Statens Havarikommisjon for Transport

SL Report 2007/33

REPORT ON SERIOUS AVIATION INCIDENT, 19 MAY 2004 APPROX. 20 NM WEST-NORTHWEST OF SANDEFJORD AIRPORT TORP, NORWAY, INVOLVING BOMBARDIER DHC-8-402, LN-WDA, OPERATED BY WIDERØES FLYVESELSKAP ASA

This report has been translated into English and published by the AIBN to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

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The Accident Investigation Board has compiled this report for the sole purpose of improving flight safety. The object of any investigation is to identify faults or discrepancies which may endanger flight safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for flight safety should be avoided.

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REPORT ON SERIOUS AVIATION INCIDENT

Aircraft type:	Bombardier Aerospace Inc. DHC-8-402
Registration:	LN-WDA
Owner:	HPA Leasing Limited, Don Street, St. Helier Jersey, UK
Operator:	Widwerøe Flyveselskap ASA, Post Office Box 247, 8001 Bodø
Crew:	2 + 2
Passengers:	27
Incident location:	Approx. 20 NM west-northwest of Sandefjord Airport Torp, Norway (ENTO)
Date/time of incident:	Wednesday 19 May 2004, at 0739

All times mentioned in this report are local time (UTC + 2 hours) unless otherwise indicated.

REPORTING OF THE INCIDENT

The Accident Investigation Board Norway (AIBN) was notified of the incident on 19 May 2004 at 0817 by the air traffic control service at Torp. The report stated that a DHC-8-400 airplane belonging to Widerøes Flyvelselskap had undertaken a controlled emergency landing at the airport as a result of a fire in one engine. Permission was granted on behalf of the AIBN to move the airplane away from the runway. Two accident investigators arrived at Torp at 1130 that same day and immediately began the investigation.

In accordance with ICAO Annex 13, Aircraft Accident Investigation, the Canadian Transport Safety Board (TSB), was informed. The TSB appointed an accredited representative who monitored parts of the investigations which took place in Canada.

SUMMARY

A Bombardier DHC-8-402 from Widerøe with the radio call sign WIF404 took off from Sandefjord Airport Torp (ENTO) at 0732 en route to Bergen Airport Flesland (ENBR). The flight was normal until the airplane had climbed to 13,500 ft. A bang was then heard and a number of indications showed that the left engine was about to stop. Shortly later, the fire alarm actuated. The crew shut down[1] the left[2] engine and returned to Torp on one engine. Despite both of the fire extinguisher bottles being discharged, the fire alarm was on right until airplane power was switched off after evacuation. The landing and evacuation were performed without anyone being physically injured.

[1] Subsequent review of the EMU data indicated that the engine was actually shut down by the FADEC.
[2] The left engine is also designated engine no. 1, and the corresponding right engine no. 2.

The investigation showed that the engine in flight shut down arose as a result of a fatigue fracture in one of the low pressure compressor first stage rotor blades. Vibrations due to the blade fracture led to major internal damage in the engine and caused an oil leak in the fuel heater. This oil flowed backward and was ignited by the hot exhaust gases at the rear of the engine. The fire caused major damage to the engine and caused the fire alarm to continue even after the engine had been cooled completely.

The engine type concerned, Pratt & Whitney Canada PW150A, was relatively new and still maturing. The manufacturer was aware of problems in the leading edge of the blades concerned, and a new version of the low pressure compressor first stage was being developed at the time when the incident occurred. However, this Widerøe incident and a similar incident with an airplane belonging to SAS Commuter occurred due to cracking at the mid cord. A third version of the first stage compressor with a modified profile and a change of material was then developed and made available to production and PW150A operators under Service Bulletin (SB) 35191 in December 2006.

In conjunction with this investigation, it has been shown that there is potential for improvement of the crew’s initial handling of the emergency situation, weaknesses in the fire and rescue service’s fire extinguishing procedures for airplane type DHC-8-400, and a failure in the operator company’s maintenance system.

The AIBN has provided four safety recommendations in connection with this investigation.

1. FACTUAL INFORMATION

1.1 The history of the flight

1.1.1 The Commander arrived late at Sandefjord Airport Torp (ENTO) according to the specified time for checking in. The First Officer therefore, on his own, carried out planning and preparations for the flight. The First Officer was already in the cockpit when the Commander arrived. However, the flight crew spent a good length of time going through the checklists and preparations prior to take-off.

1.1.2 At 0732, LN-WDA took off from runway 18 on route WIF404 with a planned landing at Bergen Airport Flesland (ENBR). There were 4 crew members and 27 passengers onboard. The First Officer flew the airplane (Pilot Flying – PF) and the Commander (Pilot Not Flying – PNF) operated the radio. Flying was undertaken in accordance with clearance for Standard Instrument Departure (SID) SKI 1S. After take-off, the airplane was established at a course of 297^{o} and climbed at a speed of 240 kt.

1.1.3 The flight was normal until 07:38:49 when the crew and several passengers heard a bang and noticed a jolt in the airplane. The airplane had reached 13,500 ft. Prior to the bang, the left engine (engine no. 1) indicated 92% torque and the right engine (engine no. 2) 95% torque. A series of indicators in the cockpit showed that the left engine was about to stop. These included ‘Fuel flow’ going to ‘0’ and the rotational speed of the low pressure compressor (NL) dropping from 91 to 0% (approx. 25,000 to 0 revolutions per minute) in 4 seconds. In addition, several warning lights came on. The following then happened in rapid succession (the time is indicated on the left):

07:38:52 The First Officer commented that the autopilot had disengaged.

07:38:58 The First Officer traced the problems to the left engine. At the same time, the fire alarm for the left engine actuated.

07:39:02 The First Officer ordered the left engine to be shut down *(“Engine failure shut down engine number one, engine fire”*). The Commander pulled back the left engine Power Lever to IDLE without confirming which engine was being shut down.

07:39:04 The Commander pulled back the left engine Condition Lever to FEATHER and confirmed *“Shutting down.”* This was followed by a comment from the First Officer that could be interpreted as meaning that the he wanted to be assured that the correct engine had been shut down.

07:39:06 The Commander pushed the right engine Power Lever past the detent and into manual control (over travel). This led to the right engine:

- for a period of 22 seconds exceeding 100% in torque with a highest recorded value of 102%
- for a period of 23 seconds, the engine temperature (ITT) exceeded the highest permissible value of 880 ºC. The highest recorded value was 917 ºC).
- for a period of 23 seconds exceeding 100% in rotational speed in the low pressure compressor (NL) with a highest recorded value of 101%

07:39:12 The First Officer asked the Commander for confirmation that engine no. 1 was in feather, and his response was *“Number one in feather.”*

07:39:14 The left engine Condition Lever was pulled back to FUEL OFF. In addition, an emergency shutdown of the engine was carried out by pulling the PULL FUEL/HYD OFF handle.

07:39:17 The cabin crew called up to make contact with the flight crew.

07:39:18 The first fire extinguisher bottle (FWD BTL) was discharged.

07:39:19 The Commander had previously communicated with Oslo Control (ATCC) on 120,370 MHz. The First Officer then took over the radio and gave the following report: *“Widerøe four-zero-four, returning to base as soon as possible. We have engine fire!”*

07:39:24 Oslo Control: *“Widerøe four-zero-four turning back. Left or right turn, you can choose.”*

07:39:32 First Officer: *“Turning right and declaring an emergency.”*

07:39:35 The First Officer began a right turn which implied maximum bank angle of 47º after 21 seconds. As a result of this, the crew received the warning “BANK ANGLE – BANK ANGLE”. A bank angle of more than 35° was maintained for 30 seconds. Descent was commenced at the same time.

07:39:44 Oslo Control: *“Widerøe four-zero-four turning back. Emergency and descend when convenient FL 100”*

07:39:50 First Officer: *“Descending back to 100, Widerøe four-zero-four”*

07:39:55 The crew noticed that the fire warning light was still on and the aft fire bottle (AFT BTL) was discharged.

07:39:57 Oslo Control: *“Four-zero-four, contact Farris Approach for unrestricted descend 134.05”*

1.1.4 At 07:40:00 the First Officer asked for confirmation of items on the checklist being carried out. This resulted in the Commander reading out and going through the first items on the checklist “ENGINE FAILURE/FIRE/SHUTDOWN (In Flight)” (the 7 first ‘memory items’).

1.1.5 At 07:40:58 the Commander took over the radio and called up Farris Approach: *“Farris, Widerøe four-zero-four, MAYDAY – MAYDAY – MAYDAY we have one engine on fire, returning visually to Torp.”* The crew was then given unlimited descent and clearance for visual approach to runway 18 at Torp.

1.1.6 The flight crew informed the passengers that they were returning to Torp. The cabin crew were additionally informed about what would happen and were given instructions on the preparations for evacuation on the right hand side. It was decided that both forward and aft doors should be used.

1.1.7 At 07:42:17 the crew were asked to contact the control tower at Torp (TWR) on 118,650 MHz. Available indications were that the left engine was still on fire and this information was passed on to the control tower. Clearance for landing was then given:

> *“Widerøe four-zero-four turning back. Roger…….Emergency.…Cleared to land one eight…wind is two-two-zero one-six knots…....fire trucks are out”*

1.1.8 At 07:43:44 the crew began to run through the checklist “ENGINE FAILURE/FIRE/SHUTDOWN (In Flight)” to verify that all of the items had been carried out.

1.1.9 LN-WDA came in high relative to its distance from the threshold for runway 18 and the crew carried out a 360^{o} turn on the final approach to obtain the correct altitude. The crew went through the relevant emergency checklists and concluded that all systems were functioning as presumed.

1.1.10 Three vehicles from the fire and rescue service took up positions along the runway. One of the fire and rescue crews noticed that smoke was coming out of the left engine during the approach.

1.1.11 The actual landing at 07:48:16 was problem-free according to the flight crew. Braking was normal and as soon as the airplane came to a standstill, the right engine was shut down and the airplane evacuated. At the same time, the fire and rescue service began to spray foam on the left engine. No flames were observed coming from the engine and the situation was assessed as being under control after a short time.

1.1.12 The First Officer stated to the AIBN after the incident that there had never been any problem in manoeuvring the airplane and that the effect of losing the engine was insignificant.

1.1.13 None of the crew or passengers were injured. First they were taken a safe distance away from the airplane and then brought into the terminal building and informed about what had happened.

1.1.14 LN-WDA was towed away from the runway approx. one hour after landing. Normal traffic operations at the airport were then resumed.

1.2 Injuries to persons

Table 1: Injuries to persons

Injuries	Crew	Passengers	Others
Fatald			
Serious			
Light/none	4	27	

1.3 Damage to aircraft

The left engine installation sustained extensive damage and had to be replaced. The right engine had to be sent to the engine manufacturer for inspection (see section 1.12 for details).

1.4 Other damage

None

1.5 Personnel information

1.5.1 <u>Commander</u>

1.5.1.1 The Commander, male aged 50, had done his basic training at Den Norske Luftfartsskole at Torp during the period 1976 – 79. He was employed by Widerøes Flyveselskap in 1985 and gained type rating for the DHC-8-400 on 15 April 2004. The Commander had a total of approx. 3,700 flying hours experience on the DHC-8, most significantly on the -100 and -300.

1.5.1.2 The Commander had his ATPL-A first issued on 3 December 1996, valid until 29 March 2006. His last proficiency check (PC) was undertaken on 26 November 2003. His last operational proficiency check (OPC) was undertaken on 5 May 2004 on a DHC-8-400. The Commander had a Class 1 medical certificate valid until 22 November 2004. The certificate had the following limitation: “VDL – Shall wear corrective lenses and carry a spare set of spectacles.”

Table 2: The Commanders flying hours

Flying hours	All types	Current type
Last 24 hours	0:25	0:25
Last 3 days	5:43	5:43
Last 30 days	46:59	Not reported
Last 90 days	151:57	Not reported
Total	approx. 12,700	Not reported

1.5.2 First Officer

1.5.2.1 The First Officer, male aged 33, undertook his basic training at Flygteoriskolan in Jarfalla in Sweden. He was employed by Widerøes Flyveselskap in 1998 and gained his type rating on the DHC-8-400 on 8 November 2003. The First Officer had a total of approx. 2,900 flying hours experience on the DHC-8.

1.5.2.2 The First Officer held a CPL-A valid until 30 April 2006. His last proficiency check (PC) was undertaken on 30 September 2003. His last operational proficiency check (OPC) was undertaken on 14 March 2004. The First Officer had a Class 1 medical certificate valid until 10 March 2005 with the following limitation: "VDL – Shall wear corrective lenses and carry a spare set of spectacles."

Table 3:The First Officers flying hours

Flying hours	All types	Current type
Last 24 hours	0:25	0:25
Last 3 days	3:01	3:01
Last 30 days	54:15	54:15
Last 90 days	144:36	144:36
Total	approx. 4,000	approx. 650

1.5.3 Cabin crew

Both members of the cabin crew had valid certificates and had been authorised to serve on board the DHC-8-400 from 11 October 2002 and 26 February 2003, respectively.

1.6 Aircraft information

1.6.1 General

The DHC-8-400 (often also called the Q400) is a twin-engine, high-wing turboprop airplane developed out of earlier versions of the de Havilland Canada DHC-8. In comparison with its predecessor, the DHC-8-300, it has a considerably longer cabin which can accommodate up to 78 passengers; another, more powerful type of engine, and a modernised cockpit. This aircraft type was first brought into operation in February 2000. Widerøes Flyveselskap took delivery of its first on 17 November 2001, and at the time of the incident, it had 3 airplane of the type DHC-8-402.

1.6.2 Data

Manufacturer:	Bombardier Aerospace Inc.
Model:	DHC-8-402
Airworthiness certificate:	Valid until 31 July 2004
Year of manufacture:	2002
Serial number:	4069
Total number of flying hours:	3.477
Number of landings:	3.464
Engine type:	Pratt & Whitney Canada PW150A
Serial number, left engine:	FA0019
Operating time, left engine:	3,963 hours
Cycles, left engine:	4,284

1.6.3 Mass and balance

1.6.3.1 On take-off, 4,000 kg of JET A-1 type fuel was onboard. The take-off mass was estimated at 24,388 kg. The maximum permissible take-off mass was 29,257 kg.

1.6.3.2 The airplane was within the limitations with regard to the position of the centre of gravity.

1.6.4 Description of engine and systems

1.6.4.1 *General*

This engine type was type certified in June 1998. It is designed with four turbine stages of which the first stage drives the high pressure compressor (rotor speed is designated NH), the second stage drives the low pressure compressor (rotor speed is designated NL) and the two last stages drive the propellers via a through-shaft and a reduction gearbox (see figure1). The engine can supply 5,071 SHP (Shaft Horse Power).

