

INCIDENT

Aircraft Type and Registration:	Bombardier DHC-8-400, G-JECE
No & Type of Engines:	2 Pratt & Whitney PW150A turboprop engines
Year of Manufacture:	2004
Date & Time (UTC):	4 August 2005 at 0748 hrs
Location:	Near Leeds, West Yorkshire
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - 4 Passengers - 56
Injuries:	Crew - None Passengers - None
Nature of Damage:	Internal damage to No 2 engine
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	35 years
Commander's Flying Experience:	4,150 hours (of which 400 were on type) Last 90 days - 150 hours Last 28 days - 70 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after initiating a descent, an oily smell was noticed on the flight deck, almost immediately followed by a smoke build-up in the flight deck and cabin. The flight crew carried out the initial part of the smoke checklist procedure, declared an emergency and carried out a diversion. The cabin crew members donned smoke hoods, which caused appreciable communication difficulties, and prepared the cabin for an emergency landing. After landing, an emergency evacuation was carried out, without injury.

The smoke was found to be the result of fatigue cracking of a compressor support member of the No 2 engine. This had led to damage to an oil seal, allowing oil to leak into the bleed air supplying one of the air conditioning

units. Fleet modification action aimed at preventing fatigue cracking of the component and at improving the affected oil seal was completed on all of the operator's fleet by July 2006.

No means of rapidly ascertaining the source of the smoke was available to the crew. Carrying out the subsequent actions prescribed in the checklist would have stopped the supply of smoke but the procedure was relatively protracted and could not be completed because of a high flight crew workload associated with the diversion.

Four safety recommendations have been made.

History of the flight

The following information was obtained from reports by the aircraft crew, ATC controllers and from RTF recordings.

The aircraft was on the second sector of the day, from Birmingham to Edinburgh. On the first sector the commander noticed a slight musky smell on engine start but, as engine maintenance activities had just been completed, he did not consider it to be out of the ordinary. During the previous sector a slight oily smell had been noticed on the flight deck for approximately 30 seconds during the descent.

On the second sector, while in the cruise at FL200, a 'de-ice pressure' caution activated when the de-icing system was switched on. The caution light remained illuminated after the relevant checklist from the Flight Crew Operating Manual (FCOM) had been actioned and consequently, at 0731 hrs, some 15 minutes after takeoff, the crew requested a descent to FL120. At around 0736 hrs Manchester ATC, which was controlling the aircraft at the time, gave an initial clearance to descend to FL160. Shortly after retarding the throttles and while descending through FL180, both pilots noticed the same oily smell as before. They asked the cabin crew, via the interphone, whether the smell was evident in the passenger cabin and, almost immediately, noticed a white/blue haze appearing on the flight deck, accompanied simultaneously by the toilet smoke alarm.

The commander initiated the procedure specified in the FCOM smoke checklist and both pilots donned their smoke masks and actioned the checklist memory items. One item, switching off the recirculation fans, was initially omitted but was carried out subsequently. Smoke goggles were not used as there was no difficulty in

reading the instruments. While the pilots were actioning the checklist the two cabin crew members heard the smoke alarm in the forward toilet sound and then found that the toilet was full of whitish coloured smoke. The senior cabin crew member informed the flight crew using the interphone. The pilots' response was delayed because they were occupied with the checklist actions. The cabin crew then donned smoke hoods.

The commander declared a 'MAYDAY' and was given clearance for a further descent. He then requested vectors to the nearest suitable airport. ATC suggested Leeds Bradford International Airport (LBA), around 45 nm away, and this was accepted by the commander. After some delay due to communication difficulties, ATC informed G-JECE's crew of the required heading, requested selection of the emergency transponder code and transferred the aircraft to a quiet frequency. At the crew's request, ATC passed the crew an airfield weather report, after a further delay while the information was obtained from LBA. The report indicated a wind of 14 kt from 260°M, visibility of 20 km, scattered cloud at 1,100 ft and 1,500 ft above aerodrome level (aal) and an ambient temperature of 14°C.

