Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Occurrence Investigation Report AO-2007-008
Final

Engine failure 259 km SSE of Broome, WA 24 May 2007 VH-IWO Raytheon Beechcraft B200 King Air

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Abstract

A Raytheon Beech Kingair aircraft, registration VH-IWO, was cruising at FL290 on an aero-medical flight from Newman to Fitzroy Crossing, WA with the pilot, a flight nurse and a doctor on board. When approximately 140 NM (259 km) south-south-east of Broome, the right engine inter-turbine temperature indication (ITT) was observed by the pilot to rise without any engine control input. The ITT rise was accompanied by a slight fluctuation in a number of associated engine indications. The pilot reduced power on the right engine.

Shortly after the power reduction, there was a slight right engine surge, with an accompanying rise in ITT. The pilot observed smoke coming from the right engine exhaust. The pilot shut down and secured the right engine and, after briefing the flight nurse and doctor, diverted to Broome Airport where a single-engine landing was completed.

Examination of the right engine revealed extensive damage caused by the separation of one of the compressor turbine blades at mid span.

As a result of this occurrence, the engine manufacturer has modified the alerting feature in the case of the interruption of the supply of electronic trend monitoring (ECTM) information to customers from its automated ECTM program.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory Agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

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 a function of the ATSB to apportion blame or determine 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.

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 enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation, the person, organisation or agency must provide a written response within 90 days. That response must indicate whether the person, organisation or agency accepts the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

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

History of the flight

On 24 May 2007, at about 1530 Western Standard Time[1], a Raytheon Beechcraft B200 King Air aircraft, registered VH-IWO, was cruising at flight level (FL) 290 on an aero-medical flight from Newman to Fitzroy Crossing, WA. On board the aircraft were the pilot, a doctor and a flight nurse.

The pilot reported that, when approximately 140 NM (259 km) south-south-east of Broome, the aircraft's right engine inter-turbine temperature indication (ITT) increased without any engine control input by the pilot. The ITT rise was accompanied by a slight fluctuation in the right engine's torque, fuel flow, ITT and N_1[2] indications. In response, the pilot reduced power on the right engine, and the ITT appeared to return to within the normal operating range, although the fluctuations persisted. The pilot stated that, shortly after the power reduction, there was a slight right engine surge with an accompanying rise in ITT, and that a wisp of smoke was observed coming from the right engine.

The flight nurse, who had a better view from the cabin, confirmed that smoke was emanating from the right engine. The pilot shut down the right engine and decided to divert to Broome Airport.

At 1532, the pilot transmitted a PAN[3] call to air traffic control and requested a direct track to Broome. He also contacted his operations centre to ensure the availability of appropriate support at Broome. The pilot then briefed the flight nurse and doctor on the situation and they prepared the cabin for landing. The remainder of the flight and subsequent single-engine landing was uneventful.

The operator's maintenance personnel examined the aircraft and right engine at Broome and found that they were unable to rotate the right engine compressor. It was later determined that there had been a major internal failure of the right engine. The engine was removed and forwarded to an approved engine overhaul facility for examination.

Right engine information

The aircraft was fitted with two Pratt and Whitney (Canada) PT6A-42 turboprop engines. The details of the right engine and a summary of its maintenance history are listed at Tables 1 and 2.

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1 The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST), as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC) + 8 hours.

2 Rotational speed of the gas producing section of the engine.

3 A radio transmission indicating uncertainty or alert.

Table 1: Engine details

Manufacturer	Pratt and Whitney (Canada)
Model	PT6A-42
Serial Number	PCE-PJ0243
Time Between Overhauls	6,000 hrs
Total Time Since New (TSN)	7,131.6 hrs
Total Cycles Since New (CSN)	5,753
Time Since Overhaul (TSO)	1,258.7 hrs
Cycles Since overhaul (CSO)	997

Table 2: Summary – engine maintenance history

Date and details	Maintenance completed
29 October 2005. 5,872.9 hrs TSN and 4,756 CSN	Engine overhauled (zero time on engine and all components) by the engine manufacturer and a release certificate issued.
8 December 2005. Zero hrs TSO	The engine was received by the operator in a built-up condition[4], and installed in the aircraft as the right engine.
19 January 2006. 115.3 hrs TSO	Engine Condition Trend Monitoring (ECTM) analysis completed by the engine manufacturer's Designated Analysis Centre (DAC) – assessed as 'in the green[5]'.
5 April 2006. 329.6 hrs TSO	Borescope[6] inspection completed, nil defects found.
6 June 2006. 428.3 hrs TSO (830.4 hrs prior to the incident) and 6,301.2 hrs TSN	Hot Section Inspection[7] (HSI) and repair (see section 'HSI and repair' below).
20 July 2006. 539 hrs engine TSO	ECTM analysis completed.
15 September 2006. 725.6 hrs TSO	ECTM analysis completed– assessed as 'in the green' by the contracted ECTM company.
15 September 2006. 725.6 hrs TSO	Engine instruments calibration check and borescope inspection, with nil defects found.
15 December 2006. 924.2 hrs TSO	ECTM analysis completed – assessed as being 'in the green' by the contracted ECTM company.
22 March 2007. 1,103.7 hrs TSO	Borescope inspection, nil defects found.

4 The engine was received with all of the appropriate accessories fitted.

5 A reference to all recorded data parameters being within the normal range.

6 Internal examination conducted with an illuminated optical periscope.

7 An internal inspection of the turbine section.

Date and details	Maintenance completed
22 March 2007. 1,103.7 hrs TSO	ECTM analysis completed and assessed as being 'in the green' by the engine manufacturer's DAC.
24 May 2007. 1,258.7 hrs TSO	Engine failed in-flight.

