Australian Government
Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Investigation – 200702219

Final

In-flight engine failure
9km NE Wagga Wagga, NSW
de Havilland Canada Dash 8, VH-TQY
11 April 2007

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In-flight engine failure, 9km NE Wagga Wagga, NSW, de Havilland Dash 8, VH-TQY, 11 April 2007

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Abstract

On 11 April 2007, shortly after takeoff from Wagga Wagga Airport, NSW, the crew of a de Havilland Dash 8 aircraft registered VH-TQY, noticed an unusual popping sound, followed by a slight vibration through the power levers. On passing 3,800 ft there was a significant drop in torque on the left engine, with associated popping noise. The crew shut down the engine and returned to Wagga Wagga Airport. After initial inspection on the wing, the engine was removed and sent to the manufacturer for disassembly and examination.

The examination found that the engine's number-5 bearing, the high pressure (HP) turbine disc and stub-shaft had failed. These components were sent to the Australian Transport Safety Bureau for further examination. That examination determined the number-5 bearing had failed at its roller cage through fatigue cracking, the stub-shaft had failed under overload and the HP turbine disc had suffered blade tip rubbing.

The operator had experienced a previous number-5 bearing failure on another of its engines. That bearing displayed the same failure pattern of its roller cage and was consecutively serial numbered to the VH-TYQ engine's number-5 bearing.

As a result of this investigation, the engine manufacturer identified a batch of 15 bearings that required replacement and introduced procedures to minimise the risk of further number-5 bearing failures.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external organisations.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

FACTUAL INFORMATION

Sequence of events

On 11 April 2007, shortly after takeoff from Wagga Wagga Airport, NSW, the crew of a de Havilland Dash 8 aircraft, registered VH-TQY, noticed an unusual popping sound, followed by a slight vibration through the power levers. On passing 3,800 ft, there was a significant drop in torque on the left engine, with a continued popping noise. The crew shut down the engine in accordance with the operator's in-flight engine failure procedures and returned the aircraft to Wagga Wagga.

Passengers on the flight reported observing the left engine shuddering in time with the popping noise. Some passengers believed smoke and sparks were emitted from the engine's exhaust prior to the engine being shut down.

A subsequent examination of the engine oil filters revealed that the main engine oil filter blockage indicator had tripped. On opening the filter, thin threads and small chips of metal were found. The engine oil tank magnetic chip detector (MCD) was also examined and found to contain metallic slivers approximately 19 mm long and 0.05 to 0.1 mm wide. Further examination of the gearbox and oil scavenge filters did not reveal any evidence of foreign object damage or contamination.

Attempts to manually rotate the engine's high pressure compressor (HPC) by hand were unsuccessful. The propeller however, was able to be rotated, indicating that the failure was confined to the high pressure (HP) section of the engine. The engine was removed from the aircraft and sent to the manufacturer for disassembly and inspection.

Engine findings

Table 1: Engine details

Make	Pratt & Whitney Canada
Model	PW123E
ESN	AW0015
Time of manufacture	June 2000
Total Time	12,798.3hrs
Total cycles	15,921
TSO	1,006.7hrs
CSO	1,024
Where O/hauled	Pratt & Whitney Canada (UK) Limited

The engine (Figure 1) was disassembled and examined on behalf of the Australian Transport Safety Bureau (ATSB), at the manufacturer's facility in Quebec, Canada, under the supervision of the Transportation Safety Board of Canada. The examination found that the number-5 bearing, the high pressure turbine disc and stub-shaft had failed (Figure 2). These components were sent to the ATSB for further examination.