The commander considered that the smoke level in the flight deck was unchanged, so the cabin crew were briefed to prepare the cabin for an emergency landing in 10 minutes and a passenger evacuation on the runway. The cabin crew found the smoke in the cabin getting thicker, until they could no longer see the length of the cabin. The senior cabin crew member played an emergency announcement tape and made a public address to the passengers, briefing them that there would be an emergency landing, for which they should adopt the brace position. The cabin crew then checked the passengers and secured cabin baggage. Some passengers enquired about breathing protection for themselves, but

smoke protection for passengers is not a requirement on public transport aircraft.

The ILS frequency and runway heading at LBA were passed by ATC on request from the crew and the aircraft was radar vectored for an ILS approach to Runway 14. About 15 nm from the airport ATC suggested a frequency change to Leeds Approach, which was accepted. The flight crew judged that their priority was to get the aircraft safely on the ground. With the limited time available and the high workload situation the flight crew were able to complete only the first item of the subsequent actions of the Smoke checklist, which was *'No 1 Bleed Off and wait up to 1 minute'* (Section 4). As power was increased during the approach a significant increase in the smoke level was experienced. Because of hearing difficulties caused by the smoke hoods, the cabin crew members did not hear the landing calls from the flight deck.

The aircraft landed on Runway 14 at 0748 hrs, around 12 minutes after the crew had become aware of the smoke. To expedite their arrival the crew accepted a tailwind reported, at that time, to be 15 kt. A firm landing was made and the aircraft stopped around two-thirds of the way along the runway.

After coming to rest the park brake was applied, the engines were shut down and an evacuation was ordered. This was carried out through the left forward exit, using the airstairs, and the left and right aft exits. The first officer left the aircraft to assist and supervise the passengers while the commander completed the shutdown actions. The passenger evacuation proceeded in an orderly fashion, with the Aerodrome Fire and Rescue Service (AFRS) present, and was completed without injury. The commander confirmed that the cabin was empty and left the aircraft. A check by AFRS personnel found no signs of fire and the aircraft was towed to a stand.

Crew communications

In their reports on the incident the flight crew noted that, after the emergency had been declared, a high workload had prevented them from communicating with the cabin crew for some time. The cabin crew commented that delays in obtaining a response from the flight deck to cabin emergency calls at times had caused concern as to the state of the flight crew. It was suggested that consideration should be given to introducing a standard method by which the flight crew could confirm to the cabin crew that they were not incapacitated but were temporarily too busy to reply, such as a triple activation of the seat belt audio alert in the cabin.

The cabin crew also reported that the smoke hoods had severely hindered communications with the passengers, impeding both hearing and being heard. Because of this, one of the cabin crew had removed her hood shortly before landing.

FCOM checklist

The *'FUSELAGE FIRE OR SMOKE – SMOKE'* checklist in the operator's FCOM had the following memory items:

- ◆ *Oxygen Masks*..... *On + 100%*
- ◆ *Smoke Goggles* *On*
- ◆ *Mic switch*..... *MASK*
- ◆ *Hot Mic* *OFF*
- ◆ *Headset* *On*
- ◆ *Recirc Fans*..... *OFF*
- ◆ *Emergency Lights* *ON*
- ◆ *Passenger Signs*..... *ON*
- ◆ *Descend* *ASAP - Check MSA*
- ◆ *Land immediately at nearest suitable airport*

The initial part of the subsequent actions in the checklist were:

“IF Unknown Source of Fire or Smoke:

- ◆ *Bleed 1 OFF*
Wait up to one minute, if no improvement:
- ◆ *Bleed 1 ON*
- ◆ *Bleed 2 OFF*
Wait up to one minute, if no improvement:
- ◆ *Bleed 2 ON*
- ◆ *Flt Compt Pack..... OFF*
Wait up to one minute, if no improvement:
- ◆ *Flt Compt Pack.....AUTO or MAN*
- ◆ *Cabin Pack OFF*
Wait up to one minute, if no improvement:
- ◆ *Cabin PackAUTO or MAN*

IF Source of Fire or Smoke still cannot be identified:

Caution: Following completion of this drill fly A/C from the LHS (torches req’d at night) in order to read active instruments. 45 mins battery duration.