Hot Section Inspection and repair

The HSI and repair on 6 June 2006 was an unplanned maintenance activity, which was carried out as a result of compressor turbine 'rub'[8] that was detected during a scheduled borescope inspection.

That maintenance included:

- an HSI and grind of the compressor-turbine shroud segment[9]
- the replacement of the number-2 bearing oil seal gasket
- the repair of the;
  - number-2 bearing cover
  - small exit duct
  - shroud housing
  - compressor-turbine disc
  - vane ring assembly
  - combustion outer liner weld.

The operator's engineering manager stated that similar rub damage was observed previously on four other engines, each within 900 hrs TSO of those engines. He also stated that, in December 2005, the engine manufacturer introduced Service Bulletin (SB) 3424, which increased the inter-segment gap tolerances between the individual compressor-turbine shroud segments, and changed the material that was used to manufacture the segments. The aim of the SB was to increase cooling and to reduce the possibility of any curling (or bending) of the segments.

Operators were required to comply with the SB at their aircraft's next maintenance opportunity. In this case, the next maintenance was the HSI and repair that was conducted on 6 June 2006. After that repair, the engine was returned to service, completing a further 830.4 hrs service prior to this incident. During that period of service, two additional borescope inspections were carried out, with no anomalies found.

8 Indicating actual contact between the rotating turbine blades and the stationary abrasive segments located circumferentially around the turbine. A small operating clearance between the two components was normal and any rub required remedial action to restore that clearance.

9 Segments were arranged circumferentially around the compressor-turbine and provided the clearance sealing for the rotating compressor-turbine blades. The gap tolerance between rotating blades and stationary segments was adjusted by a specialised grinding technique that was applied to the segments.

Examination of the right engine and its associated systems

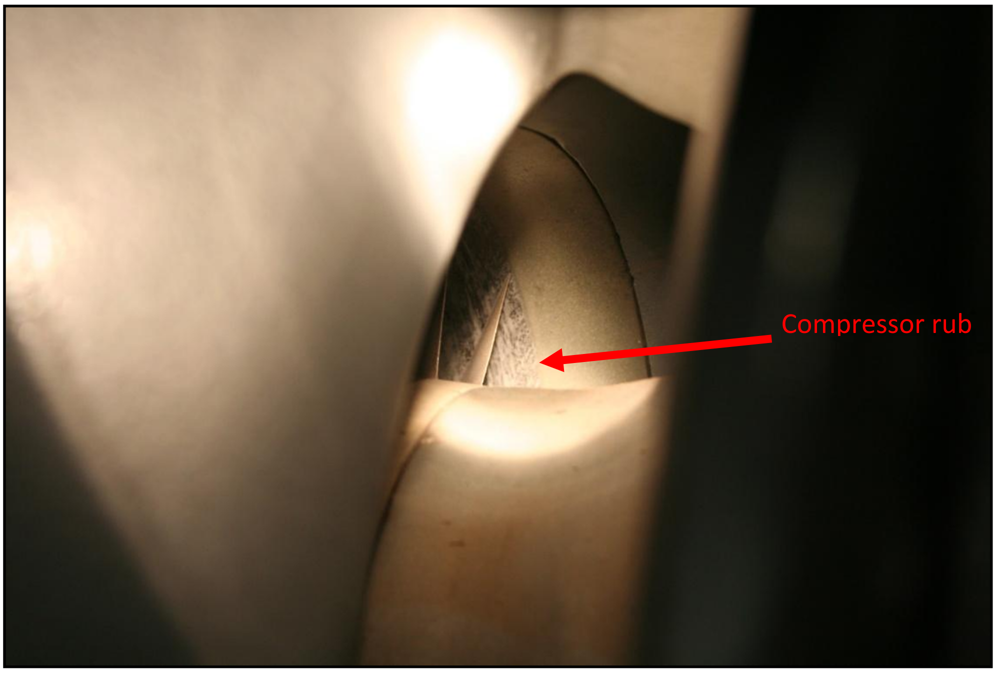
Engine disassembly and inspection

The right engine was sent to the engine manufacturer’s authorised overhaul facility and examined under Australian Transport Safety Bureau (ATSB) supervision.

An initial external inspection found no defects. The propeller shaft turned freely, with no mechanical interference or noises coming from the power turbine or reduction gearbox sections. The chip detector[10], oil, P_3[11] air and fuel filters were removed and inspected, with no evidence of any contamination or debris noted.

Upon removal of the air inlet screen, evidence of first stage compressor rub was observed on the engine’s inlet casing (Figure 1). The first stage compressor blade tips were discoloured, indicating prior localised heating. There was no evidence of any foreign object damage in the compressor section of the engine.

Figure 1: Compressor casing rub (first stage)



The engine compressor could not be turned by hand. However, after some manipulation, the compressor rotated with the aid of a turning tool that was inserted into the starter generator accessory drive pad.

The engine was disassembled to allow the inspection of the combustion chamber and compressor-turbine. That inspection found that:

- the combustion liner exhibited signs of heat distress

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[10] A magnetic plug that was designed to collect ferrous particles as a product of wear within the engine.

[11] Engine compressor discharge air pressure.

- there were small pieces of metal debris in the combustion case liner, the gas generator case and at the bottom of the turbine case
- there was foreign object damage to the trailing edges of two of the vanes of the compressor-turbine guide vane
- the compressor-turbine shroud exhibited light rubbing marks as a result of contact with the compressor-turbine blade tips
- there was a large amount of heat distress-related CT blade tip erosion
- one compressor-turbine blade had fractured at about one third of its span (Figure 2).

Six compressor-turbine blades, including the remaining part of the fractured blade, were removed from the compressor-turbine disc and forwarded to the ATSB for technical examination.

