contain silicon or fluorine.	Found in the air data accessory kit.

Table 1

Samples of available materials for analysis

Footnote

[1] A surfactant is a compound that lowers surface tension and in this case acts as a foaming agent.

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Examination

Under microscopic examination trace amounts of a white residue was visible around the two aft and the inboard forward static holes (Figure 4). Inside the outboard rear static hole enough residue remained to allow for a sample to be taken for chemical analysis. No holes were fully blocked. A videoscope was inserted into all the probe holes and no blockages were observed, with only trace amounts of environmental debris found.

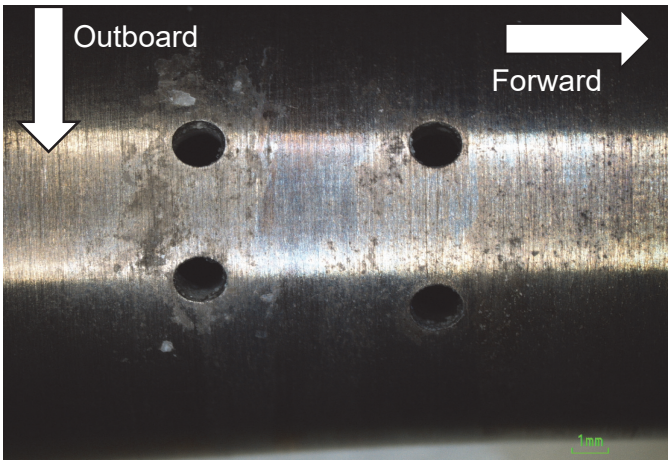

Figure 4

Left pitot static probe – note white residue inside static holes

Fourier Transform Infra-Red (FT-IR) spectroscopy and Scanning Electron Microscopy with semi quantitative Energy Dispersive X-ray (SEM-EDX) spectroscopy were used to chemically characterise the recovered samples and the candidate materials. The SEM-EDX analysis of the residue samples showed elevated levels of silicone and fluorine along with other lower levels of inorganic elements which could be associated with a lubricating product such as a grease. The presence of lower levels of inorganic elements suggest environmental material had collected over a period of time.

Air data accessory kit

Description

To perform functional and operation checks of the pitot static system, including a leak test, it is required to connect the pitot static probes to an air data test kit. The air data test kit enables air pressures to be applied to the static and pitot holes of the probe to simulate various altitudes in flight. They are used on several aircraft types.

The air data accessory kit includes all the aircraft type specific items required to make the connection to the air data test kit and is supplied by a specialist company. The air data accessory kit comprises three pitot static probe adaptors (left primary, right primary and standby), pneumatic hoses, three pre-test probes and lubricating fluid LF5050 (Figure 5).

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Figure 5

Air data accessory kit

The primary pitot static probe adaptor is a machined aluminium tube which is slid onto the pitot static probe and has three hose connectors; one for pitot pressure [13], and one each for static pressure S1 and S2 [14] (Figure 6). Internally, there are seals [4, 8, 9 & 10] to enable the separate parts of the system to be tested and a knurled locking sleeve [2] to compress the seals onto the probe. A glycol and water-based lubricant (LF5050) is also supplied to aid installation.