- ◆ *Battery master..... Confirm ON*
- ◆ *DC and AC Gens 1 and 2 OFF*
- ◆ *Main, Aux and Stby Batteries OFF*
- ◆ *Emergency Lights OFF (until finals)*
- ◆ *Descend and Land.....*
<10000 ft ASAP – Check MSA
- ◆ *Refer to ‘battery essential services’*
– Page 17B.
- ◆ *When cabin diff is 0.5psi or less, complete Ram Ventilation page 10A”*

Engine description

The Pratt & Whitney Canada PW150A is a gas turboshaft engine with a nominal sea level static power output of approximately 5,100 shaft horsepower. It has an axial Low Pressure (LP) compressor, a centrifugal High Pressure (HP) compressor, a two-stage gas generator turbine and a two-stage power turbine. Bleed air for the fuselage air conditioning units is taken from either the LP or HP compressors, depending on the power settings.

A ring of stator blades at the outlet of the LP compressor is located on an approximately conically shaped component known as the Inner Compressor Support (ICS). With the modification standard of G-JECE’s No 2 engine, the ICS is radially located by a fit with the No 3 bearing housing. A flange on the ICS, provided with an O-ring static oil seal, mates with the Inter Compressor Case (ICC) and the ICS and ICC together form part of an engine bearing chamber. At the forward end of the chamber a double spring-loaded carbon oil seal (the ‘No 2.5 bearing seal’) mounted in the ICS seals against the LP shaft.

Previous cases had occurred of loss of material from the outer part of the ICS where it contacts the stator ring, due to fretting wear that had resulted in a change in the ICS vibration characteristics and consequent fatigue cracking. The material detached from the ICS could cause impact damage to compressor blades and could lodge inside the compressor rotor and unbalance it. Abnormal vibration associated with the ICS damage and/or the effects on the compressor could lead to degradation of both the static oil seal and the bearing chamber carbon oil seal and possibly to fatigue cracking of the ICC struts. Degradation of the oil seals could allow oil to escape into the gas flow through the compressor and thence into the air conditioning units,

leading to oil mist or smoke in the cabin and flight deck. The aircraft was not fitted with an engine vibration monitoring system.

A Service Bulletin (P&WC SB No 35158), issued by the engine manufacturer on 22 July 2005, noted that:

'Summary: There can be a possible material loss from the Inner Compressor Support (ICS). The piece of material can either enter the Low Pressure (LP) Compressor or the high pressure compressor. This can result in a possible deterioration in engine oil sealing.'

The SB also noted:

'Cause Relative movement between the support and the LP compressor stator causes fretting wear on the support. This reduces the fit between both parts, which allows the support to freely vibrate and crack.'

The SB recommended:

'Do boroscope inspection to verify for cracks and loss of material of the LP inner compressor stator support.'

The recommended time for initial and repeat inspections of an individual engine varied according to the engine's background, thus determining which of three groups it fitted into. See Table 1 below.

G-JECE's No 2 engine was in Group 2. The SB recommended that, if ICS cracks were found, the boroscope inspection should be repeated at an interval of not more than 65 flight hours. If a loss of material were evident the engine should be removed for ICS replacement.

Information from the engine manufacturer indicated that at July 2005 there had been 12 incidents of oil smell or smoke in the fuselage, of which five had been attributed to ICS cracking.

Emergency air and oxygen supplies

The DHC-8-400 was not required to be fitted with individual passenger oxygen masks because of the limited maximum altitude capability of the aircraft type. However, on aircraft types where individual masks are provided they are typically not intended to be used in the case of smoke in the cabin, as this may be associated with a fire which could be fuelled by oxygen from the masks. G-JECE was provided with portable therapeutic oxygen equipment, which was available for use in the event

Group	Engine Background	Initial Inspection Time flight hr	Repeat Inspection Time flight hr
1	LP ICS replaced at previous shop visit due to cracks or material loss	≤200	≤200
2	LP ICS not inspected at last shop visit or never had a shop visit	≤500	≤500
3	LP ICS replaced at previous shop visit due to fretting or reinstalled	Latest of 500 hr or 2,000 hr ICS TSN (time since new)	≤500

Table 1

of passenger breathing difficulties being experienced.