Figure 2: Severe CT blade tip erosion and fractured blade (circled)

Apart from evidence of minor impact damage, the power turbine housing, guide vane ring, and inter-stage baffle were all in good condition. There was evidence of debris impact damage to the trailing edges of the power turbine vane airfoils, and there was a crack through the inner drum of the power turbine vane. The damage was consistent with the liberated debris moving downstream in the gas path from the compressor-turbine.

The power turbine and shroud were in good condition with minor impact damage. There was some molten debris deposited on the power turbine airfoils.

The engine accessory gearbox was in good condition, and there was no evidence of oil contamination. The bleed valves were inspected and considered by the overhaul technician to be serviceable.

The fuel nozzles were placed on a flow rig and checked for pattern quality and flow rates. No anomalies were found.

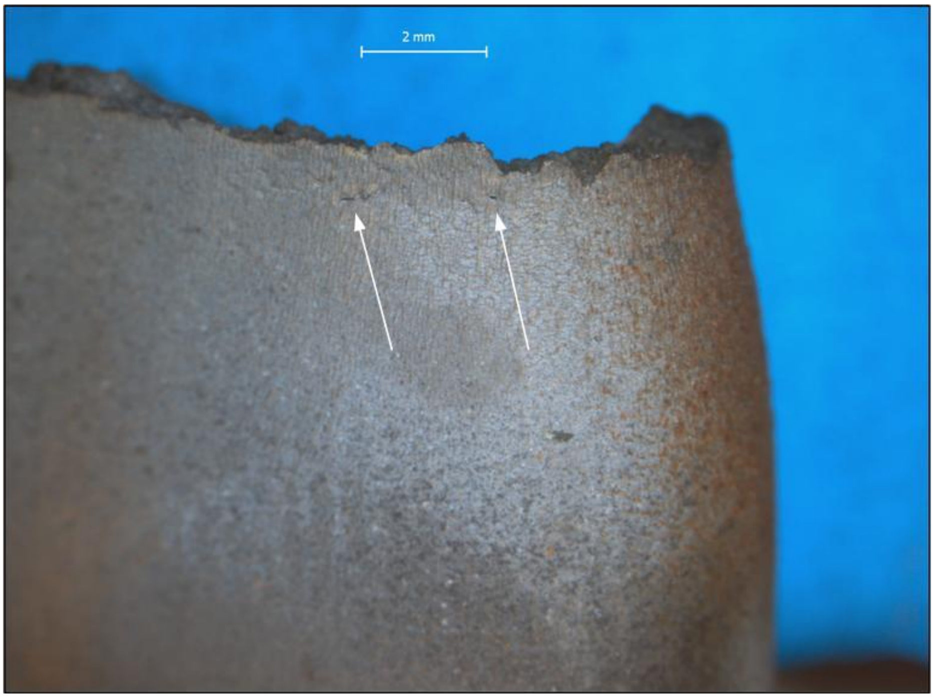
The engine fuel control unit (FCU) was removed from the engine and sent to the ATSB for technical examination.

Compressor-turbine blades examination

An examination of the compressor-turbine disc and blades found impact and wear damage to the outer span and blade tips, with the loss of varying amounts of material from the leading edge corners of the blades. The disc and blade surfaces showed a uniform grey surface oxidation, with varying levels of a brown deposit overlay. The concave (or bucket) surfaces of most of the blades displayed a symmetric zone of the brown deposit, characterised by a smaller central region where the deposit had spalled away from the base material.

Of the 58 disc blades examined, one had fractured transversely through the mid-span section, about 10 to 12 mm above the blade platform transition (Figure 2). There was localised plastic deformation (or necking), and numerous surface fissures were identified at the point of blade fracture. Plastic deformation and surface fissures at the point of blade fracture are often observed in the case of stress-rupture failures of high-temperature componentry (Figure 3). Stress-rupture occurs as a product of excessive loss in material strength, and is typically a late-stage result of microstructural creep[12].

Figure 3: Profile view of blade fracture – note reduction in section and fissuring (arrowed)



Creep and eventual stress-rupture is a time/temperature dependent failure mechanism, and the onset of a premature stress-rupture failure is often precipitated by a period (or multiple periods) of exposure to temperatures above the design limits identified for the component alloy type. In the context of a turbine aircraft engine, fuel scheduling and engine handling during start and acceleration have the potential to produce overheat events, which can have a cumulative damaging effect on the high temperature components of the engine.

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[12] Creep is the progressive deformation of a material under a sustained force.

Right engine fuel control unit

Operation and maintenance

The engine start sequence was mechanically controlled by an internal start mechanism within the fuel control unit (FCU). That mechanism was adjusted at overhaul to a pre-determined number of 'set' points or targets that were listed in the manufacturer's test schedule. Once adjusted, the start mechanism provided for a controlled, predictable and safe start acceleration schedule for the engine through to the low, or ground-idle speed. During start, the FCU was in a low-flow position and some of the fuel supply was diverted back to the fuel pump via a spill valve. A pneumatic governor took over control of the start in the latter stages of the acceleration of the engine, and captured the commanded throttle setting for idle.

The adjustment of the start set-up to meet the start mechanism set points or targets was only permitted during overhaul, and was not accessible during normal maintenance. In-the-field adjustment of the engine's ground and high (flight) idle speeds, that was not part of the start mechanism set-up, was a permissible operational maintenance adjustment.

The FCU (part number 3244768-13, serial number A69229) was overhauled by the engine manufacturer at the same time as the engine and had accrued the same TSO. The FCU was bench tested at an authorised overhaul facility under ATSB supervision. In the period from 2005 to the time of the examination, the overhaul facility had completed maintenance on 41 FCUs of the same part number for the operator and 31 for other operators.

External examination

Prior to an in-depth examination of the FCU, its general condition was examined and its factory settings confirmed. All factory lead seals were intact, indicating that the factory settings from overhaul, including the fuel schedule test points (see *Test points results* discussion below) remained unchanged.