In 2004, the engine type was only used on the DHC-8-400 and as at May 2004, around 200 had been produced.

The engine compartment is ventilated using an ejector in conjunction with the exhaust tube. Air from the engine compartment is drawn into the exhaust tube via an annular gap formed between the engine's exhaust nozzle and the exhaust tube, which exits at the aft end on top of the engine nacelle.

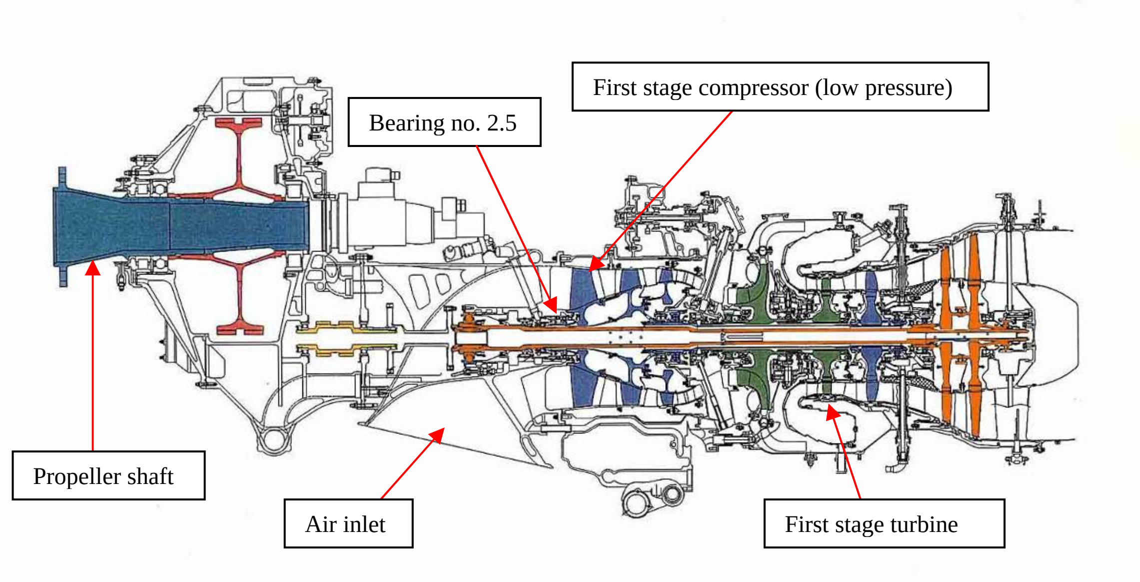

Figure 1: Overview of the engine's main components including reduction gearbox.

1.6.4.2 *Engine and propeller control*

The engines and propellers on the DHC-8-402 are controlled via Full Authority Digital Engine Control (FADEC) and Propeller Electronic Controller (PEC). FADEC and PEC obtain signals from a series of transmitters for pressure, temperature, rotor speed etc, which are collated with inputs from the controls in the cockpit. Based on this information, FADEC and PEC optimise the output of the engine and propeller for the various phases of flight. The following main engine controls are located in the cockpit:

- Power Lever (PL): Controls the engine power via FADEC when PL is past Flight Idle. Rated power is achieved when PL is in detent. In this position, the engine is well protected against exceeding critical limit values. If PL is moved past the detent, the FADEC increases the engine power beyond that of the selected power rating and up to 125% of maximum takeoff power rating. This feature is intended for emergency situations. The PL position also determines the minimum propeller blade pitch angles in flight and directly controls the propeller blade pitch during ground operation.

- Condition Lever (CL): Regulates the propeller speed and determines the power ratings, via PEC, in the forward position. CL actuates propeller feathering in the Start & Feather position. CL supplies a fuel shut-off command in its rearmost position.

The FADEC monitors several conditions and amongst others shut down the engine if a NL shear shaft condition arise. In addition, the engine installation is equipped with an Autofeather and Uptrim system. The Autofeather system ensures that the affected propeller blades are feathered automatically when engine power is lost and is armed by the crew for takeoff operation. The Uptrim system automatically increases engine power from Normal Take-Off to Maximum Take-Off (MTOP) in case of opposite engine power loss and is enabled throughout all phases of flight. The Uptrim system has no effect on engine power when in Climb and Cruise power ratings.

1.6.4.3 *Compressor first stage*

The rotor in the compressor first stage is milled out of one piece of "Titanium alloy forging 6AL-4V triple melted". To improve mechanical properties, the top surfaces of the blades are glass bead peened. This reduces the tension stresses in the surface. When the incident occurred, the engine with the longest operating time had, according to Pratt & Whitney, Canada, accumulated approx. 6,800 flying hours. The compressor with the longest running time had accumulated approx. 6,000 flying hours. As at 30 April 2004, cracks were discovered in the leading edge of the blades in 9 different compressors. These had each accumulated between 2,553 and 4,003 flying hours.

1.6.4.4 *Engine oil*

Normally each engine installation accommodates around 24 litres of oil. The engine oil that is used in the engine has a flash point of 204 ºC. It self-ignites at 382 ºC.

1.6.4.5 *Fuel heater*

The fuel stored in the wings is cooled significantly while flying in cold air. To avoid too low fuel temperature, the fuel is heated by hot engine oil in a heat exchanger (fuel heater) before entering the engine's fuel control (see figure 14). This unit is also called the fuel to oil heat exchanger.

1.6.4.6 *Fire detection system*

Each engine installation (nacelle) has a system for detecting overtemperature or fire. Altogether, three sensors (detector loops) are installed, respectively, the Main Wheel Well Zone, the Leading Edge Zone and around the Propeller Electronic Controller. The latter two sensors are linked in series and together cover the Primary Engine Zone. Each sensor consists of a thin flexible tube, sealed at one end and linked to two pressure sensors at the other end. The tube is filled with pressurised helium gas. The tube also contains a titanium core that has been impregnated with hydrogen. If the entire tube heats up, the pressure of the helium gas rises and one of the pressure switches actuates and issues a high temperature/fire alarm. The sensor in the engine compartment should actuate if the ambient temperature rises to between 243 ºC and 277 ºC. If sections of the tube is heated to 538 ºC or more, hydrogen gas will also be released. This means that the system is actuated even if only a limited part of the tube is exposed to high temperatures.

If the tube is damaged and the helium gas leaks out, the pressure will diminish and the second of the two pressure sensors will actuate. A light in the cockpit warns of this. The fire detection system can be tested from the cockpit.

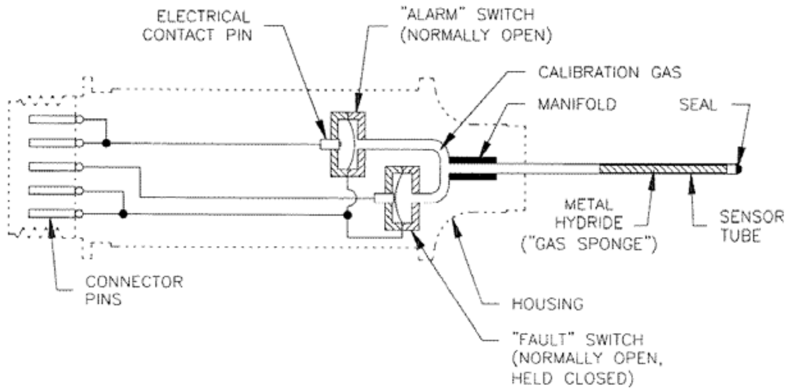

Figure 2: Outline drawing of heat detector (sensor).

In the event of overtemperature or fire in the engine, the warning issued comprises:

- a red light in the appropriate PULL FUEL/HYD OFF HANDLE on the overhead panel
- two red warning lights WARNING PRESS TO RESET at the top of the instrument panel (glareshield panel)
- two red warning lights ENGINE FIRE at the top of the instrument panel (glareshield panel)
- red warning light CHECK FIRE DETECTION on the overhead panel (caution & warning panel)
- acoustic signal (ringing)

1.6.4.7 *System for extinguishing fire*

When a fire alarm activates, the PULL FUEL/HYD OFF HANDLE is pulled out and the valves for hydraulics and fuel are closed. In addition, the fire extinguishing system is armed. The airplane has two bottles containing Halon extinguishing medium for the engines – one front and one rear bottle. The crew first actuates the front bottle. Halon is then routed to the engine concerned. If the fire alarm does not cease within 30 seconds, the second bottle (rear) should also be actuated.

1.6.5 Operations Manual (OM) Part B

1.6.5.1 *Abnormal and Emergency Procedures*

The following quotation has been taken from OM Part B, Section 3.0 GENERAL FOR ALL EMERGENCIES:

> ***"3.0.2 Crew Co-ordination during Emergencies***
>
> *In the event of an abnormal situation, the primary objective of the flight crew is to control the aeroplane. The crew will assess the problem when vertical and lateral flight path control is established and ground contact is no longer a threat. Once the nature of the problem has been established, the PF will call for the appropriate memory items if applicable. The PNF actions the memory items*

which are confirmed by the PF. When the memory items are complete, the PF will call for the appropriate emergency checklist. The PNF actions the checklist using the 'read and do' method."

1.6.5.2 *Q400 Dash 8 Quick Reference Handbook:*

ENGINE FAILURE/FIRE/SHUTDOWN

(In Flight)

Affected Engine

- *Power Lever……………………………………Flight Idle*
- *Condition Lever……………………………… Fuel Off*
- *Alternate Feather (if req'd)………………… Fthr*
- *Pull Fuel/Hyd Off Handle……………………Pull*
- *Tank Aux Pump……………………………… Off*

If Fire:

- *Extg switch (affected engine)……………… Fwd Btl*

If Fire Persists, Wait Up To 30 Seconds:

- *Extg switch (affected engine)……………… Aft Btl*
- *Autofeather…………………………………… Off*
- *Power levers……………………operate together*
- *Ignition (Affected Engine)……………………Off*
- *Bleed Air:*

Operating Engine………………………………as req'd

Affected Engine…………………………………… Off

- *Stby Hyd Press……………………………… On*
- *Tank Aux Pump (Operating Engine)………On*

If No. 2 engine inoperative:

- *PTU Cntrl…………………………………… On*

Landing Considerations:

- with #1 Engine inoperative DO NOT select PTU Cntrl to ON

Landing Distance Factor:

Flap 10…………………………………………1.40

Flap 15…………………………………………1.40

Flaps 35……………………………………… 1.50

Caution: *Propeller may unfeather if Autofeather is selected off before condition lever is selected Fuel Off."*

The text within the frame should be remembered (memory items) and executed before the items are later verified using the checklist.

1.6.6 Maintenance status

Last A check:	24 April 2004	Flying hours: 3,329:17	Landings: 3,324
Last Line check:	17 May 2004	Flying hours: 3,470:53	Landings: 3,458
Last Over Night check:	19 May 2004	Flying hours: 3,477:14	Landings: 3,464

There were no remaining observations in the aircraft's journey log (Hold Item List - HIL).

1.6.7 Information from the engine manufacturer

1.6.7.1 *Service Bulletin 35111*

Due to cracks in the blades on the low pressure compressor first stage being experienced, on 13 December 2002 Pratt & Whitney Canada issued Service Bulletin (S.B.) no. 35111. When the incident occurred, revision no. 6 dated 18 December 2003 was applicable (R6). The service bulletin is declared as being in Category 3[3], in other words it is a recommendation and not an absolute requirement.

S.B. 35111R6 describes a Fluorescent Penetrant Inspection or an Eddy Current Inspection along the leading edge of the blade roots on the low pressure compressor first stage. It is estimated that the inspection will take 3 hours. S.B. 35111R6 is relevant to all engines that have been operating for more than 2,000 hours in total. The inspection must be carried out for every 500 hours.

P&WC S.B. no. 35111R6 (first stage compressor rotor inspection) for the left engine was complied with on 29 April 2004 with an engine operating time of 3,845 hours (118 hours before the incident). The work was executed in accordance with Widerøe's Task 723000W301 (Eddy Current Inspection) which is based on the Pratt & Whitney Canada Task 72-00-00-250-801. No cracks were found in the rotor during this inspection.

1.6.7.2 *Field Issues Monthly*

Pratt & Whitney Canada Customer Support discussed the problem of the low pressure compressor in the April 2004 issue of PW150 "Field Issues Monthly". It is established there that 9 cases of cracks had been discovered in the first stage compressor blades. The engines had an operating time of between 2,553 and 4,003 hours. The cracks had started in the leading edge at the blade root. The cause was explained as being "High Cycle Frequency/Low Cycle Frequency interaction". The following solution to the problem was outlined:

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[3] Category 3: P&WC recommends doing this service bulletin within…… hours or …… cycles.

- FPI / Eddy Current Inspection (SB35111), initially when 2,000 engine hours were reached and then for every 500 engine hours.

- Replace low pressure compressors. This should be done for all engines sent to the workshop, and when the engine has been operating for more than 3,000 hours.

In addition, there was also the expectation that an improved issue of the first stage compressor would be on the market in September 2004[4].

1.6.8 Type certification

1.6.8.1 *General*

Type certification of the DHC-8-400 is based on requirement specifications from 1995. The aircraft type was certified in August 1999 in compliance with the Transport Canada Airworthiness Manual (AWM) Chapter 525, Change 525-6. Type certification in compliance with JAA was granted in November of that year, based on JAR 25 and JAR E. Norwegian Type Certificate was issued 14 December 1999.

The engine was certified by Transport Canada in June 1998 in compliance with the Transport Canada Airworthiness Manual (AWM) Chapter 533, Change 533-4. The engine was also certified by the FAA in November 1998 in compliance with FAR 33.

1.6.8.2 *Certification requirements for the fire detection system*

The requirements for the fire detection system are described, for example, in FAR 25 under "Subpart E – Powerplant" in the sub-section "Powerplant Fire Protection". The requirements include revisions (amendments) 25 – 26 and the latest change was dated 24 March 1971.

> *"**25.1201 Fire extinguishing system materials***
>
> --------
>
> *(b) Each system component in an engine compartment must be fireproof.*
>
> -------
>
> ***25.1203 Fire detector system***
>
> --------
>
> *(b) Each fire detector system must be constructed and installed so that –*
>
> *(1) It will withstand the vibration, inertia, and other loads to which it may be subject in operation;*
>
> --------
>
> *(e) Wiring and other components of each fire or overheat detector system in a fire zone must be at least fire-resistant."*

[4] The improved first stage Low-Pressure compressor was released to the market in November 2004 under service bulletin SB35139

1.6.8.3 *Certification requirements for the fire extinguishing system*

The requirements for the fire extinguishing systems are described, for example, in FAR 25 under “Subpart E – Powerplant” in the sub-section “Powerplant Fire Protection”. The requirements include revisions (amendments) 25 – 46 and its latest change was dated 30 October 1978.