Smoke protection for passengers is not a requirement on public transport aircraft and was not provided.

Other cases of fuselage air contamination

A search of the CAA database revealed that in the three-year period to 1 August 2006 there had been 153 cases of fumes, abnormal odour or smoke or haze in the flight deck and/or cabin of UK registered public transport aircraft of various types. Details on a number of the cases were limited but the available information suggested that around 119 of the cases had probably resulted from conditioned air contamination. This had commonly been caused by oil release from an engine, APU or air conditioning unit or ingestion of de-icing or compressor wash fluid by an engine or APU, with consequent smoke and/or oil mist in the conditioned air supply to the fuselage. It appeared that in many of the cases the crew members had found it difficult or impossible to establish the source of the contamination.

Adverse physiological effects on one or both pilots, in some cases severe, were reported in 40 of the cases. A diversion was made in 31 cases.

In the event of smoke or fumes, there is the possibility that an uncontrolled fire is burning. Although infrequent, some catastrophic events have occurred to large public transport aircraft as a result of fires which were not, or could not be, extinguished. A well-known example was a catastrophic fire which occurred on an MD-11 aircraft, registration HB-IWF, near Halifax, Nova Scotia, in 1998, with the loss of the 229 occupants (Transportation Safety Board of Canada Report No A98H0003). The report notes that in this case the crew had initially assessed that an unusual odour and smoke on the flight deck had originated from the air conditioning system.

In fact, there was a fire spreading above the ceiling in the fuselage. Damage from the fire resulted in a loss of control and the aircraft impacted the sea around 20 minutes after the odour was first noticed.

In December 2006 the Flight Operations Group of the United Kingdom's Royal Aeronautical Society and the Guild of Air Pilots and Navigators (GAPAN) published a specialist paper entitled '*Smoke, Fire and Fumes in Transport Aircraft*'. This paper draws extensively on work by the International Air Transport Association (IATA), the US Federal Aviation Administration (FAA), National Transportation Safety Board (NTSB) and Flight Safety Foundation (FSF) and the UK's Civil Aviation Authority (UK CAA). It uses material culled from numerous major accident investigations worldwide, from research organisations and from industry. It makes a large number of recommendations to reduce the risk arising from fires, smoke and fumes.

The report states that:

'during the 36 months examined (by IATA), there occurred an average of two and a half smoke events each day.'

It takes into account the unique nature of an emergency due to fire or smoke, and this special concern is clearly stated in one of the report's appendices:

'The stress and workload of responding to these events is exceptionally high and unlike many other types of emergency or abnormal situations, the flight and cabin crews absolutely must communicate and co-ordinate their assessment and response. However, even the most rigorous joint training cannot realistically present crews with the full extent of the demands they will face when dealing with smoke, fire and fumes in flight.'

The report makes a recommendation as follows:

'Increase the number and location of sensors to alert the flight crew of smoke/fumes. These sensors should take advantage of new technology to minimise the false alarm rate.'

Engine examination

Inspection of G-JECE's No 2 engine by the engine manufacturer found that a one inch long piece of the ICS ring in contact with the stator ring had broken off, due to fatigue cracking. Pieces of the detached portion were found within the LP compressor rotor and a small fragment of material that had probably broken off the ICS was found within the No 2.5 bearing carbon oil seal assembly. The seal had been severely damaged. One of the sealing elements had been chipped and the manufacturer concluded that this had been caused by interference with part of the detached ICS portion. Additionally, the tension spring and metal plates between the carbon elements of the seal were found worn and broken; this was considered to be the result of abnormal vibration due to imbalance caused by the presence of the detached part of the ICS inside the LP compressor rotor. Other damage consisted of extensive fatigue cracking of two of the ICC struts. Substantial quantities of oil were found inside the LP compressor 2nd stage rotor and in the HP compressor bleed path, fully consistent with the effects of the damage to the No 2.5 bearing oil seal.