Internal anomalies

The FCU's cut-off modulation function, which was associated with the shutdown of the engine, was examined and found to be operating incorrectly. The spill valve housing, which housed the spill and cut-off valves, was removed to allow access to the fuel cut-off valve.

The condition of the fuel cut-off valve seat was considered by the examining technician to be appropriate for the TSO. However, after removing the cut-off sleeve, it was identified that the cut-off valve could slide in and out through the sleeve, but was unable to rotate on its eccentrically-mounted pivot pin (Figure 4) due to binding between the two components. Damage in the form of tool marks was evident to the pivot pin and cut-off valve slot (Figures 5 and Figure 6).

Figure 4: Cut-off valve eccentric shaft and pivot pin

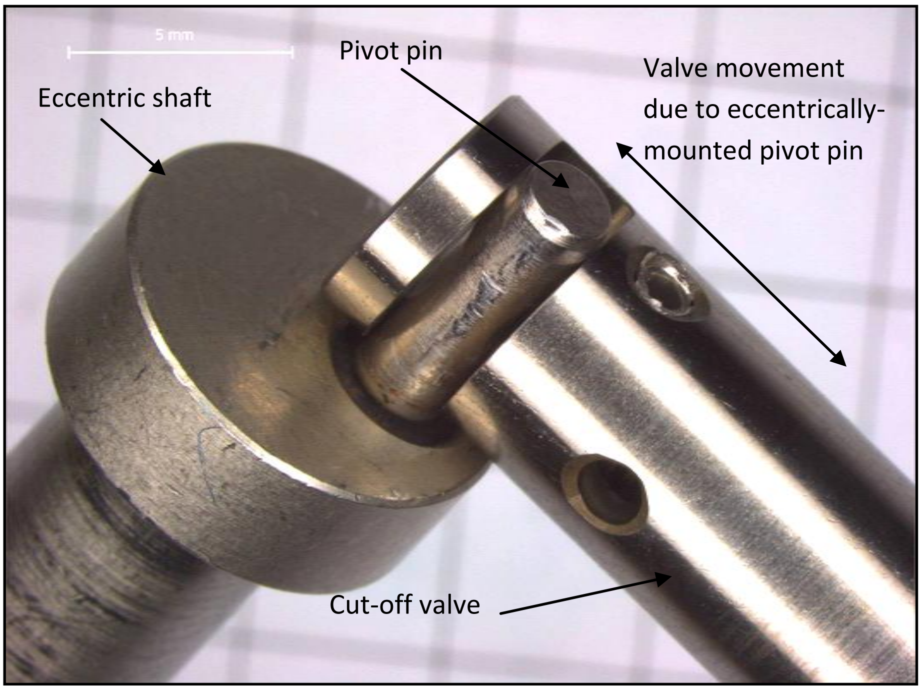


Figure 5: Pivot pin showing tool marks (boxed in red)

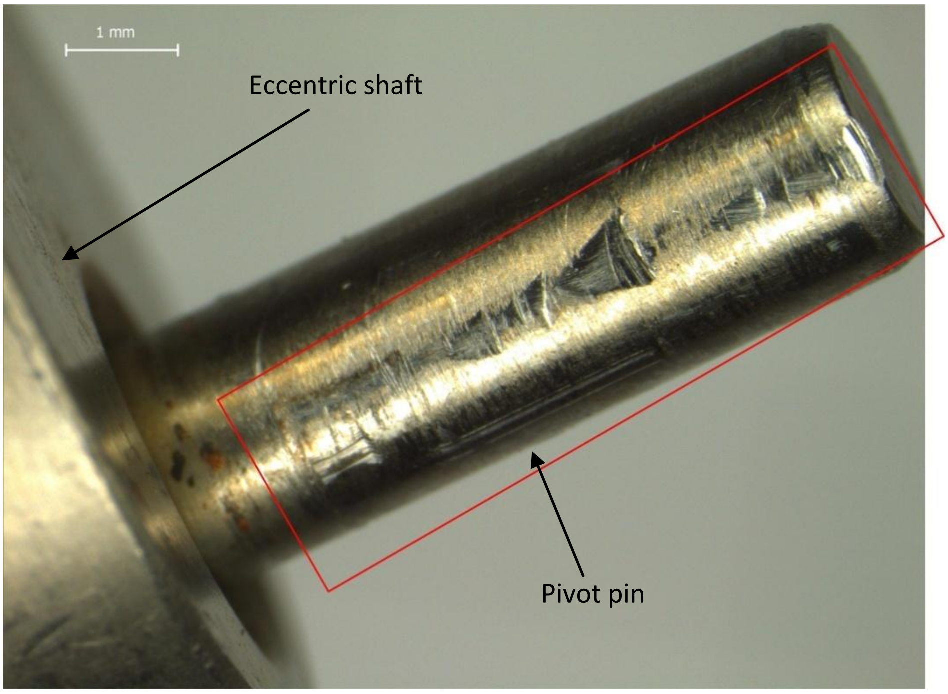
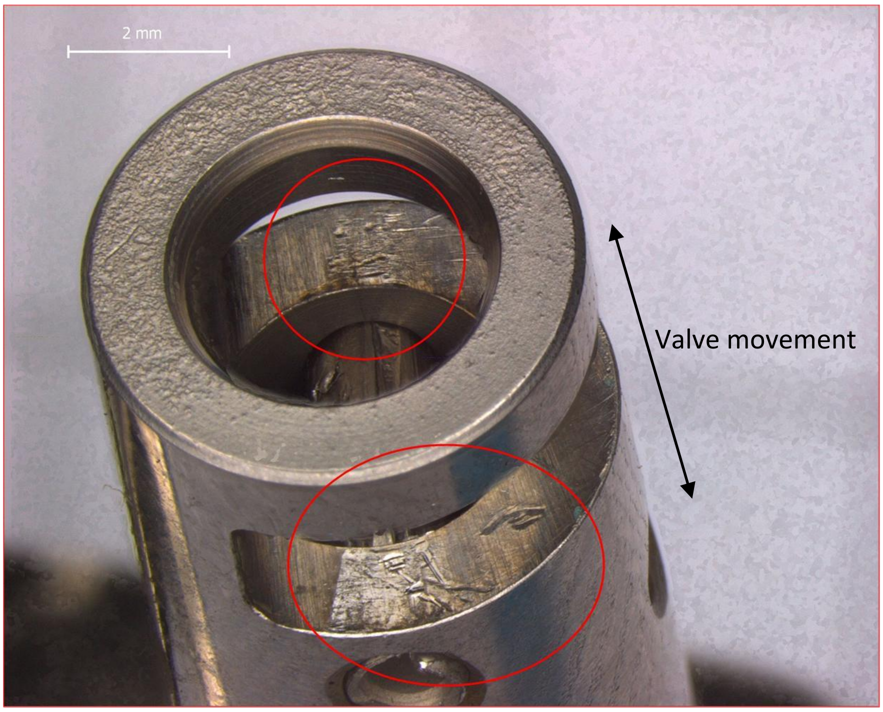