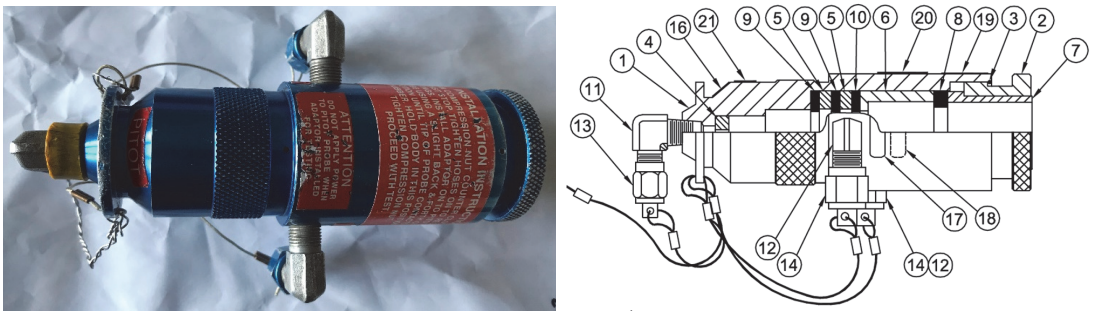

Figure 6

Primary pitot static probe adaptor

Examination

The air data test kit used during the preceding maintenance period was checked and verified to be within calibration limits. The air data accessory kit used on the incident aircraft during maintenance prior to the incident flight was subjected to a visual and microscopic inspection which revealed the probe adaptors seals to be in good condition with no significant amounts of residue inside. However, a trace amount of material was recovered from the first seal

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of each adaptor and the FT-IR results showed that it was a type of petroleum product, with the SEM-EX results showing elevated levels of silicone that were not consistent throughout the sample. There was evidence of damage to the knurled finish on the locking sleeves of all the adaptors.

In service use

To understand how the air data accessory kit is utilised in the maintenance organisation the 'varieties of human work' concept, as described by Shorrock (2016)[2], was used. The concept breaks down human work in to four varieties: work as imagined, work as prescribed, work as disclosed and work as done. This concept provides a framework to analyse a maintenance task, and the differences between the four varieties are often indicative of missing or incomplete safety barriers.

'*Work as imagined*' is the prediction by the manufacturer of the air data accessory kit of how a maintenance organisation will connect and use the equipment. It will be based upon their previous knowledge of working practices and will be written in general terms as it will be used in many different organisations.

The technical information guide supplied with the air data accessory kit contains a description of all the individual components and a brief explanation of when each one should be used. No detailed instructions for use are included as it is the expectation of the kit manufacturer that this should be documented in the AMM. It does however include a recommendation to apply a small amount of LF5050 to lubricate the seals of the adaptor and thereby '*insuring a smooth installation*' onto the pitot static probe.

The kit manufacturer also recommends that hand tightening the knurled locking sleeve is sufficient to enable a good seal, however this information is not included in the guide. They also stated that they have never received any feedback from operators on issues using the air data accessory kit.

'*Work as prescribed*' is the formalisation of a task or piece of work (in this case a work order). It is often written by those not involved in the accomplishment of the task and it is often viewed as the right or safe way to complete the task.

During the maintenance check prior to the incident flight, a work order was raised to clean the aircraft pitot static pipes. The work order stated to perform a leak test of the main system in accordance with Aircraft Maintenance Manual (AMM) task 34-11-00-790-801 and then to repeat the leak test after the cleaning has been completed. The AMM task details the procedure to follow for the leak testing of the system including precautions, set up, required tools and the test procedure.

Footnote

[2] https://humanisticsystems.com/2016/12/05/the-varieties-of-human-work/ - Accessed July 2019.

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To connect the air data accessory kit to the pitot static probes the following instructions are given:

(1) Connect the air data test set to the pitot/static probes. Refer to (Figure 7)