> *“§25.1195 Fire extinguishing systems*
>
> ---------
>
> *(b) The fire extinguishing system, the quantity of the extinguishing agent, the rate of discharge, and the discharge distribution must be adequate to extinguish fires. It must be shown by either actual or simulated flight tests that under critical airflow conditions in flight the discharge of the extinguishing agent in each designated fire zone specified in paragraph (a) of this section will provide an agent concentration capable of extinguishing fires in that zone and of minimizing the probability of re-ignition. An individual ‘one shot’ system may be used for auxiliary power units, fuel burning heaters, and other combustion equipment. For each other designated fire zone, two discharges must be provided each of which produces adequate agent concentration.”*

According to the details provided by Bombardier, the fire extinguishing system had been tested in compliance with all applicable regulations as in Bombardier certification report AEROC 84.5.PE.1 section 4.1. The requirement is that the fire extinguishing medium should have a minimum concentration of 6% (volume) for a period of 0.5 seconds. The test was passed under ‘worst case’ conditions, which included the fire extinguisher bottles being cooled down to – 40 °C.

1.7 Meteorological information

1.7.1 TAF

ENTO 190500Z 190615 21012KT 9999 FEW 040 TEMPO 1015 27015G25KT

1.7.2 METAR (time given as Z)

ENTO 190550 21014G24KT 9999 FEW010 10/06 Q1000

1.7.3 Other information

1.7.3.1 It was daylight at the time of the incident.

1.7.3.2 When the airplane landed, the tower reported the wind as 220° 16 kt.

1.8 Aids to navigation

No faults or defects have been reported in the navigation aids for Sandefjord Airport Torp at the time of the incident.

1.9 Communications

During the entire flight, two-way radio communication were maintained between the respective units of the air traffic control service and the crew onboard LN-WDA.

1.10 Aerodrome information

The runway is tarmac and measures 2,939 x 45 metres. Landing Distance Available (LDA) for runway 18 is 2,530 metres. The runway is situated 286 ft above sea level. Both runways are equipped with High Intensity Approach Light System (HIALS) and High Intensity Runway Edge Lights (HIRL). Both runways are equipped with Precision Approach Path Indicator (PAPI) with an angle of 3^o.

1.11 Flight recorders

1.11.1 <u>Flight data recorder</u>

1.11.1.1 LN-WDA was equipped with a Flight Data Recorder (FDR) of the type Allied Signal 980-4700-027, with serial number 6508. Data from the flight recorder was retrieved at the premises of the operator Widerøe. The flight recorder contained good quality data.

1.11.1.2 The following recorded items ought to be mentioned:

- The high pressure part on the left engine continued to rotate (NH) for 5 minutes and 33 seconds after the compressor blade came loose. It only stopped 3 minutes and 54 seconds before the airplane touched down on the runway at Torp. NH reached 12.5% 2 minutes after the blade came loose. At a lower rotational speed the engine oil pressure pump has little efficiency and little or no oil will flow out of it.

- Propeller de-ice was OFF.

- The propeller RPM was 849 when the compressor blade fractured.

1.11.2 <u>Cockpit voice recorder</u>

LN-WDA was equipped with a Cockpit Voice Recorder (CVR) of the type Allied Signal 980-6022-011, with serial number 120-04575. The voice recorder was played back at the British Air Accident Investigation Branch (AAIB) at Farnborough. It contained good quality data.

1.12 Description of damage to the engine installations

1.12.1 <u>Initial examination of the left engine</u>

1.12.1.1 When the AIBN arrived at the Widerøe hangar, the airplane was cordoned off and only the forward access door on the left side of the left engine was open (see figure 3). Both access doors on the left side of the left engine were discoloured by heat on the outside. It was evident that the temperature inside the engine compartment had been high. In particular the rear door showed signs of having been exposed to high temperatures. On the right side of the engine, there was only a minor area where the white paint was discoloured. The underside of the nacelle from the landing gear backwards was soiled with engine oil.

Figure 3: Left side of left engine.

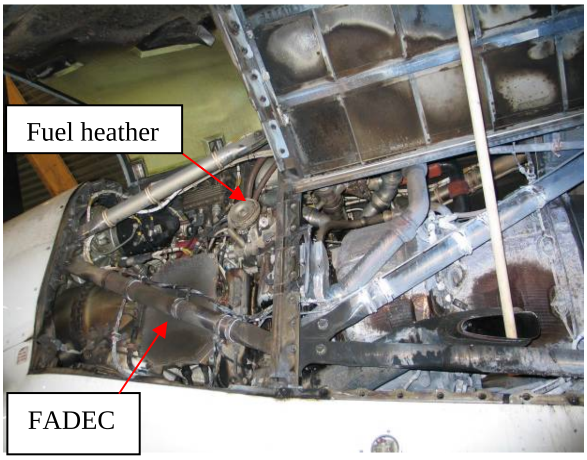


Figure 4: Visible heat damage once the rear left door was opened.

1.12.1.2 All engine access doors were opened. The support strut for the rear left door had partially melted,[5] and a rod had to be used to hold the cover open. On the top of the air intake section (the bottom of the engine compartment) were a number of remnants of rubber components from fixing brackets, small beads of melted metal and data plates etc. In addition, the top was covered with soot; partially mixed with oil. When the air intake section was to be lowered at the front, it was clear that the entire nacelle was distorted. The left front bolt had to be knocked out, and when the bolt did come out, the holes were displaced by 6 mm. When the section was lowered at the front, a number of metal parts from the engine's intake section and the compressor were found in the flow-through channel inside the air intake.

1.12.1.3 In general, the engine and the engine compartment were covered in soot. At first glance, it looked as if the temperature had been highest at the lower left part of the engine compartment from FADEC back towards the firewall, and on the underside of the turbine section. In this area, some smaller aluminium components had melted. The area around the reduction gearbox was not badly affected by heat.

[5] Bombardier has provided the information that this indicates the temperature had reached 500 – 620 °C

Figure 5: Left side of the turbine section. The foam is still visible on the bottom of the engine compartment. The arrow points at the lower left engine mount strut which is bent upward.

Figure 6: The underside of the engine viewed towards the back once the air intake section was lowered.

1.12.1.4 An inspection inside the air intake showed that there was major damage in the trailing edge of the supports for bearing nos. 2 and 2.5 (front inlet casing struts). Later examination revealed that cracks in the struts penetrated right in to the internal oil channels. There was also major damage to the bearing no. 2.5 housing. The low pressure compressor first stage had sustained major mechanical damage. On more detailed examination, fractures were detected in one of the compressor blades. The pattern in the fracture surface indicated that the fracture had been caused by metal fatigue. Internally, the air inlet was covered generally by a thin layer of engine oil. In addition, there were several small notches and dents in the parts of the air intake that are made of composite materials.

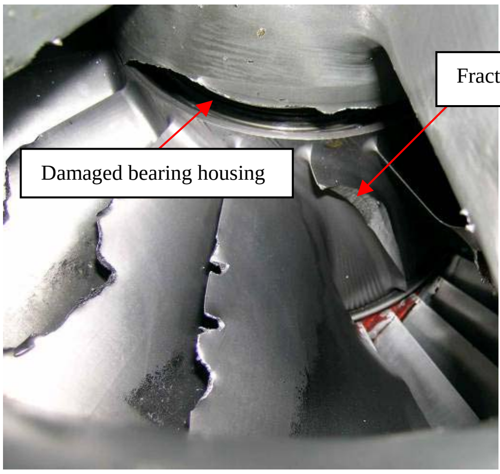


Figure 7: The air inlet with visible damage.

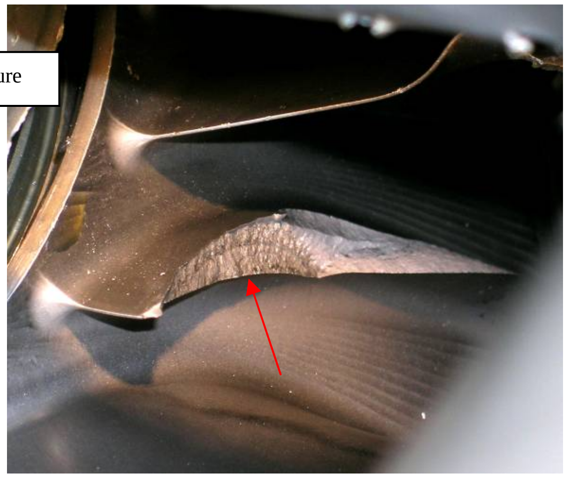


Figure 8: fracture in one compressor blade. The lines in the fatigue fracture are clearly visible.

1.12.1.5 In the cockpit, all switches and handles were found in their expected positions when relevant checklists have been adhered to in conjunction with shutting down and securing the left engine, and the subsequent landing and emergency evacuation. The only unusual observation was that the automatic circuit breaker on the air intake de-icer (INTK LIP HTR ENG 1) and the indicator for clogged oil filter (ENG 1 OIL CLG) had tripped.

1.12.1.6 When the airplane was powered up, the fire detection system indicated that there was still a fire in the left engine. When the system was tested, neither the FAULT A nor FAULT B lights came on despite further fault-finding having detected that the fault had to be in the fire detection sensors. Two of the sensors were sent out to the manufacturer for more detailed investigation (see subsection 1.16.2).

1.12.1.7 The decision was made to remove the engine and send it to the manufacturer, Pratt & Whitney, in Montreal, Canada (see paragraph 1.16.1). This work meant that most of the cowlings and the propeller were removed. After that, the engine itself was hoisted out of the nacelle. In conjunction with this work, 4 litres of engine oil were drained out of the engine and the oil cooler. During later disassembly of the engine, 5 further litres of oil were drained. Large amounts of metal fragments were found in the oil filter for the reduction gearbox (RGB scavenge filter).

1.12.1.8 A representative of the airplane manufacturer, Bombardier, inspected the engine and the nacelle before it was sent to Canada. The following was noticed:

- All fire walls between different fire zones were intact.
- The rubber in the engine mount in the rear left engine bracket was badly damaged by heat and the stainless steel in the bracket itself had blue zones due to the effect of heat.
- The rubber padding in several wiring and hose fixings had burnt away.
- The strut that constitutes the lower left engine mount was bent up in the middle by around 7-8 mm (see fig. 5).
- There were traces of soot and oil in the exhaust ejector (bell mouth).

- Several small metal particles were found in the exhaust tube.
- Few signs of heat in the upper part of the nacelle
- There was no sign of fire inside the engine's bleed air duct.
- A few drops of oil were found in the engine's $P_{2.2}$ valve/duct.

1.12.2 Damage to right engine

Data from the FDR showed that the right engine had exceeded Engine Limitations. The engine was subsequently disassembled and sent to the factory for more detailed examination. In this examination, no damage was found that could be linked to these excesses. On the other hand, damage was found on the high pressure turbine due to carbon erosion corresponding to that found on the left engine (see figure 17 and 18). This blade condition was not directly related to the incident 19 May (see subpara. 2.7.2.2).

1.13 Medical and pathological information

No blood samples were taken from the crew. Neither was there any suspicion that the crew were under the influence of alcohol or other drugs.

1.14 Fire

1.14.1 Introduction

1.14.1.1 Fire broke out in the left engine. The fire was limited to the engine compartment (Primary Engine Zone) and did not spread further to any other fire zones. Essentially, it was engine oil that caught fire. In conjunction with this inspection work, 9 litres of engine oil were drained from the engine. Consequently, 15 litres of engine oil disappeared in conjunction with the incident. Some of this oil soiled the nacelle without burning. The AIBN therefore believes that considerably less than 15 litres was combusted.

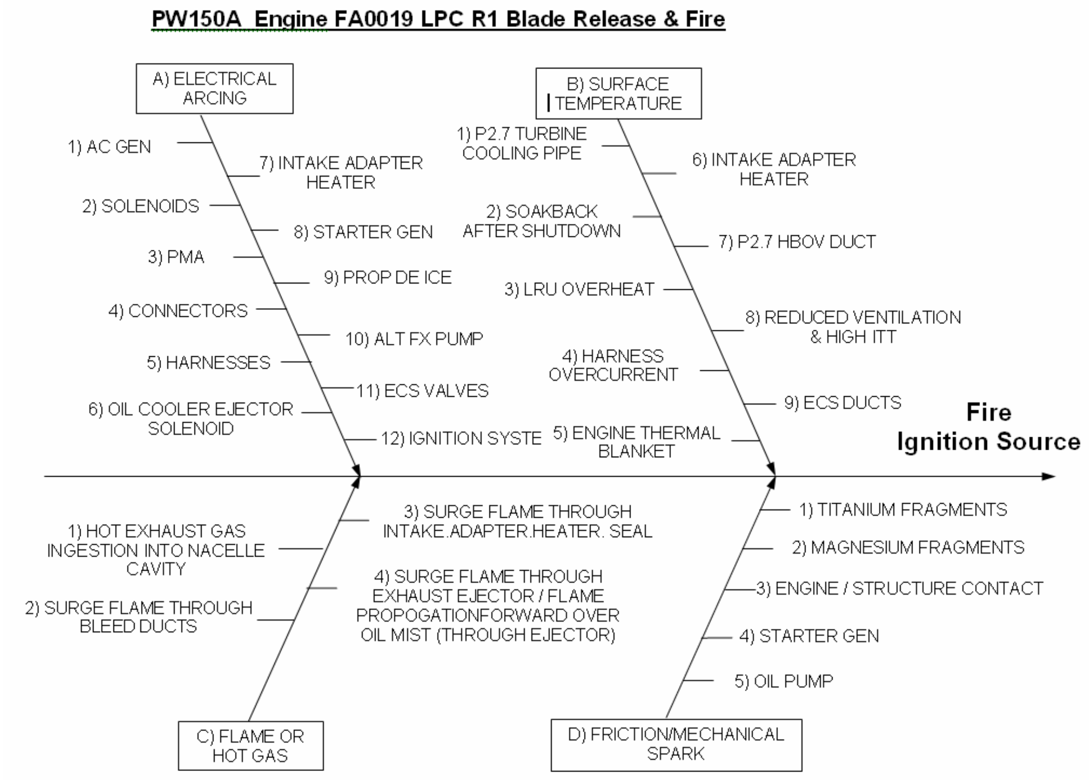
1.14.1.2 During the investigation, it became known that the sensor in the fire detection system had been exposed to extremely high temperatures over a large area. On that basis, Bombardier tried to estimate how high the temperature had been. In an e-mail received on 13 February 2006, Bombardier wrote the following:

> *"Based on evidence of partially melted aluminium maintenance strut in the nacelle, a conclusion can be reached that the localized fire reached a temperature of at least 935 to 1,159 degrees F. Additionally, the inspection performed by Kidde on the affected fire loop indicated that approximately 5.6 meters of the 8 meter long fire loop would have been exposed to temperatures on the order of 1 000 degrees F."*

1.14.2 Source of ignition

1.14.2.1 The examinations of the left engine were also carried out with the intention of finding the ignition source of the engine fire. Damage to electrical wiring and equipment, the pattern of soot, mechanical damage etc. were recorded and evaluated. Later, Bombardier and

Pratt & Whitney Canada set up a working party to evaluate the various sources of ignition. The following 'fishbone diagram' was used in this work:



1.14.2.2 A series of experiments and calculations were carried out. Each possible ignition source was then categorised as: Non, Very Low, Low, Medium and High. Quotation from the working party's conclusion:

> *"The team concluded that the most likely ignition source was the surge flame from the engine exhaust nozzle associated with the blade-off event / sudden engine stoppage. The actual mechanism of ignition would either be: (i) exhaust nozzle choking and surge flames passing through the exhaust ejector into the nacelle, igniting the oil spray from the cracked fuel to oil heat exchanger, or (ii) oil spray from the cracked fuel to oil heat exchanger being pumped out trough the exhaust ejector where it ignited by the surge flame and the flame subsequently propagated forward into the nacelle through the ejector, over the oil mist. The second potential ignition source, substantially less likely, was identified as surge flames trough the P2.2 handling bleed duct."*

1.14.3 <u>Efficiency of the engine's fire extinguishing system</u>

The AIBN questioned Bombardier about the efficiency of the fire extinguishing system. In an e-mail received on 13 February 2006, the manufacturer wrote the following:

> *"Bombardier has reviewed available data from the Wideroe event as well as the subsequent SAS event. The third event of LPC1 blade fracture did not result in a fire and neither EMU or FDR data was retrieved in time by the operator. Additionally, a review of nacelle ventilation and cooling certification data was completed to support the investigation. In summary, Bombardier is satisfied with the performance of the nacelle ventilation and fire suppression system. In*

particular, the data suggest that the fire initiated immediately following the engine blade release. In less than 20 seconds following the blade release the oil cooler ejector solenoid electrical harness was sufficiently burned through to trip its corresponding circuit breaker. The fire indication illuminated approximately 9 seconds following the blade release, and the crew discharged the first bottle approximately 26 seconds following the blade release.

Due to the deformation of the fire detector switch diaphragm resulting in permanent indication, the exact time at which the fire was extinguished cannot be identified. However, visual examination of the nacelle after the event revealed oil film and coked (uncombusted) oil covering most side and lower areas of the engine and nacelle. This indicates that the fire was extinguished before the source of flammable fluid (oil) was depleted."

1.14.4 Fire and rescue service

1.14.4.1 The fire and rescue service at the airport was notified by the tower at 0741 that WIF404 was returning with engine problems and that there was a possible fire. Later, the fire and rescue service was updated with regard to the number of people onboard, landing time, which engine was on fire and the runway that would be used. In addition, information was given that the crew were planning to evacuate the passengers on the right side.

1.14.4.2 The fire and rescue service turned out with three vehicles and six people. The vehicles took up their positions at exit W3 and the firefighters got ready. Immediately the airplane came to a standstill just before exit W4, foam was sprayed into the air intakes and the engine intake bypass door on the left engine. At the same time, the passengers evacuated on the right side. After 6 – 10 minutes, the front engine access door was opened and it was possible to spray foam into the engine compartment itself. No one at any time saw any flames, but when water entered the engine compartment it turned immediately into steam. When a technician from Widerøe arrived and opened the rear engine access door on the left side, it also became possible to reach the turbine area with fire suppression media. A total of 7,000 litres of fluid was used in putting out the fire. Of this, approx. 250 litres was foam of the type Rosenbauer Lightwater type Sthamex A FFF.

1.14.4.3 Because of the mixing of old and new emergency response plans, ambulances and the Sandefjord fire brigade were not notified in time. This had no consequence on the work of extinguishing the fire and evacuating the plane.

1.15 Survival aspects

1.15.1 The air quality in the cabin was not affected by the engine fire because the shut-off valve for cabin pressurisation closed as intended. The passengers and crew were not exposed to abnormal physical stresses during the flight and subsequent landing.

1.15.2 The DHC-8-402 is not equipped with slides at the doors. The distance from the door sills down to the ground is 1.55 metres at the rear door and 1.24 metres at the front. During evacuation, passengers thus have to jump down to the ground. According to Widerøe all passengers were in good physical condition and no one sustained any physical injury during the evacuation.

1.16 Tests and research

1.16.1 Left engine

1.16.1.1 *Introduction*

The left engine (serial number FA0019) was sent to Pratt & Whitney Canada after being removed from the nacelle. The engine was examined in Service Centre plant 5 in Montreal. The work was led by the AIBN in collaboration with Pratt & Whitney Canada. In addition, representatives of the Transport Safety Board of Canada, the Transport Canada supervisory authority, the airplane manufacturer (Bombardier Aerospace), and the operator (Widerøe) participated in the work, which started on 1 June 2004.

1.16.1.2 *General examination of the left engine*

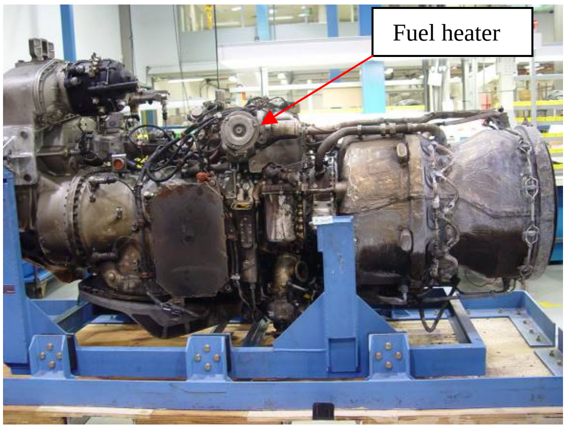


Figure 9: The left side of the engine before examination in Montreal started.

Figure 10: The right side of the engine before examination in Montreal started.

In short, the examination findings can be listed as follows:

- The engine had fire damage, traces of high temperatures and soot in a number of places. The damage was particularly severe on the left side around the fuel manifold and the underside of the gas generator casing. Large areas of the engine were covered in a white powder.

- An aluminium bracket holding two oil transfer tubes in place between the compressor section and the oil pump had broken and had come loose from both of its retaining bolts. The two transfer tubes had backed off 1.5 cm from the pump ports and there were oil droplets in the area. The bracket had several plastic deformations (see figure 12). In the same area is a double clamp holding the ignition cables. This was completely burnt out.

- The left hand igniter tube showed evidence that the brazing at the lead ferrule had melted.

- P2.2 bleed valve and P2.7 bleed valve were partially wet from oil internally. There was no trace of fire inside the valves.

- Samples were taken from several places on the engine for chemical analysis of the black coating. Most of the results showed traces of engine oil. None of the samples contained traces of fuel.

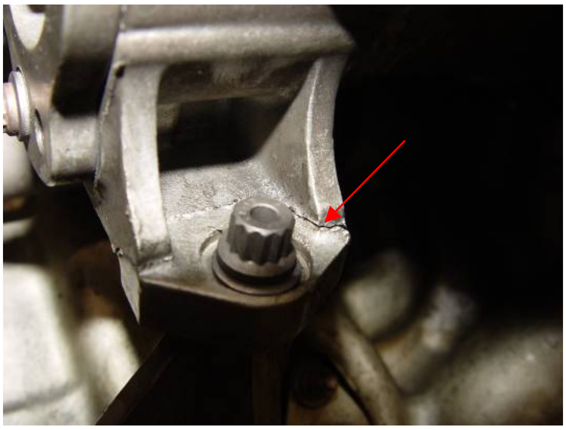


Figure 11: Facture in the lower mounting lug on the fuel heater.

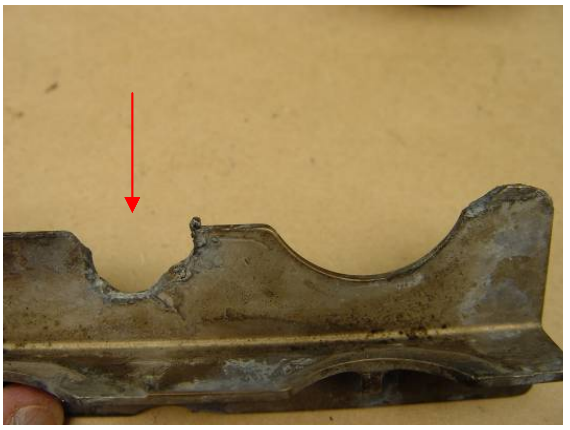


Figure 12: The bracket holding the oil transfer tubes. The arrow points at the fracture.

- The front, lower mounting lug on fuel heater was cracked (see figure 11). The other retaining bolts were found loose. After the fuel heater was removed, a crack was found running right through at the oil outlet left (see figure 13). A smaller external crack was also found in a re-inforcing web near the fuel port of the unit. During bench testing at an oil pressure of 100 psi, 5.7 kg of oil a minute leaked through the crack. The oil sprayed out through large parts of the crack and created a finely distributed spray of oil (see figure 14).

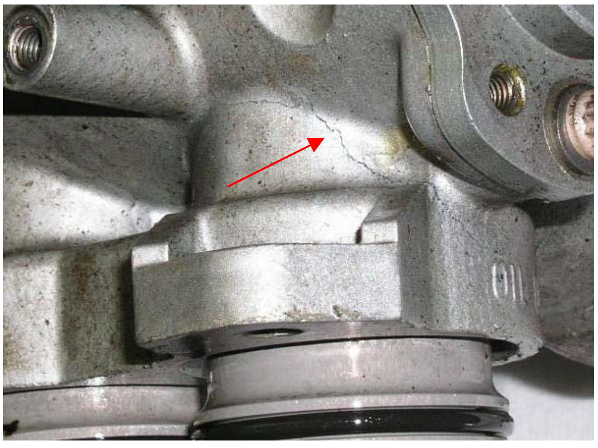


Figure 13: Crack going right through the fuel heater.

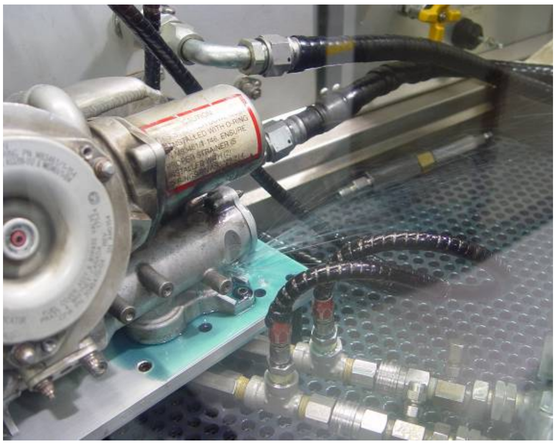


Figure 14: Fuel heater on the test bench.

- The speed probe for the low pressure compressor (NL probe) was damaged at the tip after contact with the rotating toothed wheel.
- The flange on the exhaust nozzle adapter had several cracks around the bolt holes, particularly in the 3 and 9 o’clock positions.

- Disassembly of the power turbine showed no trace of abnormal heat damage. No traces of damage to the temperature sensors (T6). Some oil was found at the bottom of the turbine support case.

- The power transmission shaft (the PT shaft) had several marks from contact with rotating parts. The damage was particularly severe at the front of bearing no. 2.

- The front inlet case was removed to provide access to the first compressor stage. This showed that there was damage to the trailing edge of all of the front intake case struts. The greatest damage had occurred on the supports at the 7 and 9 o'clock positions (viewed from behind). The bearing housing for bearing no. 2.5 was damaged, exposing the return oil channel.

- One first stage compressor blade had broken approx. 12 mm from the blade root. All of the other blades had varying degrees of damage (see figure 15).

- Bearing no. 2.5 was totally damaged (see figure 16). The rollers were, to a varying degree, flattened and squeezed into the inner race. At the 3 o'clock position, the rollers were completely flattened.

- The second stage compressor showed varying degree of tip rubbing. All other stage stator blades had been pulled out of the inner brackets. A similar pattern of damage could also be found on the compressor third stage.

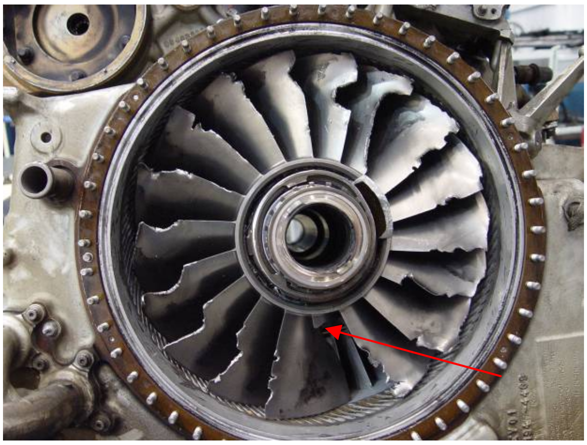


Figure 15: The first stage compressor rotor after the inlet case was removed. The arrow is pointing at the blade root of the missing compressor blade.

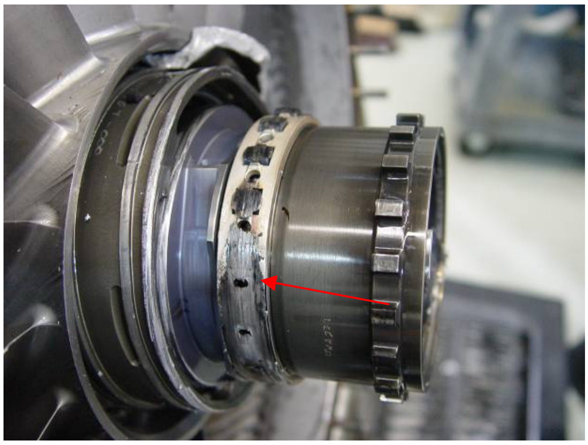


Figure 16: Bearing no. 2.5. The arrow is pointing at completely flattened rollers.