Figure 1: PW100 series engine

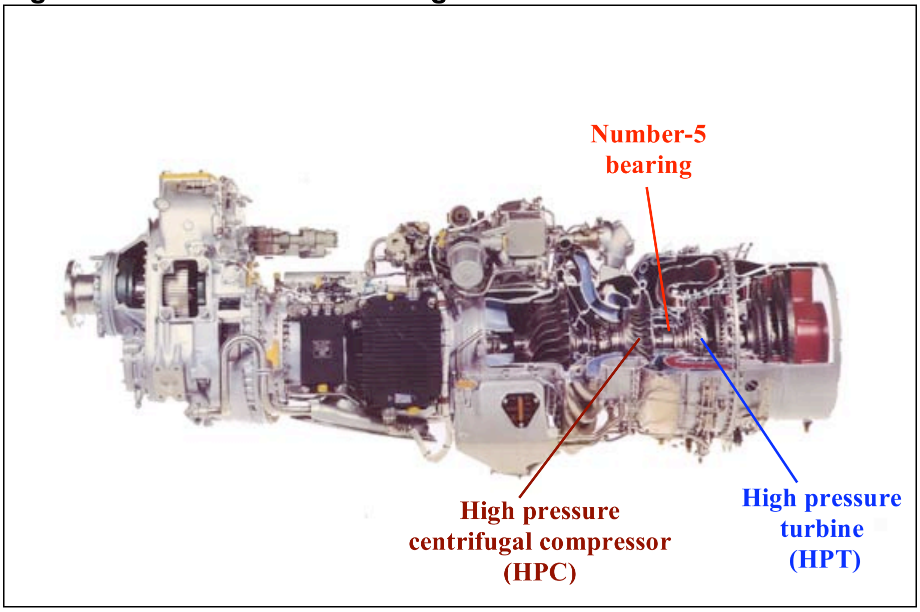
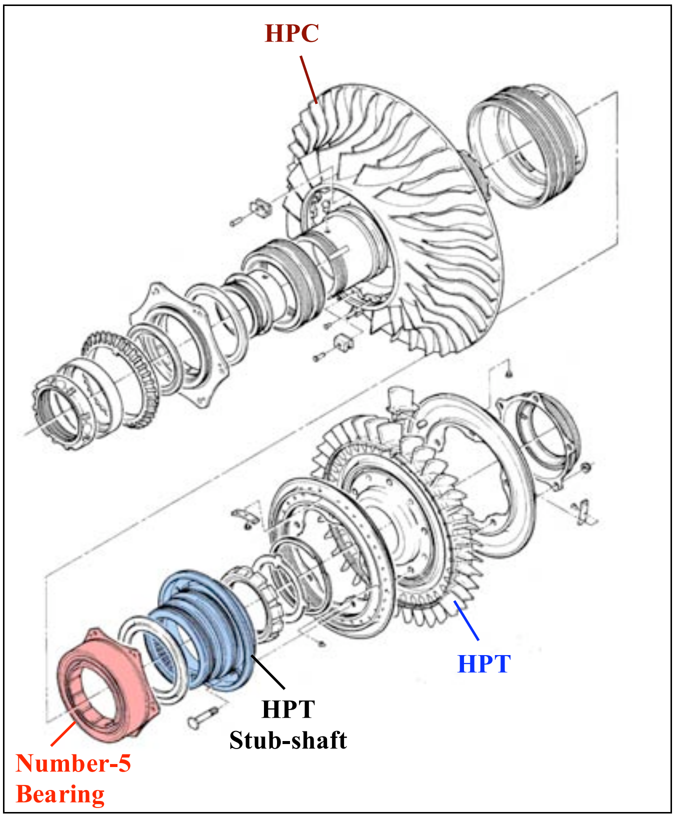


Figure 2: High pressure section



Number-5 bearing

The number-5 bearing was located in the high pressure section of the engine, between the high pressure centrifugal compressor (HPC) and the high pressure Turbine (HPT). The bearing assembly was a roller type, comprising 12 cylindrical rolling elements, a single-piece machined and silver-plated cage, an inner raceway and an outer raceway housing. Manufacturing identifiers etched onto the non-contact surfaces indicated that the bearing had been manufactured by the FAG Company with a part number 3121706-01A and a serial number FCN171486.

The examination found that the roller cage had fractured axially at the rails of one of the roller pockets (Figures 3 and 4). High magnification examination of the cross member fractures showed that the cage had failed due to fatigue cracking at the cage pocket corners.

Figure 3: Bearing components ESN AW0015 (fracture of cage pocket arrowed)

Figure 4: Fracture of cage pocket

Most of the cage pockets had been enlarged with evidence of the rollers skewing and rotating up to 90 degrees within some pockets (Figure 4).

Figure 4: Elongation of cage pocket

There was no evidence of heat distress on the roller cage. However, the inner and outer surfaces of the cage displayed evidence of rubbing contact against the inner and outer bearing raceways.

The bearing's outer raceway had a 0.4 mm deep wear groove around its entire circumference. The physical appearance of the raceway damage indicated that, as the cylindrical rollers became skewed, the resultant skidding induced frictional heating and machining of the race surface.

All 12 bearing rollers were accounted for. However, several had rotated within their pockets, with some displaying longitudinal skid wear and others spalling[1] damage to their outside diameters. All rollers had reduced dimensions and contained bluish discolouration, some rollers displayed evidence of coning (Figure 5).