Figure 6: Valve piston slot (mates to pivot pin) tool marks (circled in red)



It was not possible to determine when the pivot pin seizure occurred in the life of the FCU. However, after freeing the observed pivot pin binding, the assembly was refitted to the FCU. The FCU was again tested, and the cut-off modulation function performed to specification.

Test point results

The FCU's internal start mechanism was tested against the manufacturer's fuel schedule test point specifications. The results of those tests are at Appendix A and showed that the FCU's basic fuel scheduling (or fuel flow) exceeded the maximum fuel flow, expressed in pounds per hour (pph) at all test points.

The excess cut-off modulation throttle travel was consistent with the excessive leakage of 8 pph that was found at the cut-off modulation and leakage set point (test point 8.01, see Appendix A). However, it was unclear to the examining technician how that excess modulation would affect the start sequence as, when operating correctly, the cut-off modulation function should have had no effect on the fuel flow after 20° of throttle travel.[13] The engine and FCU manufacturers stated that this would not have had any influence.

Ground-idle adjustment

The engine's ground-idle speed had been adjusted by the aircraft operator to give a fuel flow of 214 pph at 3,560 RPM[14]. That was 69 pph (47.5%) over the manufacturer's recommended maximum ground-idle fuel flow of 145 pph, and 24

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13 A throttle travel of 20° related to an FCU set-up test point. It did not directly relate to the manipulation or position of the throttle.

14 RPM referred to in this passage is the FCU drive speed provided by the engine accessory pad to which the FCU is normally mated. That speed was duplicated on the test bench during test.

pph (12.6%) above the operator's 'normal' elevated ground-idle setting. The examining technician recalled that '...a high ground-idle fuel-flow setting (190 pph) was normal for their operation.' The operator advised the technician that the higher-than-normal fuel-flow setting of 190 pph was in order to support the high onboard electrical power requirements that were associated with the aero-medical role.

The technician further advised that, in his experience, a fuel flow of 214 pph was very high for one of the operator's engines. The technician indicated that a setting of that magnitude meant that there would have been a rapid acceleration of the engine during start.

Third party analysis of test point results

The technician that conducted the tests of the FCU stated that those results suggested excessive fuel would have been available for combustion, especially during the start sequence. Normal wear and deterioration of the FCU was discounted by the technician as an explanation for the rich fuel schedule as, in his experience, the relevant wear patterns biased towards leaning (or reducing) the fuel schedule. The technician highlighted the enrichment spring differential setting of 8 pph, or 1 pph below the maximum allowable differential fuel flow, as evidence that the fuel schedule had not deteriorated as a result of normal operation.

The test results were also provided to one of the engine manufacturer's local technical representatives, whose assessment of the out-of-tolerance condition disagreed with that of the technician. The representative believed that the test results were not sufficiently off-schedule to have had any significant effect on the engine start sequence or operation. The representative believed it more likely that the engine damage was as a result of operational handling technique.

Clarification was sought directly from the engine manufacturer. However, opinion remained divided as to the effect that the out-of-tolerance FCU settings may have had on the engine. The manufacturer's initial advice was that:

> ...the increased schedule can result in accelerated deterioration (over time) of the hot section. However [the manufacturer's technical expert] does not have statistical evidence to prove this.

Later, the engine manufacturer indicated its agreement with the assessment of the test results by its local representative. That was:

> The [FCU manufacturer] contend that the damage to the cut-off valve did not impair its operation, and this was confirmed during testing of the FCU. During the functional check of the cut-off valve there was no leakage with the throttle in the 8 to 10 degree range (the cut-off range), confirming that cut-off had been achieved.
>
> The only area of doubt is the difference in fuel flow from the 20 degree to 30 degree throttle angle (test point 8 on the attached). The limits are 160 to 170 pph at 20 degrees, with an expected increase of 2 pph at 30 degrees (resulting in a range of 162 to 172 pph). The recorded fuel flow noted at 20 degree throttle angle was 163 pph, with an increase at 30 degrees of 10 pph, resulting in a flow of 173 pph. This is only 1 pph over the maximum limit, and may have been due to field adjustment.
>
> Therefore, based on the evidence provided and the results of the final test of the FCU from the last [engine manufacturer] shop visit, we conclude that:

1. The pilot's control of the engine was not impaired,

2. The FCU was correctly set during the last shop visit at [the engine manufacturer's premises], but the readings had moved by the time of the testing after the event, possibly due to field adjustment,

3. The FCU did not contribute to the event without input from the pilot.

Interpretation of FCU test point results

The FCU manufacturer's interpretation of the requirements of the cut-off modulation and leakage set point, appeared to be at odds with that used and understood by the approved FCU overhaul facility that examined the unit. The interpretation by that facility of the component manufacturer's test procedure was that the fuel flow must be within the range of 160 pph to 170 pph at a throttle angle of 20°.