- The high pressure compressor had damage from contact with the compressor housing.

- The low pressure compressor, high pressure compressor, combustion chamber, high pressure stator and high pressure turbine all had damage from having been hit by foreign objects moving through the engine. The damage decreased towards the back of the engine. The same areas were also moistened by engine oil.

- The high pressure turbine had severe damage caused by carbon erosion. Pratt & Whitney Canada provided the information that this was caused by carbon deposits in the combustion chamber working loose and hitting the turbine blades on their way back through the engine. (see figure 17 and 18). This evolved gradually before the actual incident and was not related to the compressor blade failure.

- A series of heat-damaged cables were examined closely to identify whether cables or associated plugs could have been a possible ignition source. All of the effects of heat were shown to be external, and there were no traces of internal electrical heat generation.

Figure 17: Carbon erosion on the first stage high pressure turbine (left engine).

Figure 18: Close-up damage to turbine blade.

1.16.1.3 *Examination of first stage compressor rotor*

After disassembly, the first stage compressor was examined in more detail at the metallurgy laboratory in PWC's main manufacturing facility in Plant 1. A visual examination confirmed that the fracture was initiated by a fatigue crack that had begun on the concave side of the blade profile approx. 30 mm from the leading edge of the profile. There was no visible damage in the area where the crack started.

After photographic documentation, the compressor rotor was divided to allow the components to be put into the laboratory's Scanning Electron Microscope (SEM).

It then became clear that the fracture presented three distinct zones (see figure 19).

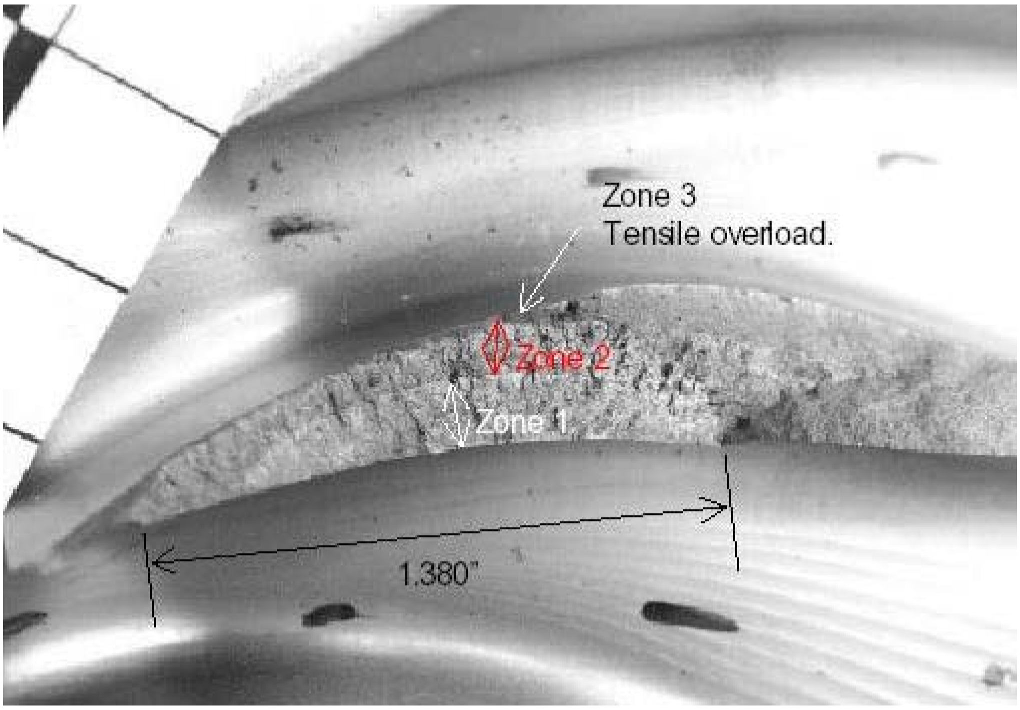


Figure 19: Picture of the three zones. The leading edge of the blade to the left. Zone 3 continues out of the picture to the right.

Zone 1 (see figure 20 and 21): Crystallographic nature. River lines were found starting from a point approx. 80 µm (0.003 inch) from the surface. It was possible to use these river lines to determine the direction of crack growth on the fatigue fracture. More detailed examinations of the initiation area showed quasicleavage facets with no striations. The crack growth in Zone 1 was designated as very slow. Analysis of a material found in Zone 1 showed that this was primarily aluminium and oxygen (aluminium oxide). The material was deposited in a manner indicating that it had come there after the crack appeared.

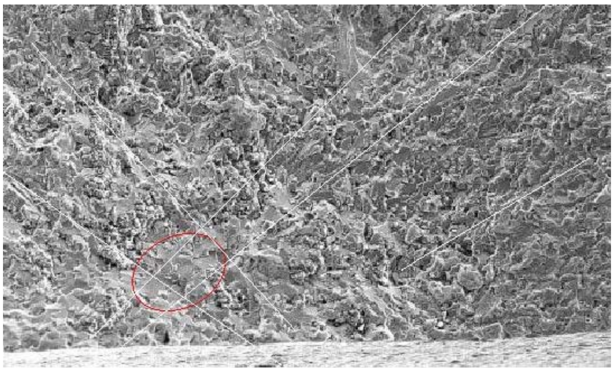


Figure 20: Zone 1. Initiating area is within the circle just under the surface.

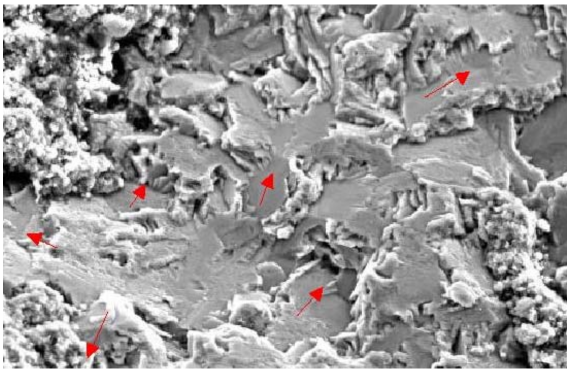


Figure 21: Zone 1. Close-up of area in figure 20. The arrows indicate the direction of crack growth.

Zone 2 (see figure 22): This zone has clear fatigues striations. A count showed at least 1400 lines in the zone.

Zone 3 (see figure 23): The zone has dimples typical of overload fracture (residual fracture).

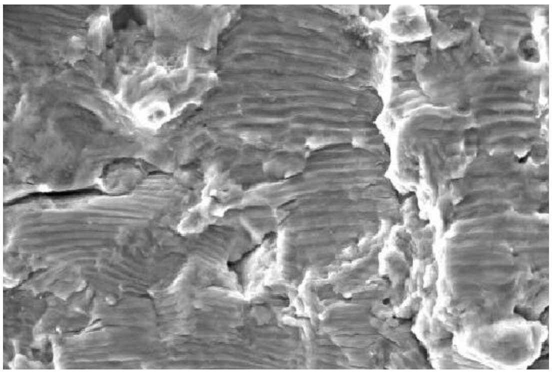


Figure 22: Clear fatigue striations in Zone 2.

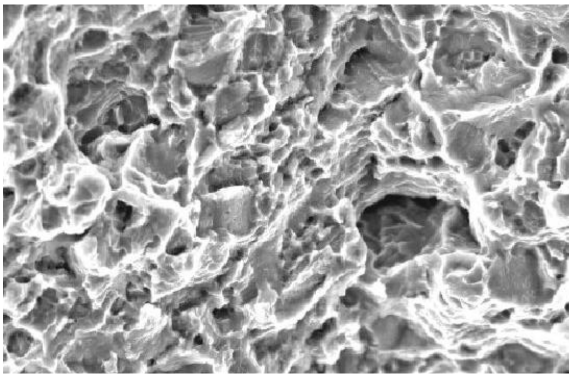


Figure 23: Dimples in Zone 3.

A metallographic cross section taken at the fractured airfoil indicated that the microstructure and material composition matched the prescribed specifications.

1.16.1.4 *Examination of the fuel heater*

After disassembly, the fuel heater was examined in more detail at the metallurgy laboratory in PWC's main manufacturing facility in Plant 1. There it was established that all of the fractures was caused by overloading. However, some corrosion was found close to the surface of the fracture on the front lower mounting lug.

1.16.1.5 *Report from Pratt & Whitney Canada*

On the basis of the examination of the engine with serial no. FA0019 in Montreal, Pratt & Whitney Canada drew up report no. PW15-041. This quotation is from the conclusion:

> *"The failure of the 1st LP compressor airfoil was due to fatigue. The fatigue initiation site was located .003 inch below the surface at the airfoil mid-cord length. An in depth Engineering analysis into the cause of this fatigue showed that it was most likely due to vibration excitation due to the geometry of the front intake struts at the compressor entrance."*

1.16.2 Examination of the engine's fire detection system

1.16.2.1 The fire detection system for the left engine continued to warn of fire after the engine was cold. Trouble shooting on the airplane located the fault to the two overtemperature/fire detectors linked in series in the engine compartment and the wing leading edge. The two sensors were removed and sent to the manufacturer, Kidde Aerospace, in the USA for closer examination. The work was carried out on 12 August 2004, and a representative from America's National Transportation Safety Board (NTSB) was present.

The following detector loops were examined:

P/N 10-1096-01 S/N 01-5166 (155 cm long)

P/N 10-1098 S/N 01-0147 (838 cm long)

Initially, the two sensors were examined by measuring the continuity between pins A and C, and between C and D (see figure 24).

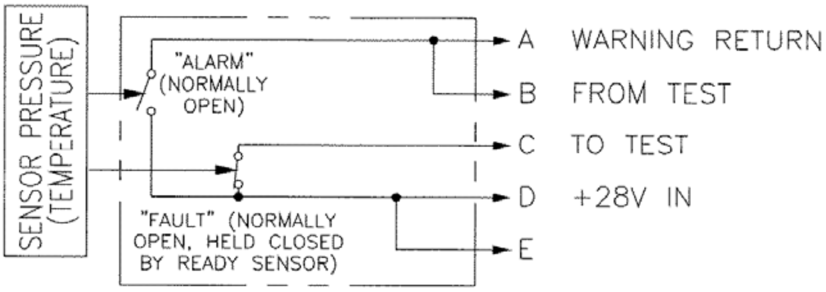


Figure 24: Electrical diagram of sensor.

The following results were obtained:

	Between pins A and C	Between pins C and D
P/N 10-1096-01	BREAK	CONTACT
P/N 10-1098	CONTACT	CONTACT

1.16.2.2 The results show that P/N 10-1096-01 has normal values and P/N 10-1098 has a faulty value. P/N 10-1098 was therefore examined in more detail to chart the open and close functions of the alarm switch (between pins A and C). Opening the contact between pins A and C was only successful once the sensor had been submerged in liquid nitrogen (- 196 ºC). The alarm switch closed again at 77 ºC. According to the manufacturer's maintenance records, the switch closed at 263 ºC when the sensor was checked during initial build.

1.16.2.3 The end of the sensor (tube) was then cut off and pressure applied to test switch function. The results were as follows (Pressure given in psi. The result of the initial build check given in parentheses):

	Between pins C and D	Between pins A and D	Between pins A and C
BREAK	22 (21)	31 (75)	35
CONTACT	18	60 (77)	57

1.16.2.4 It was evident that the sensitivity of the switch actuating the alarm function had changed. The pressure switch was cut open to allow access to the electrical contact side of the diaphragm (see figure 2). The diaphragm proved to be intact, but it exhibited a small dimple that was offset to one side that had arisen at some stage after manufacture. The diaphragm consequently did not have the same curve as a new diaphragm would have.

1.16.2.5 Kidde Aerospace was of the opinion that diaphragm deformation had arisen as a result of extremely high pressure in the sensor tube. This was due to the sensor having been exposed to extremely high temperature over a large area. For example, this type of pressure might occur if 5.6 m of the sensor tube was subjected to 538 °C. The manufacturer had no previous experience of diaphragm deformation due to temperature. There was nothing to indicate any flaw in the manufacture of the diaphragm. The manufacturer believed the situation was so extreme that implementing improvements would be difficult without introducing completely new sensor technology.

1.17 Organizational and management information

1.17.1 Widerøes Flyveselskap

Widerøes Flyveselskap ASA was established in 1934. The company is currently wholly owned by the SAS Group. At the time of the incident, Widerøes Flyveselskap had approx. 1,200 employees and operated 29 airplanes of the type DHC-8-103/311/402.

The company has a licence for air passenger transport, mail and freight and an Air Operator Certificate (AOC) based on BSL JAR-OPS 1.

1.17.2 Technical maintenance

1.17.2.1 The maintenance programme is described as follows in the company’s Continuing Airworthiness Management Exposition, subparagraph 1.10.1 Reliability Programmes:

> *“Widerøe’s Aircraft Maintenance Programme is based upon the MSG-3 logic, Maintenance Review Board Report process and all the associated programs for the continuous surveillance of the reliability are considered as a part of the Aircraft Maintenance Programme.*
>
> ---------
>
> *Internal Maintenance Review Board analyses the reliability data once a quarter.”*

In addition, there is a description of Engine Condition Trend Monitoring (ECTM) being included in the company’s Reliability Programmes and that:

> *“Engines are controlled by ECTM programme.”*

1.17.2.2 It appears from the company’s investigation report that ECTM had not been carried out on the PW150A engines within the company during the period from 15 November 2003 up to the date of the incident. According to the report, this was linked to the ECTM task being transferred to new personnel without the necessary training having been provided. In addition, problems were found with Ground Based Software (GBS). It was later decided that engine monitoring should be taken care of by Pratt & Whitney Canada, but this had not started when the incident occurred.

1.17.2.3 PW150A engines use a system of error codes (Time Limited Dispatch – TLD) which provide warnings according to degree of severity. The system is an integrated part of the FADEC system. It covers only those faults associated with the safety aspects of the control system related to loss of redundancy and the subsequent potential loss of thrust control. Errors give points which when totalled determine whether flying has to cease (No Dispatch), or how long flying can continue before maintenance has to be carried out.

The error codes are read off for every Line Check and computations for TLD are made every time. The personnel involved in the technical department gave the AIBN the impression that the TLD system would take care of any necessary safety monitoring of the engines. They therefore believed that the period involving the ECTM problems consequently had not had any immediate consequences on the maintenance.