Figure 5: Selection of bearing rollers showing damage sustained

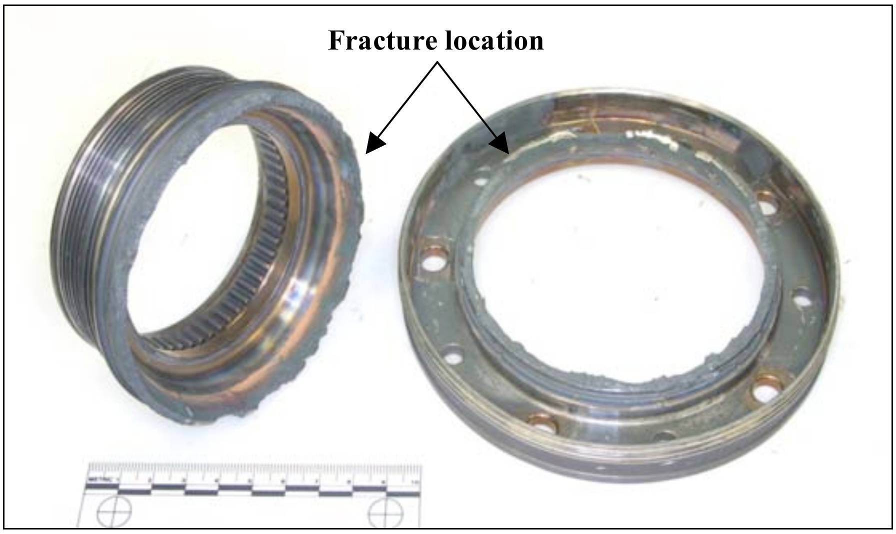
1 Spalling - Spalling is the result of fatigue and is recognized by craterlike cavities in the surfaces or raceways or rolling elements. *ASM Handbook, Failure Analysis and Prevention, Volume 11, Fourth Edition, p 503.*

The bearing's lubrication holes were found to be free from obstruction, with evidence of normal residue deposits found. A flow check of the number-5 bearing oil jets was conducted and found to be satisfactory.

High pressure turbine (HPT) and stub-shaft

The HPT assembly had separated from the HPC assembly at its stub-shaft. The stub-shaft's flange remained attached to the HPT disc by its retention bolts with the stub-shaft failing through overload at a change in section thickness close to the shaft-to-flange transition point (Figure 6). No evidence of pre-existing defects or evidence of progressive cracking that might otherwise have explained the shaft failure were identified. There was evidence of rubbing contact between the HPT stub-shaft and the stepped air-seal (Figure 7).

Figure 6: The fractured stub-shaft

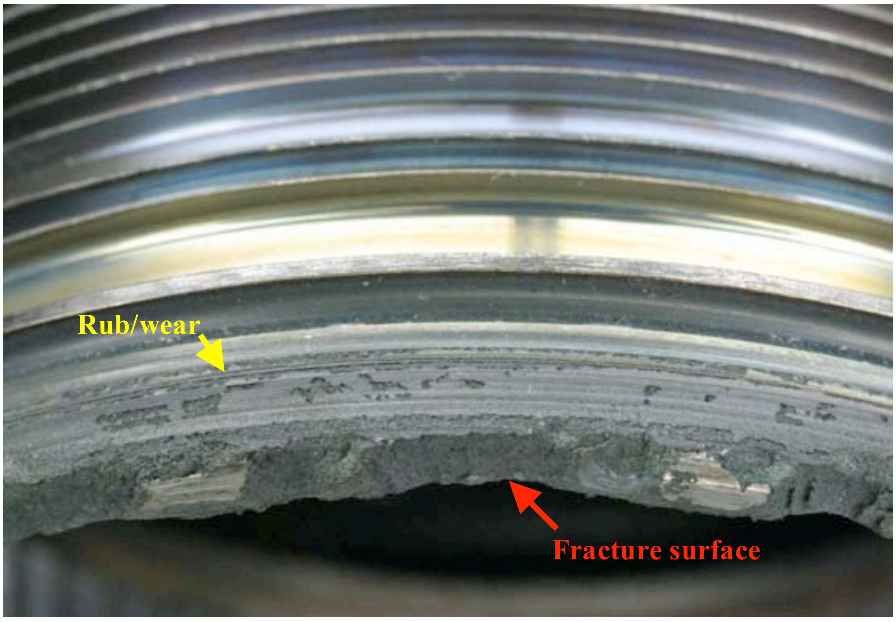


All retention bolts between the HP disc and stub-shaft displayed similar levels of torque when removed from the HP turbine disc assembly. Examination of the contacting surfaces between the bolted stub-shaft and the HP turbine disc assembly revealed no evidence of fretting.