The overhaul facility understood that the initial test requirement was the establishment at a 20° throttle angle of a fuel flow of between 160 pph and 170 pph (including the as-required adjustment of the fuel flow to within those parameters). In this case, the fuel flow at 20° throttle angle was 163 pph. The throttle angle was then to be increased to 30°, which represented ground-idle. The overhaul facility's understanding was that the allowable increase in fuel flow at a throttle angle of 30° should be no greater than 2 pph over that observed at 20°.

The acceptance of the overhaul facility's understanding would result in a maximum fuel-flow limit of 165 pph at 30° throttle angle. The observed 173 pph maximum fuel flow at that throttle angle exceeded the test point limit as understood by the overhaul facility.

Engine Condition Trend Monitoring

Under specific operating conditions, gas turbine operating parameters, such as compressor speed (N_1), inter-stage turbine temperature (ITT) and fuel flow (Wf) are predictable by individual engine. An Engine Condition Trend Monitoring (ECTM) program is an engine health monitoring system with the capacity to provide timely warnings to an operator of any trends in the measured engine parameters that might be precursors to a loss of engine performance or efficiency, or of an engine failure. The engine manufacturer adopted the ECTM concept in order to improve safety, reduce operators' costs, and to save time.

The ECTM software allowed the establishment of a baseline[15] as a stable reference. Once an aircraft was stabilised at the required in-flight condition, the stipulated engine and airframe data was recorded for comparison with figures that were deduced from a mathematically-derived model to provide a daily confirmation of the efficiency of the engine's gas path. Since engines were required to operate in a wide range of ambient conditions (such as the outside air temperature, indicated airspeed and pressure altitude), corrections to the engine parameters were necessary to allow for the comparison of in-flight observations with the mathematical model.

15 A straight line that was derived from the average of the first 15 ECTM test points that were recorded when the engine was in a healthy condition (new or overhauled), from which point deterioration could be determined.

The difference between an actual or observed in-flight engine parameter, and that predicted by the ECTM mathematical model, was called a ‘delta point’. In the case of the PT6A-42 turboprop engines that were installed in the aircraft, the N_1, ITT and Wf delta point values were plotted on a graph for ECTM trend monitoring. Any out-of-limits deviation from the ECTM baseline triggered an alert. The utility of the ECTM software to successfully identify a problematic trend was dependent on the accuracy of the data that was gathered and entered into the software to generate the delta points.

The operator gathered ECTM data manually via its pilots, and automatically by an onboard data acquisition unit. The manually-recorded data was not routinely examined by the operator; reliance being placed on the automatic ECTM capability.

In an effort to minimise scatter[16], and to assist in the accurate collection of the ECTM data and analysis of any trend, the engine manufacturer’s training manuals recommended that:

- operators should record data once per day, or at least every 6 to 8 flight hours
- the aircraft should be established in the cruise condition for a minimum of 3 to 5 minutes before data capture
- the daily data acquisition should take place;
  - within a consistent altitude band of 5,000 ft
  - in the same flight configuration (for example, with the same electrical, air-conditioning and pressurisation loads affecting the aircraft)
- once data was acquired, it should be analysed within 5 days.

The engine manufacturer’s recommendation for the aircraft to be established at the target altitude and in the cruise configuration prior to data acquisition, was not reflected in the operator’s procedures at the time of the incident. In particular, the altitude band for data capture was between 3,000 and 30,000 ft and a number of the remaining mask values did not imply the need for data capture in the same flight regime. When queried about that disparity, the designated analysis centre (DAC)[17] advised that:

> The altitude filter in the mask values was set this wide to ensure autotrends are captured for all operators using our product. If one particular operator flies the same mission profile every time then the autotrends will consistently be taken within the same altitude band as a result of their flight profile.
>
> For the operator that flies [sic] several different flight profiles our system will capture a trend point for all flights, with no limitations on target altitude. We do not impose any limits in this scenario, as we do not want to limit the amount of data being collected by the system.

The capture of the ECTM data from a stabilised cruise altitude was not considered to be necessary by the DAC.

16 Scatter (also referred to as ‘noise’). A large disparity between data points that adversely affected the interpretation of the observed ECTM data. The effect was a reduction in the accuracy of the trending analysis.

17 Engine manufacturer’s nominated ECTM analysis centre.

Automatic data acquisition system

The operator employed an enhanced automatic data acquisition system (ADAS+), which recorded selected engine paramaters during normal operation and was independent of pilot actions. In addition to the automatic recording, the collection of data could be manually triggered by the pilot via a switch in the cockpit.

In the case of automatic data acquisition, a number of manufacturer-recommended criteria, or 'mask' values were required to be programmed into the ADAS+ unit. It was recommended that those values should be agreed by an operator with the manufacturer's data capture recommendations in mind. The attainment of those target mask values triggered the capture of the data by the ADAS+ unit.

After the data was captured, it was automatically transmitted by the ADAS+ system via satellite link to the engine manufacturer's DAC for review. If the delta points were outside the pre-determined limits, the analysis of the anomaly by the DAC generated an alert that usually took the form of an e-mail notification to the operator's designated maintenance person. Once received, the maintenance organisation could instigate troubleshooting or rectification as necessary.

The ADAS+ also recorded the engine's peak start temperature.