1.17.2.4 The company's Maintenance Review Board has as its objective:

> *"To detect strengths and weaknesses in the maintenance system, implement measures that take care of the company's objectives for flight safety and economy."*

Two meetings of the Maintenance Review Board were held in the period prior to the incident (2 December 2003 and 1 April 2004, respectively). Vice President Technical, Vice President Quality Assurance and Vice President Operations and also a number of other central people from the company's technical and operations department were invited to attend the meetings of the Maintenance Review Board. Externally, the company's technical and operations inspectors from the Civil Aviation Authority – Norway were invited. The minutes of the meetings indicate that a large proportion of the people invited by the company to attend, attended both meetings. No one from the Civil Aviation Authority – Norway attended the meeting on 2 December and only the technical inspector attended the meeting on 1 April.

On the basis of the documentation submitted, the AIBN cannot see that any deficiencies concerning ECTM were items on the agendas of these meetings.

1.18 Aditional information

1.18.1 Similar incident

1.18.1.1 9. July 2004, the crew of a DHC-8-402 belonging to SAS Commuter experienced an equivalent blade fracture. While flying on FL 240 en route from Zürich (LSZH) to Stockholm Arlanda (ESSA) they heard a bang, noticed that the airplane yawed to the right and saw that the right engine was shut down automatically. A short time afterwards, the fire alarm actuated for the right engine and the crew carried out the Abnormal and Emergency checklists. The fire alarm stopped after a short time. The crew declared an emergency and went straight to Hamburg (EDDH), landing there without further complications.

1.18.1.2 The right engine proved to have sustained a fracture in a compressor blade in the first stage compressor (see figure 25). Consequently, the decision was made to remove the engine and send it to the manufacturer, Pratt & Whitney, in Montreal, Canada. The engine (serial no. FA0016) was examined in Service Centre Plant 5 in Montreal. Apart from Pratt & Whitney Canada, representatives of Canada's Transport Safety Board (TSB) and the airplane manufacturer (Bombardier Aerospace) were present during the examination. In total, the engine had accumulated 5,656 flying hours and 5,629 cycles.

1.18.1.3 On the basis of the examination, Pratt & Whitney Canada drew up report no. PW15-042. In brief, the report's content can be listed as follows:

- The engine showed traces of heat damage to the silicone rubber enclosing the fuel nozzle manifold lines. Analyses and experiments in heating up the silicone rubber showed that the heat damage found on the engine had come from naked flames.

- The ignitors and associated high tension leads were examined in detail to see if they might have been a possible ignition source. No faults or abnormal indications were evident.

- P2.2 bleed valve was partially wet from oil inside. There was no trace of fire inside the valve.

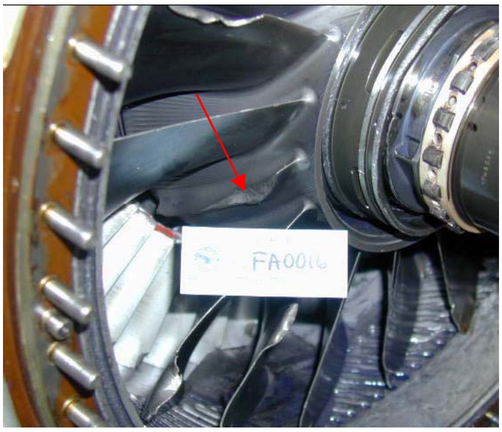


Figure 25: Fracture in compressor blade. Engine S/N FA0016.

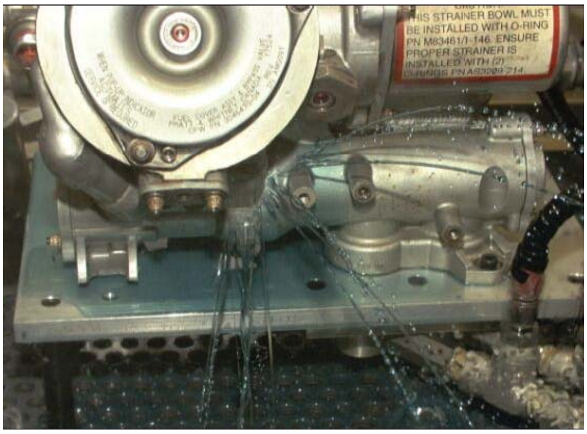


Figure 26: Leakage from the fuel heater at low pressure. Engine S/N FA0016.

- Samples were taken for chemical analysis of the black coating from several places on the engine. Most of the results showed traces of engine oil. None of the samples contained traces of fuel.

- The front, lower mounting lug on the engine’s fuel heater was cracked. The three other retaining bolts were found loose. A long crack was found in the actual fuel heater housing and the underside of the unit was wet with oil. During pressure testing on the bench, the fuel heater was not found to leak fuel. However, the crack led to an oil leak of 8.03 kg per minute at an oil pressure of 20.6 psi (see figure 26). A more detailed examination of the crack showed that it had arisen as a result of overloading.

- The speed sensor for the low pressure part of the engine (NL probe) was damaged at the tip after contact with the rotating toothed wheel.

- The power transmission shaft (the PT shaft) had several marks from contact with rotating parts. The damage was particularly severe at the front of bearing no. 2.

- The front intake case was removed to provide access to the first compressor stage. This showed that there was damage to the trailing edge of all of the front intake case struts. The greatest damage had occurred on the struts at the 7 and 9 o’clock positions (viewed from behind). The bearing housing for bearing no. 2.5 was damaged, exposing the return oil channel.

- One first stage compressor blade had broken approx. 130 mm from the blade root. The loose part had wedged itself tightly between the compressor blades and the compressor housing. All of the other blades had varying damage. A more detailed examination of the fracture surface disclosed that the fracture was caused by fatigue very like that found on engine no. FA0019 (see figure 19 and 28): Cracks were also evident on the leading edge of two other first stage compressor blades (see figure 27).

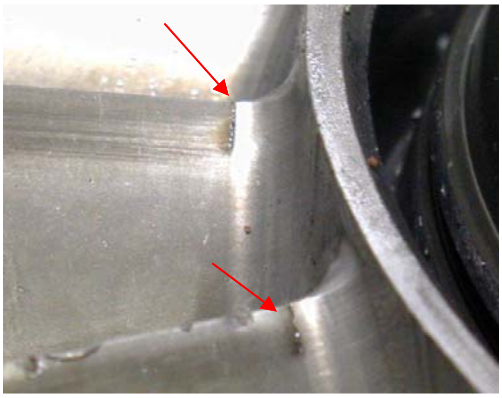


Figure 27: Cracks in the leading edge of two first stage compressor blades. Engine S/N FA0016.

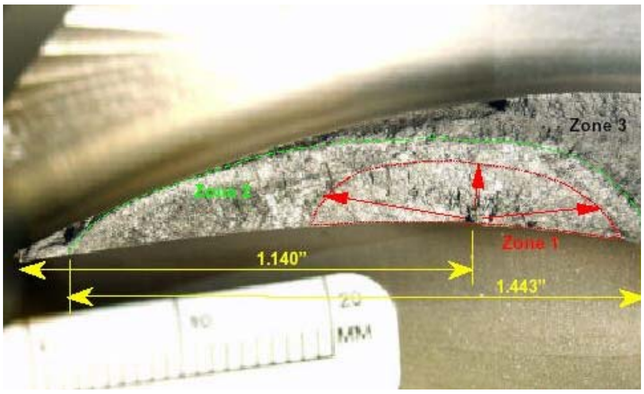


Figure 28: There are many common features in the fracture surfaces of the compressor blade from engine S/N FA0016 and the fracture surface from engine S/N FA0019 (see figure 19).

- Bearing no. 2.5 had been damaged. The rollers were, to a varying degree, flattened and squeezed into the frame that holds the rollers in place. At the 3 o'clock position, the rollers were completely flattened.

- The second stage compressor blades in parts had major wear on the blade tips. All other stage stator blades had been pulled out of the inner brackets. A similar pattern of damage could also be found on the compressor's third stage.

- The high pressure compressor rotor had damage from contact with the compressor housing.

- The low pressure compressor, high pressure compressor, high pressure stator, combustion chamber and high pressure turbine all had damage from having been hit by foreign objects moving through the engine. The damage decreased towards the back of the engine. The same areas were also moistened by engine oil.

1.18.1.4 The report from Pratt & Whitney Canada contained the following conclusions:

- A first stage compressor blade had fractured due to a fatigue crack.

- The fracture was due most probably to vibrations caused by the shape of the front intake casing struts.

- The cracks in the fuel heater resulted from overloading that arose due to the imbalance in the compressor when the compressor blade came loose.

- There was no sign that an internal fire had caused an external fire in the engine compartment.

- There was no sign of a fuel leak in the engine compartment. The fire in the engine compartment was most probably an oil fire.

- It has not been possible to establish the cause of ignition for the fire in the engine compartment (as described in subparagraph 1.14.2, a cause was shown to be probable at a later date).

1.18.2 Measures implemented after the incident

1.18.2.1 *First stage compressor*

As a result of the current incident, Pratt & Whitney Canada issued several Service Bulletins:

- SB 35132 (Category 3) was issued on 11 June 2004. It recommended a Fluorescent Penetrant Inspection of the concave side (the back) of the blade roots on the low pressure compressor first stage. The recommended deadline for making the inspection for the first time varied depending on the operating time of the airplane's engines. Performing the subsequent inspections was then recommended every 200 flying hours. The first revision of the service bulletin (SB A35132R1) was issued on 18 June 2004. Apart from several minor changes, emphasis was also placed on the number of Total Cycles Since New (TCSN) for the engines. In the event of any discoveries, Pratt & Whitney Canada should be contacted. The inspection was approved to be carried out at Widerøe with the assistance of Eddy Current, which is a more accurate and comprehensive method of inspection than the method described.

- SB 35139R1 (category 4[6]) was issued on 2 November 2004. Revision no. 1 was issued on 11 January 2005. It recommends that the low pressure compressor first stage should be replaced with a new type. Widerøe has installed the new type in all their compressors by May 2007.

- SB 35141R2 (Category 3) was issued on 2 November 2004. Revision no. 2 was issued on 2 April 2005. It appeared that the new type of first stage also had similar problems of crack formation as the original type. SB 35141 describes an Eddy Current Inspection of the convex side (front) of the blade roots on the low pressure compressor first stage. It recommends that the inspection is made when 500 flying hours are reached or 500 cycles (TCSN) depending on which comes first, and that this is repeated at the same intervals.

As a result of the repetitive inspection (SB35141) required with the improved first stage compressor, Pratt & Whitney Canada developed a new first stage compressor with a modified profile and a change of material. This improved compressor was made available to production and PW150A operators under SB35191 in December 2006 (SB35191). By May 2007 Widerøe has not introduced this third type of low pressure compressor in their fleet.

[6] P&WC recommends to do this service bulletin the first time the engine or module is at a maintenance base that can do the procedures, regardless of the scheduled maintenance action or reason for engine removal.

1.18.2.2 *Fuel heater*

As a result of the current incident, Pratt & Whitney Canada issued several Service Bulletins:

- SB 35133R1 (Category 3) was issued on 11 June 2004. It recommends a visual inspection of the fuel heater to detect any cracks in the unit's mounting lug and support web. The recommended deadline for making the inspection for the first time is 50 flying hours. Performing the subsequent inspections is then recommended every 500 flying hours. The inspection is to be performed by Widerøe.

Pratt & Whitney Canada is developing a strengthened fuel heater support that will withstand loadings in the event of blade fracture in the engine. Installation of this fuel heater will be the closing action for inspection SB 35133.

1.18.2.3 *Fire detection system*

According to the information from Bombardier, issued in February 2006, Kidde Aerospace in collaboration with Bombardier has started work on improving the fire detection system.

1.19 Useful or effective investigation techniques

During this examination no methods have been used which qualify for special mention.

2. ANALYSIS

2.1 Operating conditions

2.1.1 <u>The crew's handling of the situation</u>

2.1.1.1 The Commander had a poor start to the flight by arriving late for checking in. He therefore did not manage to prepare himself for the flight to the same degree as the First Officer. However, the crew spent a good length of time going through the checklists and preparations prior to take-off. The flight was normal for the first 7 minutes until the compressor blade came loose. The subsequent handling must be viewed in the light of the fact that the crew quickly and unexpectedly went from a calm, ordinary situation with a relatively light workload to an unclear situation with a significantly increased workload.

2.1.1.2 The bang and the jolt that was noticeable in the airplane meant that both pilots were immediately aware that something had happened. Many indicators pointed towards something being wrong with the left engine. The First Officer quickly identified that the problem was linked to the left engine and ordered the engine to be shut down at the same time as the fire alarm actuated. During the first 17 seconds after the blade fracture in the compressor, the Commander shut down the left engine (Feather) and pushed the Power Lever on the right engine past Detent. The execution of these actions was not notified to the First Officer. The AIBN cannot see that the crew in this period coordinated the tasks as described in the company's OM Part B, Section 3.0 (see subparagraph 1.6.5.1). On the basis of the First Officer's statement, it appears that he was uncertain about what the Commander was doing, and of whether the right actions had been taken. This may indicate that the crew initially acted too quickly and without coordinating their actions.

The First Officer's uncertainty about whether everything had been done correctly was again evident at 07:40:00 (see subpara. 1.1.4) when he requests verification of the items on the checklist.

2.1.1.3 The DHC-8-400 has systems for automatic feathering of the propeller (autofeather) and Uptrim during take off. A situation with loss of power from one engine would therefore be handled automatically during the most critical take off phase. The failure in the compressor took place after the Autofeather and Uptrim was deactivated. However, the airplane was flying at high speed at a safe altitude regarding the terrain below. In addition, the First Officer had no problems in controlling the airplane. The AIBN is therefore of the opinion that the crew could well have allowed themselves more time before taking action. The situation that arose did not demand immediate action without allowing time for confirmation from both crew members. The Commander had previously flown DHC-8-100/300 with less powerful engines and a more basic engine power control system. Taking into account the short time that he had been flying the DHC-8-402, it is probable that the Commander, in this rather stressful situation, reverted to previously learned procedures. This could be one explanation for why the Commander pushed the right Power Lever past the detent and thus disabled important engine protection systems. Afterwards, it was evident that operating the Power Lever had entailed an overloading of the right engine which could have been avoided if the manufacturer and airline company's procedures had been adhered to.

2.1.1.4 The First Officer decided to return to Torp and turned to right. The turn was sharp with a maximum bank angle of 47°. It is understandable that the First Officer wanted to return as quickly as possible, but the steep bank angle bears the sign of unnecessary haste, in the opinion of the AIBN. A bank angle of 47° is 17° more than the limit of 30° which triggers an automatic acoustic bank angle warning to the crew. In this case, the manoeuvre did not endanger safety because the airspeed increased and the airplane was in a descent. Nevertheless, a bank angle of this magnitude is not good because it can frighten the passengers unnecessary.