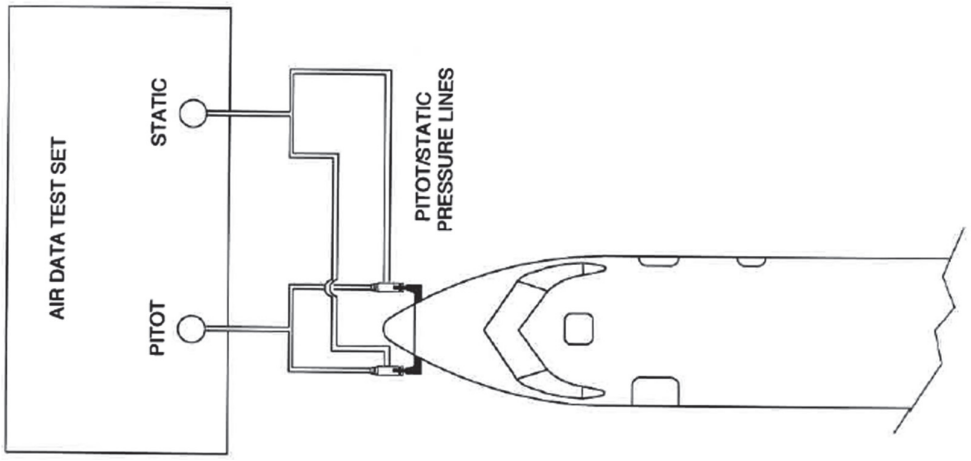

Figure 7
AMM diagram showing pitot static connections for testing

No further instructions are given, for example detailed instructions for connecting the air data accessory kit to the pitot static probes. To remove the kit, part (7) applies:

(7) Set the test set to off.

(a) Disconnect the test set from the pitot/static probes.

Following the incident flight, a further work order was raised to define the tasks required by the avionics technicians to troubleshoot the altitude mismatch on the aircraft. In addition to the leak checks, functional and operational checks were required. Both were done in accordance with AMM task 34-11-00-720-801 and 34-11-00-710-801 respectively. These AMM tasks describe the procedure to connect and disconnect the air data test kit in the same way as in the leak check task.

'*Work as disclosed*' is how work done is described by those who perform the task. How people describe their work can be influenced by several factors such as the audience, the context of the conversation and the potential outcome of the conversation.

The AAIB interviewed 10 avionics technicians from the maintenance organisation to understand how the air data accessory kits were used, if there were any issues or problems associated with them and whether they were aware of any non-standard practices. Two themes were disclosed which may have had an influence on the incident flight.

Although not a problem for all users, the avionics technicians noted that occasionally it can be difficult to establish a good seal between the pitot static probe and the adaptor resulting in incorrect air pressures being applied to the ADUs. Various remedial actions

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were described: repeatedly removing and reinstalling the adaptors until a seal was achieved, using a set of adaptors from a different accessory kit, applying various products to achieve a seal or replacing with new seals. There was no consensus on a single solution which was successful every time and several products were mentioned, other than the approved lubricant, to achieve a seal but no evidence could be provided of specific occasions when they were used.

The air data accessory kits contain many items and the maintenance organisation have multiple kits available which are taken from a controlled tool store when required. The kits are regularly audited during which they are visually examined, leak checks are performed on the hoses and the adaptors and the kit contents are assured. The kit used on the incident aircraft was last audited in July 2018 but at the time of the investigation it was missing the recommended lubricant and the instruction manual, some of the hoses were from another kit (identification label mismatch) and there was a bottle of 'Snoop' in the kit. Snoop is a commonly used water-based leak detection solution. It was stated during several interviews with avionics technicians that occasionally the approved lubricant was not available in the kit.

Analysis

Altitude mismatch

During the incident flight the altitude difference between the commander's and co-pilot's instruments was 140 ft which equates to a pressure differential of 2.8 mb under ISA conditions. There was good evidence from the post-flight troubleshooting that three of the four holes on the left primary pitot static probe were blocked; this would have affected the pressure balancing between the left and right side of the aircraft. The S1 static pressure system had one hole open in the left probe and two holes on the right probe which resulted in the higher pressure (lower altitude) whereas the S2 system had only two holes open in the right probe and gave a lower system pressure (higher altitude).

It is possible that the difference of 2.8 mb between these two dissimilar system configurations could have been caused by a slight sideslip to the right which would increase the pressure on the right side of the aircraft and would not have been averaged due to the blockage of the left side S2 holes. Although on this occasion the altitude and airspeed errors were small and resulted in a successful return to the departure airport, a blocked pitot static system has the potential to cause a large error in altitude and airspeed information displayed to the pilots. Unreliable primary flight data has previously been a contributory factor in several accidents and serious incidents.