All of the recent ECTM notifications that were provided by the DAC to the operator indicated that the engine's performance was nominal or 'in the green'. There were no deviations that might have triggered an alert to the operator, and no start temperature exceedances recorded. The respective trend assessments were entered in the engine's logbook and certified at regular intervals.

The DAC sent deficient data alerts (DDAs) to operators when there was an interruption in the receipt of ECTM data. The default periodicity of those alerts was set by the DAC at 30 days, to allow for normal aircraft down time.

On 3 May 2007, or 21 days before the engine failure, a malfunction in one of the aircraft's instruments that provided output to the ECTM system meant that the automatic capture of engine data ceased being uplinked for analysis by the DAC. In accordance with the DAC's 30-day default setting for the generation of a DDA, the cessation of data transfer did not trigger an alert to the operator. The operator remained unaware of any interruption in the transmission of ECTM data to the DAC.

The missing data that was not sent to the DAC was substituted with manually-recorded data from the operator's flight logs and forwarded to the ATSB. That allowed the examination by the ATSB of a complete data set.

Aside from the capture of a peak engine start temperature, the ADAS+ did not record the engine's start sequence. In that case, the operator's maintenance personnel were reliant on their, and company pilots' observations regarding the start sequence in a specific engine.

The engineering manager and designated ECTM engineer stated that no anomalies had been reported on the operation of the engine from either operating crew, or from maintenance personnel. There were no pilot reports of any over-temperature events during the start sequence.

ANALYSIS

The engine failure was the result of the mid-span separation of one of the compressor-turbine blades. There was no prior indication in the engine logs, or to flight crews, of the impending failure of the compressor-turbine blade.

The pilot correctly identified the failed engine and took timely and appropriate action to complete an uneventful single-engine landing. This analysis will examine the contributory and other factors in the development of the occurrence.

Compressor-turbine blade failure

The compressor-turbine blade failed due to stress-rupture. That rupture was a product of excessive loss in material strength, which was typical of late-stage microstructural creep of the blade from exposure to over-temperature events. The loss of section from the blade would have produced a substantial reduction in turbine efficiency, with a corresponding drop in the compressor-turbine speed and discharge pressure (CDP). Increased fuel scheduling, in response to the decreasing CDP, would likely have produced the escalating inter-turbine temperatures, surging and exhaust smoke reported by the pilot and flight nurse.

In addition, the liberation of the compressor-turbine blade would have resulted in the engine’s rotating components being out of balance, leading to vibratory forces that allowed those components to collide with the engine’s stationary assemblies. The resulting additional debris combined with that from the liberated blade to increase the damage to the remainder of the engine.

Opinion between the fuel control unit (FCU) manufacturer and the FCU overhaul facility was divided as to the possible influence of the out-of-tolerance FCU on the development of the failure. However, the initial advice from the engine manufacturer was that an increased fuel schedule can result in accelerated deterioration (over time) of the engine hot section.

While the mode of failure for the compressor-turbine blade was clear from the evidence, there was insufficient evidence to determine the cause of the apparent repeated exposure of the compressor turbine blades to over-temperature events, leading to that failure.

Importance of the FCU in the prevention of over-temperature events during the start sequence

The automated start mechanism emphasised the importance of the FCU in preventing over-temperature events during the start sequence. In this case, although the FCU could not be isolated as directly contributing to the over-temperature event(s), the following FCU-related anomalies could not be eliminated as potential contributing factors:

- the higher-than-normal ground-idle fuel flow
- the out-of-tolerance fuel schedule.

Each had the potential to have exposed the turbine to thermal stress.

Higher-than-normal ground-idle fuel flow

The higher-than-normal ground-idle fuel flow, and therefore the revolutions per minute (RPM) of the engine that was routinely set by the operator, was an authorised in-field adjustment to the FCU and was consistent with the operator's unique ground power support requirements. However, as indicated by the component overhaul technician, there was a resulting increased risk from that elevated fuel flow of accelerated, hot starts. Despite there having been no previously recorded over-temperature events, the higher-than-previously-measured idle fuel flow in this case of 214 pounds per hour, would have compounded that risk, and further increased the engine's acceleration during the start sequence.

The investigation could not determine the extent to which any hot and fast starts might have contributed to the four recorded instances of compressor rub in the operator's engines.

Out-of-tolerance fuel schedule

The as-found integrity of the FCU lead seals meant that there had been no unauthorised in-field adjustment of the FCU since its last factory overhaul. In that case, the post-occurrence failure of the FCU at the cut-off modulation and leakage test point, was likely a result of:

- the incorrect adjustment of the FCU at its last overhaul, or
- the seized cut-off valve, which would have affected the start mechanism fuel schedule.

Once the overhaul facility technician freed-up the seized fuel cut-off valve, the FCU met the fuel flow requirements at the cut-off modulation and leakage test point. That confirmed that the fuel flow anomaly between the 20 and 30° throttle angles was a result of the seized cut-off valve. The observed increased fuel flow at those throttle angles added to the risk of hotter and faster starts, or of an over-temperature event during start.

Opinion between the FCU manufacturer and overhaul facility was divided on the potential influence of the out-of-tolerance FCU on the event.

Engine Condition Trend Monitoring

The widely-set mask values in the operator's enhanced automatic data acquisition system (ADAS+), while different to those recommended by the engine manufacturer, allowed for greater operational flexibility during the capture of engine condition trend monitoring (ECTM) data. The capability of the ADAS+ to capture a trend point for all flights, with no limitations on target altitude, ensured the availability, and therefore analysis and reporting of relevant automatically-captured data.

The ECTM data that was received by the engine manufacturer's designated analysis centre (DAC), and manual data that was examined by the Australian Transport Safety Bureau, did not record any over temperatures during the start sequence, or warning of abnormal engine operation leading up to the failure of the compressor-turbine blade. The lack of any over temperatures during the start sequence was not consistent with the type and nature of the damage observed during the examination of the engine, which was determined to be probably as a result of an over-temperature event or events.