2.1.1.5 The First Officer (PF) initially assumed an active role. He identified the problems, ordered shutdown of the left engine, requested confirmation that the left engine was in feather and requested that the front extinguisher bottle should be discharged. It is rather uncertain whether Tank Aux Pump was switched off during this period, but otherwise the actions were in compliance with the checklist memory items (see subpara. 1.6.5.2). Later on, the First Officer also took over radio communications with Oslo Control when he stated that he was returning. He then initiated the run-through of the checklists.

2.1.1.6 During the first hectic period, AIBN is of the opinion that the Commander was unable to come to grips with the situation, and that he was passive in having the various actions verified. There may be several reasons for this. The problems arose suddenly and the First Officer responded very quickly. The First Officer was also more experienced on the DHC-8-402 than the Commander. The AIBN cannot disregard the Commander's delayed check-in as being a possible factor. In addition, the ability to handle emergency situations depends on the individual, and this may have been an explanation of the two people's patterns of reaction. The result was a 'flat' authority gradient that the AIBN believes had a negative effect on crew coordination. Ideally the Commander would have a rather higher level of authority than the First Officer, and would make strategic decisions in the event of an incident. These decisions would preferably be made on the basis of suggestions and input from the First Officer when the situation permits.

2.1.1.7 28 seconds after the incident arose, the cabin crew called the cockpit. At this time, the flight crew were in the process of gaining an overview of the situation and had a very high workload. The call came in addition to several other indications and acoustic warnings. It can be very demanding to sort out these different alarms and to give highest priority to the most important, without reaching the limit of mental capacity. The AIBN is of the opinion that the aircrew prioritised correctly when they did not answer. The AIBN however can understand that the cabin crew became uneasy and wanted information on what was about to happen. In situations in which the cabin crew ought to understand that the flight crew is just become aware of an abnormal occurrence, the cabin crew ought to wait a short while before making contact. That advice must never prevent passing on information of abnormal conditions obviously not known by the flight crew, noted by the cabin crew or passengers. In this type of situation, it is important to exercise judgement, and an assessment of when to make contact must be made in each individual case. In this context, it is also important for cabin crew to be precise in passing on things that have been observed.

2.1.1.8 It has been shown that flight crews seldom consider situations to be so critical that they make an emergency call in compliance with the guidelines provided by the ICAO. In this case, they notified Oslo Control at an early stage that there was a fire in one engine, but the term MAYDAY was sent just over two minutes after the situation arose. The AIBN is of the opinion that no one should hesitate to send a correct emergency message when a serious situation arises. As complete as possible an emergency message is a good basis for the efficient handling of the situation on the part of air traffic control. In this case, deficiencies in the emergency message had no consequences on the outcome of the incident. If an emergency message is sent, and shortly thereafter the situation appears not to deserve such high priority, the message can at any time be cancelled without having any subsequent consequences for the crew.

2.1.1.9 Several of the circumstances mentioned above ought to be reviewed by the company’s training department and evaluated as regards possible training programme improvements. It ought also to be possible to learn from those circumstances of this incident which was resolved in an excellent manner. It ought to be mentioned that the flight crew immediately decided to return to Torp. In addition, they gradually sorted things out by going through the relevant checklists in a structured manner and they kept the air traffic control service constantly informed about the seriousness of the situation. Mention ought also to be made that the crew planned the landing and evacuation well. They chose to be positioned on the runway with the wind coming in from the front right. The incident was therefore handled in a way that prevented the situation from really compromising the safety of anyone onboard and without anyone sustaining physical injury.

2.1.2 The air traffic control service’s handling of the situation

The incident was handled smoothly and well by all of the air traffic control service units involved. Communications between the crew and the air traffic control service were characterised by an understanding of the situation and a methodical approach. Neither Oslo Control nor Farris Approach burdened the crew with unnecessary questions and the crew was given necessary clearances at an early stage. The AIBN believes that the height restriction imposed for a 13-second period during the descent had no other consequences than that the crew had an extra detail to relate to for a short period. Neither does the fact that the crew had to change radio frequency twice appear to have had a negative impact on the situation. In emergency situations, however, the air traffic control service ought to endeavour to have the fewest possible number of frequency changes.

2.2 An evaluation of the fracture of the compressor blade

2.2.1 It became clear at an early stage that the fracture of the compressor blade was due to metal fatigue. A fatigue crack would become a fracture when the load exceeds the strength of the remaining material. This can occur during ‘normal’ loads, during periods with loads up to the maximum permissible or during unforeseen high loads. In this case, the engine was working under ‘normal’ load conditions, and nothing indicates that the blade fracture was due to damage applied from the outside or other abnormal loads. It was thus only a question of time before the compressor blade fell off, assuming that it was not detected in time during inspections.

2.2.2 The demands in a compressor are huge as regards strength, weight and aerodynamic efficiency. The compressor is also influenced by dynamic loads from the propeller, the shape of the air intake, and the stator and rotor stages downstream in the compressor. These loads could be difficult to trace, and further complicate the work on strength computations. A number of cracks discovered and the two incidents discussed, with compressor blades coming loose, show that Pratt & Whitney Canada PW150A engine was still in a maturing phase.

2.2.3 The AIBN has not used any resources in finding the exact cause of the blade fracture on LN-WDA. However, there is reason to note that the crack looks as if it started in an area approx. 80 µm under the surface. When the blades bend tensile stress become greatest at the surface. To avoid concentrations of tensile stress in the surface, the manufacturer has glass bead peened the blades, and in that way has applied compression stress to the surface. Applied energy can vary - for example, depending on the length of time, the distance and the velocity at which the glass beads are blasted against the surface. The amounts of energy applied indicate the depth and level of the compression stresses. To obtain the optimum mechanical characteristics, it is important that applied energy is optimised to ensure that cracks neither arise in the surface nor in the transition layer between neutral and compression stresses. The compressor first stage rotor has a complex geometric shape and is machined out of one piece. This makes major demands for a smooth surface treatment. The AIBN therefore does not exclude the fact that variations of surface treatment could have been a factor leading to locally high tension stresses and crack initiation approx. 80 µm under the surface. This situation does not necessarily conflict with the conclusions from Pratt & Whitney Canada about the fracture being due to vibrations caused by the shape of components in the air intake.

2.2.4 The PW150A engine has been recently developed. It is a well known fact that new engines can have varying degrees of reliability issues. The complexity and challenges in the design are confirmed by the fact that the second version of the compressor first stage had a similar problem at the mid-cord area. Problems of this type must initially be handled during testing before the engines are released onto the market (certified). The AIBN has not gone into details of the process the engine was subject to before it was type certified. However, it is clear that operational reliability cannot ever be fully verified – in computations or in testing. After the engines have been brought into commercial operation, any potential remaining elements of uncertainty must be taken care of by means of inspections and monitoring. The fact that the engine type in this case had a weakness that was not solved satisfactorily before a serious safety problem arose, ought to be a wake-up call.

2.2.5 Pratt & Whitney Canada has worked continually on improving the engine once the problems of cracks in the compressor first stage became known. In addition, the manufacturer has issued a series of service bulletins describing inspections to address safety. The two incidents discussed in this report show that safety was not sufficiently controlled, despite these precautions. This is serious, in the opinion of the AIBN. The organisation in the best position to resolve these problems is Pratt & Whitney Canada. It is not to the manufacturer's advantage that their products have a safety problem, and they have everything to gain from finding a satisfactory solution. The AIBN therefore finds no grounds to put further pressure on the manufacturer, and is not going to put forward any safety recommendations in this area.

2.3 Consequential damage

2.3.1 Mechanical damage

2.3.1.1 The investigation has shown that, viewed in isolation, the blade fracture did not result in the most serious damage. The blade fracture mainly meant that fragments from the blade entered the compressor, something that caused damage to the compressor stagees located behind. This is damage that could lead to a compressor stall [7] and an automatic shutdown of the engine by the FADEC when the autofeater system is armed[8]. However, the major consequential damage in the nacelle was due mainly to the imbalance arising in the compressor when the compressor blade came loose.

2.3.1.2 The AIBN believes the imbalance that arose in conjunction with the blade fracture applied loadings to the engine and the rotating components beyond design limits. The imbalance led to instantaneous damage of bearing no. 2.5 and the destruction of the bearing housing itself. Next, this led to contact between rotating and stationary parts of the compressor and an instantaneous breaking of the compressor rotation. The compressor with its associated turbine reduced the rotational speed from approx. 25,000 revolutions per minute to a standstill in approx. 4 seconds. In the AIBN's opinion, this deceleration implied torsion forces that contributed to a permanent deforming of the load-bearing structure in the nacelle. Further, the deceleration caused the FADEC logic to shut down the engine independent of the flight crew actions.

2.3.1.3 The imbalance in the engine led to cracks in the fuel heater. The fact that this component was damaged is principally because it has a large mass in relation to the strength of the attachment. It is also possible that, because of its location close to the compressor, the component became heavily exposed to the shocks.

2.3.1.4 The SAS Commuter incident on 9 July 2004 involved almost identical mechanical damage. The two similar independent events resulting in a loss of an engine indicates that damage to the fuel heater and the ignition of engine oil is to be expected when the low pressure compressor first stage loses blades. The incidents have disclosed the fact that the attachment of the fuel heater must be redesigned to ensure that internal mechanical

[7] Compressor stall arises when the airflow in the compressor is disrupted, stops or when the air turns and exits again via the air intake. The situation arises on damage to the compressor or when critical angles of attack on the compressor blades (wing profiles) are exceeded for other reasons.
[8] The autofether was not armed when the compressor blade fractured.

damage in the engine does not imply any danger of fire in the engine compartment. Pratt & Whitney Canada is developing a strengthened fuel heater support. The AIBN therefore finds no grounds to put further pressure on the manufacturer, and is not going to put forward any safety recommendations in this area.

2.3.2 Fire

2.3.2.1 *Introduction*

Damage to the nacelle shows that it has been exposed to fire with high temperatures. Particularly on the left side of the engine and back up along the lower regions, the effect of the heat has been particularly great. The melting of aluminium components indicates that the temperature was 500 - 620 °C in places. Chemical analysis of soot deposits on the engine indicates that it was engine oil that burnt. It is impossible to calculate how much engine oil fed the fire. The engine contained approx. 24 litres of oil, but some of this leaked out without burning. It has not been possible to show traces of combusted fuel (JET A-1). The nacelle otherwise contains very little combustible material. The engine compartment is ventilated to prevent any accumulation of combustible gases. At the same time, the ventilation contributes considerable volumes of oxygen for potential combustion.

2.3.2.2 *Ignition*

The damage in the compressors and the bearing housing for bearing no. 2.5 caused engine oil leak inside the compressor. Some of this oil was probably drawn into the engine and was combusted in the combustion chamber in the period when the chamber temperature was sufficiently high. This was supported by the fact that traces of oil were found in the compressor, the combustion chamber and the high pressure turbine. At the same time as the oil leak, fragments of metal from the compressor moved downstream inside the engine. Together with the compressor stall, this could result in incomplete combustion with flames and a shower of sparks emitted from exhaust tube.

While there was a high temperature and flames at the back in the exhaust tube, engine oil began to flow out of the crack in the fuel heater. The oil came out under pressure and was dispersed finely. The exhaust system, which is designed to create an ejector for ventilating the engine compartment, drew this oil mist into the flames coming out of the engine. This, according to Bombardier and Pratt & Whitney Canada working party, is the most probable explanation for the ignition, and the AIBN supports that theory. After the oil was ignited, the flames probably worked their way forward into the engine compartment. The pattern of fire damage observed during the inspection is in conformity with a theory like this.

2.4 The airplane’s fire detection system

2.4.1 The engine’s fire detection system actuated 9 seconds after the compressor blade came loose. This was immediately registered by the crew and the necessary measures were taken. The fire detection system thus fulfilled its primary task, of warning the crew of fire, in an excellent manner. However, the fire alarm stayed on for 8 minutes after the last fire extinguisher bottle should have extinguished the fire. The crew therefore believed that the engine was still on fire up till the airplane landed at Torp. Afterwards, it became known that the fire detection system malfunctioned. There is much to indicate that the fire went out before landing. In an imagined situation in which there was no suitable emergency landing place in the vicinity, such incorrect indications could lead to unendurable pressure and burden on the crew. An ongoing fire in an engine could, at worst, spread to the fuel tanks and to structural damage in the wing, for example. Although the probability of this is very low on a DHC-8-400, the AIBN believes that this type of incorrect warning is highly unfortunate.

2.4.2 The manufacturer, Kidde Aerospace, is of the opinion that their sensor was subject to extremely high temperatures and that current technology has difficulty in handling that. The AIBN believes that similar fires could occur in engines, and that oil or fuel leaks even for short periods could lead to similar intensity in the fire. It cannot therefore be ruled out that fire detection systems, with the technology discussed, would fail in a similar manner in future engine fires also.

2.4.3 There is no certainty about the requirements specified for the fire detection system with regard to cancelling the warning when a fire has gone out. The requirements given in FAR 25 (see subpara. 1.6.8.2) do not discuss this directly. Sentences such as *"It will withstand the vibration, inertia, and other loads to which it may be subject in operation"* may be interpreted as applying to 'normal operations'. In addition, questions could be asked about what '*at least fire-resistant'* means. The AIBN believes that the certification requirements in this area will have to be reviewed with a view to improving them. A fire detection system in areas where it cannot otherwise be verified whether the fire has gone out or not, must tolerate temperatures and durations of the order that arose in the fire in question. Alternatively, it should be possible to monitor the temperature in the area in some other way.

2.5 Time for fire the extinguishing

2.5.1 It cannot be established with any certainty exactly when the fire was extinguished. However, there is nothing to indicate that there was a fire in the engine when the airplane landed. The fact that uncombusted oil was found in the engine compartment supports this, and may indicate that the fire had gone out before the supply of new oil ceased. The high pressure section (NH) turned the engine oil pressure pump at sufficient rotational speed to supply the engine compartment with oil for a period of 2 minutes after the compressor blade came loose. If the pressure pump had engine oil available, this points to the fire having gone out at least 7 minutes before landing.

