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Addendum

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Safety summary

What happened

On 12 September 2013, a twin-engine Beech Aircraft Corporation, Model 200 Super King Air was conducting a passenger charter flight from Utirik Atoll to Marshall Islands International Airport (Majuro Atoll). About 40 minutes into the flight, while in cruise to the destination, the pilot observed abnormal oil pressure indications for the left engine and approximately 2 minutes later the engine failed. The crew secured the engine and elected to continue with the original flight plan. The aircraft landed at Majuro Atoll without further incident.

What the ATSB found

Failure of the left engine, a Pratt and Whitney Canada PT6A-41, resulted from fatigue cracking and breakdown of the first-stage sun and planet gears in the propeller reduction gearbox. The specific factors contributing to the initiation of the gear breakdown could not be positively identified; however, the ATSB identified certain PT6A-38, -41, -42 and -42A engines that, while in compliance with applicable maintenance requirements, could be operating with first-stage reduction gears in excess of the manufacturer's recommended maximum 12,000 hour service life. This specifically related to engines that had not been overhauled since September 1999, when it became mandatory to replace the reduction gears during every engine overhaul. The engine manufacturer has indicated that, provided the engine is maintained in accordance with the applicable instructions for continuing airworthiness, the rate of engine failure associated with high-time gearsets is extremely remote and that immediate action is not warranted in these situations.

It was also reported that the magnetic chip detector cockpit warning light did not illuminate and that the associated circuit breaker had popped. There have been similar reports of Beech 200 aircraft with popped circuit breakers accompanied by momentary or no chip detector light illumination, shortly preceding engine failure. A previous situation of accelerated engine failure, involving a large volume of liberated engine material bridging the chip detector terminals, was reported to have caused the circuit breaker to pop, precluding the illumination of the warning light. A similar scenario was considered likely in this occurrence.

Safety message

Pratt and Whitney Canada PT6A-38, -41, -42 and -42A engines last overhauled prior to September 1999 may be operating with high-time first-stage reduction gears which have an increased susceptibility to deterioration. Current maintenance procedures may be effective in identifying gradual deterioration of reduction gears, but not necessarily impending rapid, catastrophic breakdown per the subject engine failure. The ATSB therefore encourages operators and maintainers of affected engines to review their maintenance records and give consideration to the replacement of high-time gearsets.

Additionally, pilots and operators should also be aware of the potential for reduction gearbox chip detector cockpit annunciator lights to only illuminate momentarily or not at all, due to short circuits caused by the rapid accumulation of liberated gearbox material, in situations of accelerated engine failure. Even a momentary indication could be an indicator of engine deterioration and therefore should be noted for subsequent maintenance attention.

Contents

The occurrence

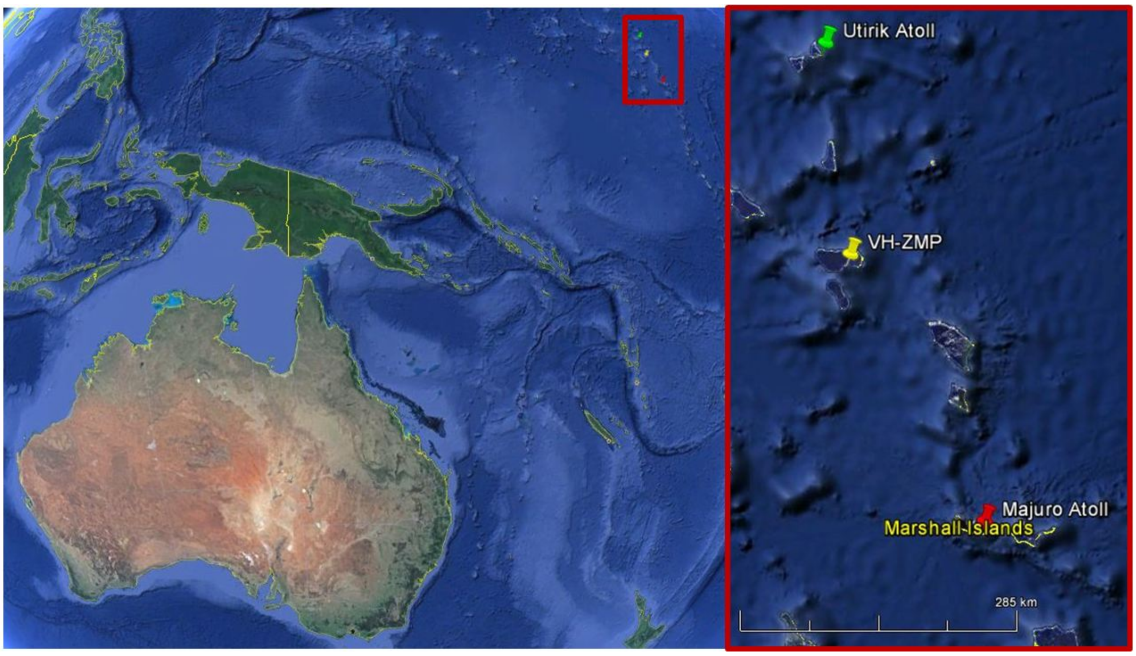
On the morning of 12 September 2013, a Beech Aircraft Corporation model 200 Super King Air was conducting a passenger charter flight in the Marshall Islands from Utirik Atoll to Marshall Islands International Airport (Majuro Atoll) (Figure 1). On board the aircraft were two flight crew and one passenger.