However, the investigation could not discount the potential for cumulative damage to the compressor turbine blades as a result of the out-of-tolerance fuel schedule, which resulted in time/temperature dependent microstructural creep, and eventual stress-rupture of the failed compressor-turbine blade. That would explain the almost 830 hrs since the last repair of the engine, during which the engine consistently passed scrutiny through ECTM analysis, scheduled borescope inspections, and by flight crew observation.

Given that the operator did not routinely examine the manually-recorded ECTM data, the aircraft instrumentation failure on 3 May 2007 meant that the operator’s ECTM program was, unknowingly, interrupted. The lack of a resulting deficient data alert to the operator was consistent with the default alert trigger of 30 days that was set by the DAC. The result was that there was no indication to the operator of the interruption in the transfer of ECTM data in the 21 days leading up to the incident. That prevented the opportunity for the operator to revert to the examination of the manually-collected data until the resolution of the ECTM data transfer problem. As a result, there was a reduced likelihood of the operator becoming aware of any developing engine problems during the lead-up to the incident.

FINDINGS

From the evidence available, the following findings are made with respect to the engine failure sustained by Raytheon Beechcraft King Air B200, registered VH-IWO, which occurred 259 km south-south-east of Broome, WA on 24 May 2007. They should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- A compressor-turbine blade failed due to stress rupture which was a manifestation of advanced creep deformation; that failure implied the sustained or periodic exposure of the blade to over-temperature conditions.

Other safety factors

- The default alert trigger of 30 days that was set by the engine manufacturer’s Designated Analysis Centre meant that there was no indication to the operator of the interruption in the transfer of the engine condition trend monitoring (ECTM) data in the 21 days leading up to the incident. *[Safety Issue]*
- The higher-than-normal idle fuel flow that was routinely set by the operator, and higher-than-previously-measured idle flow observed in this case, increased the risk of over-temperature events during engine start.
- The fuel flow anomaly between the 20° and 30° throttle angles was a result of the seized fuel cut-off valve.

Other key findings

- Examination of the FCU confirmed that only authorised field adjustments had been made to the unit.
- The ECTM data did not record any anomalies that would have triggered an alert to the operator.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.Engine trend monitoring alerts

Safety issue

The default alert trigger of 30 days that was set by the Designated Analysis Centre (DAC) meant that there was no indication to the operator of the interruption in the transfer of the engine condition trend monitoring (ECTM) data in the 21 days leading up to the incident. *[Safety issue]*

Action taken by the aircraft operator

The aircraft operator contacted the engine manufacturer's DAC and requested that all available ECTM alerts be activated to allow the company to be promptly alerted to, and rectify any data link failures.

Action taken by the engine manufacturer

In response to this incident, the engine manufacturer advised that:

> As a result of the cooperative review and consultation process between the [engine manufacturer] and the ATSB, the [engine manufacturer's] DAC has undertaken to systematically set the upload failure alerting feature of the ECTM software program to all its customers to ensure that prompt corrective action may be taken by those customers in the event of an interruption to the ECTM data upload stream.The ECTM system is set to a initial trigger value of 30 days but can also be set to shorter or longer trigger delays depending on the Operator and its operation.

The engine manufacturer subsequently clarified that:

> ...in the past the [engine manufacturer's] DAC would only set-up notifications for interrupted data stream for customers who are committed by their fleet maintenance contract with the manufacturer to provide them ECTM data on a monthly basis.
>
> It became apparent from this event that using these notifications could also help the manufacturer ensure that the data transfer unit (DTU) system is serviceable and should also be set systematically for DTU operators.

The default trigger of 30 days and the reminder of 14 days will now be set systematically for all new DTU equipped aircraft. This is also a good opportunity for the DAC to review the existing accounts and ensure they all have an alert. The customers will still have the option of setting shorter or even longer delays depending on their operation. But at least all DTU operators will begin with an alert which we can use to ensure the system is operating normally.

APPENDIX A: START MECHANISM FOR TEST POINT RESULTS

Test point	Test point title	Target (in pph)	Result (in pph)	Comment
2.01	Metering valve orifice test point	243 to 253	261	• 3% above the maximum allowable • 11 pph or 4.4% above the factory setting
2.03	Bypass head adjustment test point	569	592	• 4% above the maximum allowable • 30 pph or 5.3% above the factory setting
3.02	Enrichment spring differential setting	-9	-8	• one pph difference • no deterioration from the factory settings
3.03	Enrichment spring setting	407	434	• 6.6% above the maximum allowable • 40 pph or 10% above the factory setting
5.01	Ground-idle speed stop setting	145	214	47.5% above the maximum allowable of 145 pph
6.02	Low end acceleration	148	157	• 6% above the maximum allowable • 11 pph above the factory setting
8.01	Cut-off modulation and leakage test point	163 at 20° throttle angle with a maximum at 30° of 165	163 increasing to 173	• 8 pph above the maximum allowable at the 30° throttle position

APPENDIX B: SOURCES AND SUBMISSIONS

Sources of information

The sources of information during the investigation included the:

- engine manufacturer
- engine manufacturer's Designated Analysis Centre
- fuel control unit (FCU) manufacturer
- operator
- FCU overhaul facility.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the engine, aircraft and FCU manufacturers; the operator; the Canadian Transport Safety Board (TSB); the US National Transportation Safety Board (NTSB); and the Civil Aviation Safety Authority. A submission was received from the manufacturer of the FCU. That submission was reviewed and, where considered appropriate, the text of the report was amended accordingly.

Engine failure, 259 km SSE of Broome, WA, 24 May 2007
VH-IWO, Raytheon Beechcraft B200 King Air