2.5.2 It is possible that the fire extinguishing system put the fire out when the first fire extinguisher bottle was discharged 29 seconds after the compressor blade came loose. In that case, the engine cooled down for approx. 9 minutes after the fire, before the fire and rescue service started their work. If the fire was put out when the second fire extinguisher bottle was discharged, it burned for approx. one minute. In that case, the fire went out approx. 8 minutes before the fire and rescue service started their work

2.5.3 Whether the fire was put out by the fire extinguisher bottles, or went out by itself when the supply of new oil ceased approx. 7 minutes before landing, is difficult to determine. There is little combustible material in the engine compartment apart from the oil.

2.6 Fire and rescue service

2.6.1 The fire and rescue service at the airport was notified immediately and consequently had sufficient time to make the necessary preparations before the landing. The fact that the fire brigade at nearby Sandefjord and ambulances were not notified in time had no consequences on the outcome of the incident. Failures in the emergency response plans could have serious consequences and such problems ought to be excluded during exercises. In this case, the reason for the failure was discovered during a review of the incident and the error immediately corrected.

2.6.2 Statements from teams from the fire and rescue service indicate that the engine was very hot even after the airplane landed. Although there were no visible flames in the area, the teams had to assume that there was fire in the engine and that the area had to be cooled down. The method used, of spraying foam into the engine's air intake and the engine intake bypass door, however, was not very effective. Those two openings are only linked to internal components of the engine (compressor, combustion chamber etc.) and to the engine bypass duct which is completely separate from the area that was exposed to fire. The fire and rescue service's efforts consequently had a very limited cooling effect before the engine covers were opened. The fact that the covers were not opened initially had no consequences on the scale of the damage. However, the fire and rescue service ought to get a better understanding of essential technical designs on aircraft that use the airport regularly.

2.6.3 The AIBN has not looked into the methods that the fire and rescue service at other airports in Norway would have used in a similar situation. However, there is reason to assume that this incident could provide a valuable lesson to all fire and rescue services in Norway. The AIBN would therefore like to encourage all staff linked to the fire and rescue service to evaluate current practice for putting out engine fires on turboprop aircraft.

2.7 Maintenance

2.7.1 Maintenance of the compressors

As far as AIBN has investigated, there is nothing to indicate that Widerøe has neglected to undertake the necessary maintenance on the compressor in question. S.B. 35111R6 (see subpara. 1.6.7.1) was carried out by means of Eddy Current. This is generally a better method of detecting minor cracks than Fluorescent Penetrant Inspection, which could also be used. The inspection intervals were set at 500 flying hours. The fact that the fracture occurred only 118 flying hours after the inspection was most probably due to the fact that the inspection described should be carried out along the leading edge of the blade, and not further in on the blade where the crack started. However, S.B. 35132, issued on 11 June 2004 (see subpara. 1.18.2.1), describes an inspection of the problem area in question.

2.7.2 Engine Condition Trend Monitoring (ECTM)

2.7.2.1 At the time of the incident, the PW150A engine type was in a maturing phase. The engine that had accumulated the most flying hours had only reached 6,800 hours and only a total of only approx. 200 engines were produced. This is a small number in relation to the experience that has been built up on most other aircraft engines used in scheduled civil aviation. Even thought the engine has been certified as per appropriate rules and regulations, it can be regarded as being in a run-in and trial phase. Correspondingly, after just over two years of use, the airplane type DHC-8-402 was relatively new within the company. The PW150A engine implied the introduction of new technology for engine monitoring, something that also set new requirements for the technical department at Widerøes Flyveselskap. The AIBN is of the opinion that, in general, the operation of relatively new aircraft types sets strict requirements for oversight and monitoring. In this case, the new engine type made great demands of the technical department at Widerøes Flyveselskap with regard to condition monitoring and information exchange with the engine manufacturer. An ECTM programme is an important tool in work of this kind. Its importance is also reflected in the fact that ECTM is included in the company's Reliability Programmes (see subpara. 1.17.2.1). The AIBN cannot see that the staff involved set in motion any compensatory measures when it became evident that ECTM was not functioning as presumed. The AIBN recommends that the company's technical department should process the failure in ECTM with a view to improving the procedures internally so that no similar situations can reoccur.

2.7.2.2 However, the AIBN cannot see that the deficient ECTM led to safety-critical situations. The problems with the compressor in the left engine could not be related to deficient ECTM. The right engine supplied sufficient power to bring the airplane safely back to a safe landing. The damage that was later found on the high pressure turbine on the left engine (see figs. 17 and 18), and corresponding carbon erosion on the turbine on the right engine, however, could have been detected by using ECTM. The carbon erosion reduced the engine's efficiency, thus increasing the fuel consumption. At best, this is financially bad for the company. More serious is the fact that carbon erosion was also reducing the margins for overtemperature during manual regulation (see subpara. 1.1.3) and could have contributed to the high turbine temperature that arose in the right engine.

2.7.2.3 The AIBN has established that, for a period, airplane type DHC-8-402 operated without ECTM. However, the AINB is more concerned about the failure of the company's Reliability Programmes without this being picked up by the Maintenance Review Board. An important task for the Vice President Quality Assurance and the Technical Management must be to ensure that programmes and functions in the maintenance system function as intended. Neither was it discovered by the Norwegian CAA oversight of the operator. The fact that the failure in ECTM was not discovered ought to lead to a review of working procedures and focus in the Maintenance Review Board. In 2007 Widerøe informed AIBN that several improvements were initiated to take care of issues described in subpara. 2.7.2.

2.8 Survival aspects

The passengers were at no time exposed to physical burdens that could impact on life or health. The most critical operation was the evacuation of the passengers. The distance from the exits down to the ground is so great that any passengers with mobility problems and people with frail health could have problems in getting out uninjured by themselves. They are dependent therefore on assistance from the cabin crew or fellow passengers.

3. CONCLUSION

3.1 General conclusions

3.1.1 <u>The crew</u>

a) The crew possessed the necessary licesnces and authorisations to serve onboard.

b) The Commander gained type rating on the DHC-8-400 in April 2004 and had consequently relatively limited experience of the airplane type.

c) The First Officer gained type rating on the DHC-8-400 in November 2003, and was thus the flight crew member with most experience of the airplane type.

d) Premature actions by the flight crew immediately after the incident impaired coordination of their duties. This led to uncertainty about status of action taken, and to unnecessary damage to the right engine.

e) The First Officer initially assumed an active role in the work of handling the problems that arose. Correspondingly, it might appear as if the Commander did not manage, in the same way to grasp the situation. This meant a flat gradient of authority and contributed to the lack of crew coordination.

3.1.2 The aircraft

a) The DHC-8-400 was first brought into regular scheduled traffic in the year 2000. The airplane type was therefore relatively new when the incident occurred.

b) Widerøes Flyveselskap introduced the airplane type in traffic in November 2001 and consequently had accumulated little experience of the DHC-8-400.

c) Widerøes Flyveselskap has many years of experience in operating older versions of the DHC-8, but these are different in essential areas, so that not all experience is directly transferable.

d) The DHC-8-400 introduced a new engine type that set the company’s technical department new challenges. The Engine Condition Trend Monitoring failed, without this being picked up by the company’s technical management.

3.1.3 Operating conditions

a) The flight was normal until, just less than 7 minutes after take-off, the airplane reached an altitude of 13,500 ft.

b) During the flight, no situations ever occurred that really threatened the safety of those onboard.

c) The incident was handled smoothly and well by the air traffic control service.

d) The weather conditions permitted visual approach to Torp. This reduced the amount of work in the last part of the flight. Otherwise, the weather conditions had no impact on the sequence of events.

e) The evacuation of the airplane was undertaken without problem.

3.1.4 The low pressure compressor

a) The AIBN has not found anything to indicate that the failure of the low pressure compressor could be traced back to deficiencies in the maintenance work at Widerøes Flyveselskap.

b) Pratt & Whitney Canada was aware that cracks arose in the low pressure compressor first stage. In order to temporarily ensure continuing airworthiness, Service Bulletin no. 35111 was issued to address cracking at the airfoil leading edges. At that time no crack indications in the airfoil mid-cord area had been observed. Hence, S.B. 35111 was not sufficient to prevent the actual blade fracture in the compressor.

c) The engine was type certified by both Transport Canada and FAA.

d) The incident that took place on 9 July 2004 involving an airplane belonging to SAS Commuter was initially identical to the incident with LN-WDA on 19 May 2004. The difference in the fire evolvement was due to coincidence. The incidents show that the fuel heater will have to be improved if fire is to be avoided in the event of serious mechanical damage inside the engine.

3.1.5 The fire

a) The fire was sustained by the supply of engine oil. Apart from engine oil and fuel there is little combustible material in the engine compartment.

b) Nothing indicates that the fire was fed with fuel. There was consequently a limit to the time the fire would last before it would put itself out.

c) The high temperature in the fire brought about functional failure in the fire detection system. The fire alarm indicated that there was fire in the engine right until the system was physically disconnected.

d) It cannot be established with any certainty exactly when the fire was extinguished. However, there is nothing to indicate that there was a fire in the engine when the airplane landed.

e) The fire extinguishing method that the fire and rescue service at the airport used initially was to little effect.

3.2 Significant findings

a) The fracture of a compressor blade in the low pressure compressor first stage was due to metal fatigue. When the blade came loose, the engine was operating under ‘normal’ loading conditions, and nothing indicates that the blade fracture was due to abnormal loadings.

b) Pratt & Whitney Canada had problems with the low pressure compressor first stage and was in the process of developing a new one when the incident with LN-WDA occurred. The investigations after the incident showed that the problems of the low pressure compressor were not sufficiently under control despite Service Bulletin no. 35111.

c) The fracture in the compressor blade gave rise to major imbalance and vibrations in the engine. This led to overloading cracks on the fuel heater, and oil leakage.

d) The fire probably arose because the engine oil from the fuel heater was sprayed towards the flames that emerged from the engine’s exhaust tube.

e) There are no certification requirements for fire detection systems to notify when a fire has gone out.

4. SAFETY RECOMMENDATIONS

The Accident Investigation Board of Norway is issuing the following safety recommendations:[9]

SL recommendation 2007/32T

According to the manufacturer, Kidde Aerospace, the fire detection system was damaged by the high temperatures during the engine fire. As a result of this, the fire alarm did not cease although the engine fire had gone out. The AIBN is of the opinion that an incorrect warning of this type is highly detrimental and can put unendurable pressure on the crew. Current requirements for fire detection systems do not explicitly state that the warning should cease once the fire has gone out. The AIBN recommends the Norwegian Civil Aviation Authority to become involved internationally with a view to improving the certification requirements for fire detection systems in aircraft, so that crews are given an indication that a fire has gone out.

SL recommendation 2007/33T

According to the manufacturer, Kidde Aerospace, the fire detection system was damaged by the high temperatures during the engine fire. As a result of this, the fire alarm did not cease although the engine fire had gone out. The AIBN is of the opinion that an incorrect warning of this type is highly detrimental and can put unendurable pressure on the crew. SHT recommends that the Norwegian Civil Aviation Authority in consultation with the FAA should consider making it mandatory for Kidde Aerospace to provide information about the wrong indications that can occur on the current equipment. This information ought to be provided to all aircraft manufacturers which have installed or will be installing this type of alarm equipment for incorporation into the Aircraft Flight Manuals.

SL recommendation 2007/34T

The method initially used by the fire and rescue service at Sandefjord Airport Torp while putting out the fire had little effect since the extinguishing medium did not penetrate to the hot areas between the engine and the engine covers. The AIBN recommends that the fire and rescue service at Sandefjord Airport Torp, in collaboration with technical personnel from Widerøe, should develop specific procedures for extinguishing fires on the DHC-8-400.

SL recommendation 2007/35T

Engine Condition Trend Monitoring (ECTM) is included as part of the company’s maintenance programme for the DHC-8-400. ECTM was not conducted on the PW 150A engines from 15 November 2003 until the incident. The situation was not a contributory factor to the engine fire, but indicates a failure within the company’s maintenance system. The AIBN therefore recommends that Widerøes Flyveselskap should undertake a review of the quality control and the function of the Maintenance Review Board with a view to preventing any similar failure of internal programmes.

[9] The Norwegian Ministry of Transport and Communications ensures that safety recommendations are submitted to the aviation authority and/or other ministries concerned for evaluation and monitoring, cf. Regulation on public investigations of air traffic accidents and air traffic incidents within civil aviation, Section 17.

The Accident Investigation Board Norway

Lillestrøm, 27 November 2007

APPENDIX

A Abbreviations

ABBREVIATIONS

AOC	Air Operator Certificate – approval documentation for aviation companies
APP	Approach – approach control
ATCC	Air Traffic Control Center
ATPL(A)	Air Transport Pilot Licence, Airplane
BSL	Bestemmelser for sivil luftfart (Civil Aviation Regulations)
CAR	Canadian Airworthiness Requirements
CAVOK	Ceiling And Visibility OK – weather code
CPL(A)	Commercial Pilot Licence Airplane
ECTM	Engine Condition Trend Monitoring
EMU	Engine Monitoring Unit
ENBR	ICAO code for Bergen airport Flesland
ENTO	ICAO code for Sandefjord airport Torp
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Requirements – American aviation regulations
FDR	Flight Data Recorder
FEW	Few – about clouds
FL	Flight Level – aircraft altitude given in units of 100 ft in Standard Atmosphere
FP	Pilot Flying
G	Gust – wind
HSLB	Havarikommisjonen for sivil luftfart og jernbane – the AIBN's name in Norwegian prior to 1 September 2005
JAA	Joint Aviation Authorities – organisation for collaboration between European aviation authorities
JAR	Joint Aviation Requirements – Joint European Regulations

JAR-OPS	Joint Aviation Requirements – Operations
KT/kt	Nautical Mile(s) (1 852 m) per hour
LPC	Low Pressure Compressor
METAR	METeorological Aerodrome Report – routine weather observations
MHz	megaHertz
OM	Operating Manual – operating manual in relation to JAR-OPS
OPC	Operator Proficiency Check
PC	Proficiency Check
PEC	Propeller Electronic Control
P/N	Part Number
PF	Pilot Flying – the member of flight crew who is operating the flight controls
PL	Power Lever – the handle used to regulate the power output from the engine
PNF	Pilot Not Flying – the member of flight crew who is not operating the flight controls
Q	QNH – altimeter setting related to the pressure at sea level
RGB	Reduction Gear Box
S.B.	Service Bulletin – continuing airworthiness recommendations from the manufacturer
SHT	Statens havarikommisjon for transport (Accident Investigation Board Norway)
TAF	Terminal Aerodrome Forecast – weather notification for an airport
TCSN	Total Cycles Since New – for example, the total number of take-offs/landings
TEMPO	Code for temporary weather changes
TLD	Time Limited Dispatch – technical approval with flying hours limitation
TWR	Tower