The HPT disc's trailing edge and the leading edge face of the low pressure turbine (LPT) disc and rotor assembly also showed evidence of rubbing contact. Due to the loss of support from the number-5 bearing, the HPT rotor blades contacted the engine case shroud, sustaining heavy tip-rubbing damage.

The examination also found a dimensional discrepancy between the HPT vane ring inner-front support housing and its corresponding air-seal. The air-seal was below the design limits while the support housing was greater than its design limits. No evidence of oxidation/corrosion, wear or rubbing that could account for the dimensional deviation was found. The air-seal had been in service for 1,006.7 hours.

Figure 7: Close-up of the fractured HP stub-shaft showing abrasion and wear (labelled) from rotational contact with stub-shaft stator air-seal



Other engine components

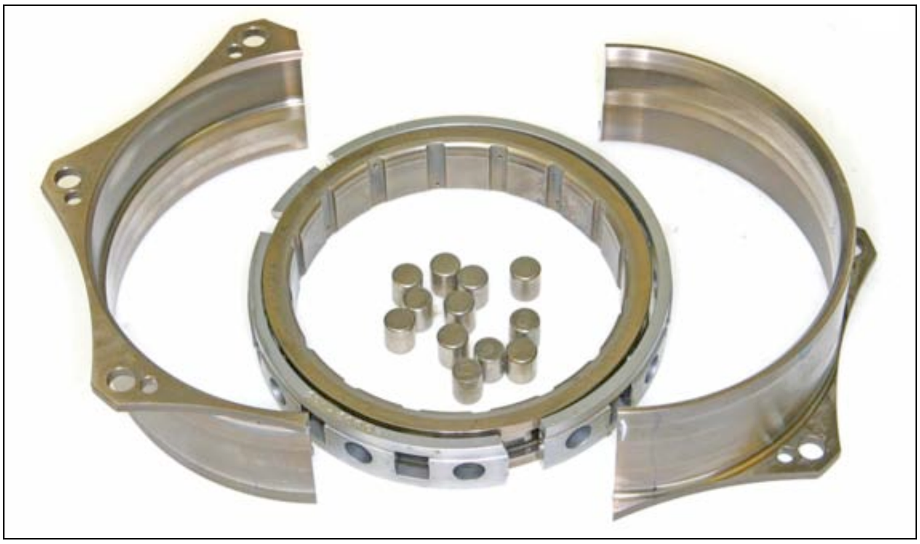
The high pressure and low pressure centrifugal compressors displayed rubbing contact with their shrouds. The rotors and stators of the power turbine did not show evidence of rubbing contact or damage. There was however, metal splattering on their airfoils. Analysis of the metal contaminants found in the main engine oil filter and MCD were identified as being from the number-5 bearing. The engine reduction gearbox module was not disassembled.

Engine serial number AW0021 failure

On 22 March 2007, another of the operator's engines (ESN AW0021) was reported as having fluctuating hydraulic pressure and a minor oil smell. During the subsequent inspection, pieces of metal were found on the MCD. The engine was sent to the manufacturer for investigation which revealed that the number-5 bearing had failed. That bearing was requested by the ATSB for comparative examination during this investigation.

The bearing was received at the ATSB with both the cage and the outer race destructively sectioned. The inner raceway was intact (Figure 8). The bearing was identical to the bearing from ESN AW0015, with part number 3121706-01A and had been manufactured by the FAG Company. Other identifiers indicated that the ESN AW0021 bearing was consecutively numbered to the failed ESN AW0015 bearing, having serial number FCN171485.

Figure 8: Number-5 bearing from ESN AW0021 as received by the ATSB



A visual examination showed that the roller cage had fractured at two locations. The failure mode was determined to be fatigue related, with each of the cracks initiating at the corner of the roller pocket. Due to instability of the rollers within their cage pockets, four of the cage pockets were enlarged. Early stages of spalling was found on four rollers and the bearing outer raceway.

Metallurgical examination

Several rollers from both failed number-5 bearings were sectioned in order to assess their physical microstructure and mechanical properties. Polished and etched samples were prepared from the undamaged and damaged (spalled and heavily worn) rollers off each engine bearing (ESN AW0015 and ESN AW0021). The microstructure of all the bearing rollers was consistent with a through-hardened structure, typically found in most high quality bearing steels. No anomalies or impurities in the roller microstructure were found that could have contributed to the degraded state of each bearing.