The No 2 engine (Serial number FA0214) had been constructed in May 2004 and had accumulated 2,103 flight hours and 2,614 flight cycles since new at the time of the incident. It had not undergone overhaul or repair.

A programme to fit an ICS of updated design, intended to prevent fatigue damage similar to that experienced by

G-JECE, has been instituted by the engine manufacturer. The change had been incorporated on 91% of the worldwide engine fleet by the end of December 2006, and all of the operator's fleet by July 2006. Incorporation of an improved No 2.5 bearing oil seal commenced in June 2006.

Other remedial actions

For aircraft with unmodified engines, the operator amended the after-start checklist by introducing a check for fumes in order to identify any similar failure of the ICS and consequential damage to the No 2.5 bearing oil seal. Bombardier subsequently adopted this as a Standard Operating Procedure for unmodified engines.

Cabin crew smoke hoods

Checks made during the investigation confirmed that verbal communications while wearing a cabin crew smoke hood were difficult, even when in close proximity to another person. This was due to the combination of a reduction in speech and hearing volume due to the hood and to interference from relatively loud sounds perceived by the hood wearer, caused by rustling of the hood, the sound of the wearer's breathing and the sound of the wearer's voice.

The operator's training regime required cabin crew members to practise donning a smoke hood once a year, and once every three years to practise operating in a smoke-filled environment while wearing a smoke hood.

Discussion

Fuselage smoke

A substantial portion of the No 2 engine ICS had broken off as the result of fatigue cracking. The detached material had caused severe damage to a bearing oil seal, both directly and by virtue of unbalancing the LP compressor rotor, and this allowed engine oil to leak into the gas path through

the compressors. The air bled from the HP compressor to supply the No 2 air conditioning pack would then have been contaminated with oil, resulting in the smoke (or oil mist) that had been experienced in the flight deck and cabin (referred to as 'smoke' in this report).

The source of the smoke should have been identifiable had it been possible for the crew to continue the FCOM smoke checklist actions to the point where the No 2 air conditioning pack had been selected off. This would have stopped the bleed air from the No 2 engine and should have resulted in a decrease in the level of smoke in the flight deck and cabin. However, the flight crew judged that landing was the priority, given the rapid rate of increase in the smoke, the lack of information as to its source and the appreciable time that would be required to complete the checklist. It was unclear to the flight crew whether the smoke was emanating from a fire or from the bleed air supplies, and it was uncertain that completing the checklist actions would stop the smoke build-up. Once the decision to land had been made, the workload in arranging a safe descent and diversion to LBA, coupled with communication difficulties, left insufficient time for the checklist actions to be completed.

It appears that in other cases where smoke has been detected in the fuselage there may well have been a similar dichotomy between either completing the specified checklist actions or making a landing as a matter of urgency. Information on previous cases indicated that most had resulted from contamination of the conditioned air supply. The information also suggested that the inability of the crew to establish rapidly the source of the smoke could result in a decision to divert and land urgently, in case of adverse physiological effects and in case there was actually a fire. Catastrophic in-flight fires have historically given crews very little time, perhaps just a few minutes, to land. This aspect was a factor in the case

of the loss of HB-IWF near Halifax, Nova Scotia, where the odour and smoke from the fire was initially assessed as having originated with the air conditioning system.

In cases where smoke did in fact result from contamination of the conditioned air supply, due to a problem with an engine, APU or air conditioning system, this could typically only be established in flight by carrying out relatively protracted checklist procedures. Modern aircraft are commonly fitted with smoke detectors in areas such as baggage bays, toilets and/or electronic component cooling air ducts but are generally not provided with means for detecting and warning of smoke in the conditioned air supplied to the fuselage. Such a warning system would provide immediate indications of smoke entering the fuselage as the result of an engine or air conditioning unit problem and also provide rapid verification of the smoke's source. This could reduce the number of cases where an urgent landing was made unnecessarily and minimise possible physiological effects on the crew and passengers. Should a false warning occur, the absence of odour or visible smoke would make it obvious that the warning was false.