Work as done - blocked static holes

'*Work as done*' according to the Shorrock concept is the actual activity taken to complete the task and may occur in an environment that is subject to a variety of constraints, challenges and demands that are not 'imagined' or 'disclosed'. The work done may be the product of adaptations to overcome these which, although intended to achieve the objective, may result in unintended consequences.

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From interviews with the avionics technicians it is known that it can be difficult to achieve an effective seal between the test adaptors and the probe, and they indicated that several different methods have been employed to achieve a seal. Analysis of residue found on and inside the pitot static probe, as well as on the seals on the probe adaptor, strongly suggests that substances other than the recommended lubricant had been used during maintenance activity. There was also some evidence of damage to the knurling on the probe adaptor, and it is probable that hand tools had been used to tighten the locking sleeve, despite the air data accessory kit manufacturer stating that hand tight is sufficient.

Instructions for use of air data accessory kits

The kit manufacturer stated that the instructions for use of the air data accessory kit should be described in the relevant section of the AMM. The work orders issued by the maintenance organisation state that to accomplish a task it is to be done in accordance with the specific AMM task. However, the AMM does not provide any details on how to install the adaptors, which products should be used, or any additional information to aid the technicians to achieve a good seal between the probe and the adaptor.

Therefore, to improve the information with the air data accessory kits, which are used on several different aircraft types, the following Safety Recommendation is made:

Safety Recommendation 2019-010

It is recommended that Nav-Aids Ltd amend the manual supplied with air data accessory kits to include more specific installation instructions, and to include warnings against using non-approved materials to aid sealing.

To improve the information in the AMM for the De Havilland Aircraft of Canada Ltd DHC-8-402 the following Safety Recommendation is made:

Safety Recommendation 2019-011

It is recommended that De Havilland Aircraft of Canada Ltd amend the instructions in the Aircraft Maintenance Manual for the DHC-8-402 for testing pitot static probes to include more specific installation instructions, and to include warnings against using non-approved materials to aid sealing.

Lubricating fluid

The air data accessory kit manufacturer recommends the use of LF5050 to aid installation and the avionics technicians stated that it is often missing from the kit box due to kit control issues. It is possible therefore that to ‘get the job done’ the technicians may resort to other more easily available products with the unintended consequence, in this case, of residual grease blocking some of the static holes. As a result of this investigation the following safety action has been taken:

The maintenance organisation has purchased new air data accessory kits and implemented tighter tool control of the kits to ensure all the components are always available.

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Conclusion

Following scheduled maintenance of the incident aircraft, a small quantity of a silicone-based grease was blocking three of the four static pressure holes of the left primary pitot static probe. The inadvertent blockage of the static pressure holes resulted in an altitude mismatch of 140 ft between the commander's and co-pilot's altimeter. This may have been caused by using a non-approved grease to aid sealing the test adaptor to the pitot static probe, a task which can sometimes be problematic. The kit manufacturer's recommended lubricant is sometimes missing from the kits and the AMM and the kits instructions do not include any details on installation or sealing.

Safety actions/Recommendations

The following two Safety Recommendation have been made:

Safety Recommendation 2019-010: It is recommended that Nav-Aids Ltd amend the manual supplied with air data accessory kits to include more specific installation instructions, and to include warnings against using non-approved materials to aid sealing.

Safety Recommendation 2019-011: It is recommended that De Havilland Aircraft of Canada Ltd amend the instructions in the Aircraft Maintenance Manual for the DHC-8-402 for testing pitot static probes to include more specific installation instructions, and to include warnings against using non-approved materials to aid sealing.

The following safety action has been taken:

Safety action has been taken by the maintenance organisation to purchase new air data accessory kits and implement tighter tool control of the kits to ensure all the components are always available.

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