The hardness of the undamaged and damaged bearing rollers was also measured and was found to range between 740 and 786 Vickers (HV_{30}). Although no engineering specifications were available for the hardness of the bearing steel, the values measured together combined with the roller microstructure were typical of what is found in other high-carbon, high strength, bearing steels.

Other failures

A search of global aviation safety databases revealed that from 1992, there had been 20 reported Pratt and Whitney Canada PW100 series engine failures involving the number-5 bearing.

ANALYSIS

Engine failure sequence

The Australian Transport Safety Bureau (ATSB) determined that the failure of the number-5 bearing was the likely initiator of the in-flight engine shut-down.

Excessive movement of the number-5 bearing rollers within their cage pockets led to elongation and fatigue cracking of the pocket walls, together with the skewing and seizure/skidding of the bearing rollers. The subsequent failure of the roller cage rendered the number-5 bearing unstable, reducing its ability to effectively support the high pressure (HP) and low pressure (LP) turbines.

The increased axial clearance experienced by the HP and LP turbines, resulted in blade tip rubbing on the shrouds. That misalignment and tip rubbing may account for the vibration felt by the flight crew through the engine controls.

The HP turbine stub-shaft displayed evidence of rubbing contact with the stepped air-seal and had failed in overload. Those conditions were consistent with number-5 bearing instability. Once the stub-shaft had separated, the HP compressor and HP turbine became uncoupled and an uncommanded loss of power occurred.

Other factors

The reason for the dimensional discrepancy found on the HP turbine vane ring inner-front housing support and the corresponding air-seal, could not be determined. However, as the air-seal had been in service for 1,006.7 hours, the engine manufacturer considered it unlikely that these dimensional deviations contributed to the number-5 bearing and HP turbine stub-shaft failures. Although the effect on bearing cooling and lubrication could not be determined, the condition of the roller cage's silver plating suggested that lack of lubrication had not been a contributory factor.

The number-5 bearing fitted to engine serial number AW0021 was of the same type and part number as that fitted to this occurrence engine AW0015. Furthermore, manufacturing identifiers indicated that both bearings were probably produced together during the same batch due to their serial numbers being consecutively matched (FCN171484 and FCN171485).

The degree of roller cage and roller degradation on AW0021 was far less than experienced in this incident. Therefore, it could be assumed that the greater the level of distress to the number-5 bearing, the higher the probability of a HPT stub-shaft failure and an in-flight engine failure event.

Although the nature of the number-5 bearing and HPT stub-shaft failures were understood, the condition that led to the bearing roller instability has not been identified. However, early detection of number-5 bearing distress can prevent in-flight failure of the engine.

FINDINGS

From the evidence available, the following findings are made with respect to the In-flight engine failure on the de Havilland Dash 8 aircraft registered VH-TQY and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- Instability of the number-5 bearing rollers within their cage pockets resulted in elongation of the cage pockets, skewing and seizure of rollers, and roller cage failure.
- The roller cage failure resulted in turbine blade tip rubbing and vibration, which led to high pressure turbine stub-shaft overload failure.

Other safety factors

- The precursors to roller instability could not be identified.
- Early identification of number-5 bearing distress can reduce the likelihood of an in-flight engine failure.
- Both failed bearings had consecutive serial numbers and were possibly from the same manufacturing batch.

SAFETY ACTION

Engine manufacturer

As a result of this investigation, the engine manufacturer advised the Australian Transport Safety Bureau it had taken the following actions:

- A batch of 15 bearings associated with the fractured bearings was identified.
- All 15 affected engines had the number-5 bearings replaced as follows:
    - 3 following bearing fracture events
    - 2 following precautionary engine removals
    - 2 at shop visit during unrelated unscheduled removal
    - 1 returned from the original equipment manufacturer (uninstalled)
    - 7 removed from service and returned for bearing replacement.

The engine manufacturer also advised that since the 15 suspect bearings were removed in 2007, there have not been any events reported involving bearings with low running time. However, the engine manufacturer has instituted a requirement for the mandatory replacement of the number-5 bearing in all Pratt and Whitney Canada PW123 up to PW127 series engines, each time the bearing is accessed during a shop visit.

In addition, the engine manufacturer will continue to monitor the situation and will address any significant problems highlighted during any subsequent investigations.