In order to enable the flight crew to rapidly identify the source of smoke in conditioned air supplies, to rapidly stop its entry, to avoid unnecessary emergency actions including diversions and to minimise possible adverse physiological effects, the AAIB makes the following two Safety Recommendations:

Safety Recommendation 2007-002

It is recommended that the EASA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit.

Safety Recommendation 2007-003

It is recommended that the FAA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit.

Crew communication

The cabin crew experienced a delay in obtaining a response from the flight deck during the descent, due to the high workload the flight crew was experiencing. This delay caused appreciable concern to the cabin crew. Although it was suggested to the investigation that this could have been allayed by a standard procedure for giving a 'standby' signal, such as repeated operation of the seatbelt audio tone, this would be no substitute for direct communication between the flight crew and cabin crew, and might constitute a greater distraction to the flight crew than responding normally. The problem was exacerbated by the locked flight deck door, which also impeded the cabin crew in offering any assistance which might, in other circumstances, have been necessary.

In the UK, the National Aviation Security Programme and the Aviation Security Act (1982) impose legal requirements on operators of large aeroplanes operating for the purposes of commercial air transport. These requirements are, however, consistent with the legal obligations of operators under the Air Navigation Order, which states:

'In the case of: ... (b) a door between the flight crew compartment and any adjacent compartment to which passengers have access, the door may be locked or bolted if the commander of the aeroplane

or helicopter so determines, for the purpose of preventing access by passengers to the flight crew compartment... ' (Rule 72 (3)(b)).

Flight deck and cabin crews work together to ensure the safety of the operation. Interphone systems, historically, have been provided and used as backups to face-to-face communications. With the advent of the locked flight deck door policy, full reliance for operationally necessary communications is placed on the electronic communications systems, and failure of the interphone system is itself considered to be an in-flight emergency. However, these systems were designed before the advent of present-day security policies and do not provide the necessary reliability for use in this role, particularly in emergencies as the busbars which supply them are not the aircraft's essential busbars. As a result, such essential communications will be lost if there is a loss of the associated electrical busbar supplies as, for example, if the aircraft were to be configured into a typical emergency electrical configuration such as might be expected if the flight crew were dealing with an electrical fire. In a recent AAIB investigation, due to such a power shutdown, a large public transport aircraft was evacuated on the stand without the knowledge or authority of the Commander (AAIB Bulletin 1/2007, Avro RJ 146-100 G-CFAE on 11 Jan 2006). In those situations where the training and resources of the flight and cabin crews are required to minimise injuries or loss of life, the necessary communications may be impeded, and may not be available at all. Therefore the AAIB makes the following Safety Recommendation:

Safety Recommendation 2007-004

It is recommended that for all large aeroplanes operating for the purposes of commercial air transport, the UK CAA and the EASA should take such steps, procedural or technical, as are necessary to improve the reliability

and availability of communications between flight and cabin crews, including the reliability of communications equipment and associated power supplies in both normal and emergency configurations.

Smoke hoods

The passengers, seeing the smoke build-up in the cabin and the cabin crew don smoke hoods, enquired about breathing protection for themselves. None was provided, nor did current regulations require any for the passengers. The operator subsequently noted that portable oxygen equipment was available for use should any passengers have experienced breathing difficulties; however the use of oxygen is not permitted unless it can be confirmed that there is no fire in the vicinity.

The cabin crew, although concerned about the delay in flight deck response, prepared the cabin for the emergency landing and evacuation. However, the

smoke hoods caused them appreciable difficulties in communicating with passengers and a trial during the investigation confirmed that communication difficulties would be inevitable. While the cabin crew members had undergone training with smoke hoods, it appeared that this had not fully prepared them for the extent of the associated communication difficulties, raising questions about the effectiveness of the training. Therefore the AAIB makes the following Safety Recommendation:

Safety Recommendation 2007-006

It is recommended that the UK CAA and the EASA review the current training requirements for cabin crew members in the use of smoke hoods to mitigate the communication difficulties which may be encountered and to improve the ability of all the crew members to communicate while wearing smoke hoods.