Around 40 minutes into the flight, while the aircraft was cruising at flight level (FL) 230, 155 NM (287 km) from the destination, the pilot in command observed a widely fluctuating oil pressure gauge associated with the left engine. There were no other abnormal indications. Approximately 2 minutes later the left engine failed. The flight crew consulted the relevant checklist, secured the left engine, and completed a controlled descent to FL180. The crew then made an assessment of the situation and determined that that the safest option was to continue with the original flight plan. The aircraft was subsequently landed at Majuro Atoll without further incident.

The engine failure was contained and there were no injuries. A post-flight inspection of the aircraft revealed significant internal damage to the turbine section of the left engine. It was also noted that the circuit breaker for the engine's reduction gearbox magnetic chip detector had popped.

The failed engine was removed from the aircraft at Majuro Atoll by the aircraft operator and freighted back to Australia. The engine was subsequently disassembled and inspected at an approved maintenance, repair and overhaul facility in Brisbane, Australia, in the presence of ATSB investigators and a representative from the engine manufacturer.

Figure 1: Approximate location of VH-ZMP engine failure (indicated by the yellow pin)



Source: GoogleEarth™, modified by the ATSB

Context

Aircraft and engine information

The Beech Aircraft Corporation, Model 200 Super King Air, registered VH-ZMP, serial number BB-259, was manufactured in the United States in 1977 and first registered in Australia in 1988. At the time of the occurrence, the aircraft had accumulated 18,964 hours total time in service. Aircraft propulsion was provided by two Pratt and Whitney Canada (P&WC) PT6A-41 turboprop engines.

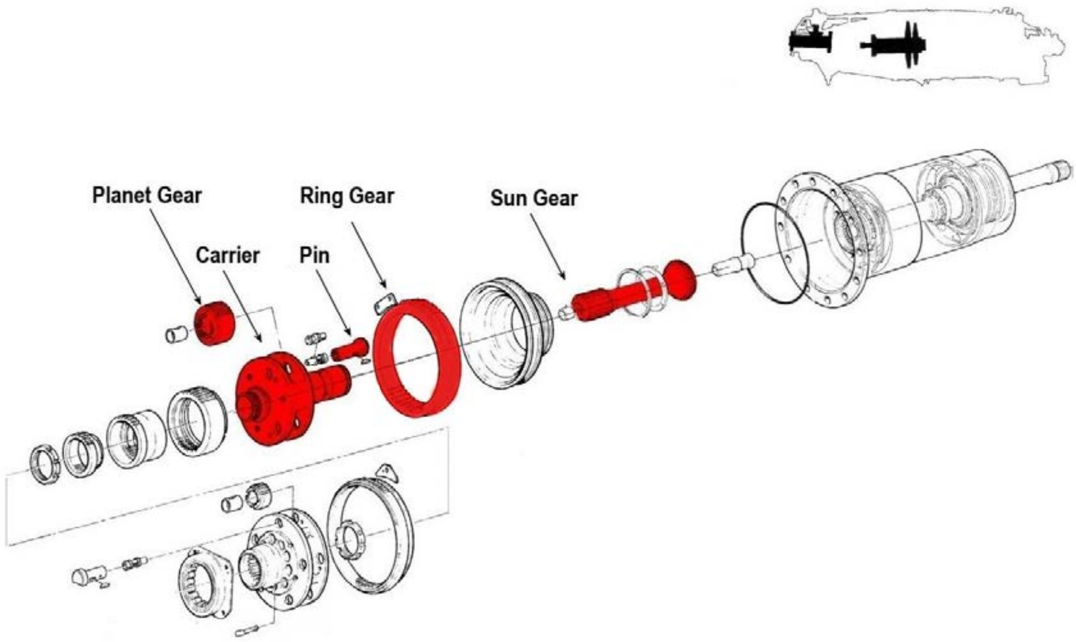
Reduction gearbox description

The P&WC PT6A-41 engine utilises a two-stage power turbine to drive the propeller via a reduction gearbox (RGB) that is located at the front of the engine. The RGB comprises a two-stage planetary gear system to reduce the rotational speed of the power turbine to a speed that is suitable for propeller operation.

Torque from the power turbine is transmitted through the first-stage sun gear, which consists of a short, steel stub shaft with an integral spur gear. The sun gear drives three first-stage planet gears, assembled in a rotating carrier (Figure 2). The planet gears react against the non-rotating ring gear, which is radially fixed to the gearbox case. The reaction against the ring gear results in rotation of the gear carrier, which provides output to the second-stage reduction gears. The second-stage gears operate in a similar fashion to the first-stage and provide output to the propeller.

A magnetic chip detector (MCD) installed in the RGB case, is designed to provide an indication of the presence of ferrous particles in the lubrication system. The MCDs in VH-ZMP were electrically connected to annunciator lights in the cockpit. The chip detector light illuminates if sufficient ferrous particles accumulate on the MCD poles to complete the electrical circuit. Illumination of the chip detector light can alert the flight crew to abnormal wear of engine components and may increase the available time to monitor, assess and plan an appropriate course of action for a potential engine failure.

Figure 2: PT6A-41 engine diagram highlighting the general arrangement of the first-stage gears within the reduction gearbox



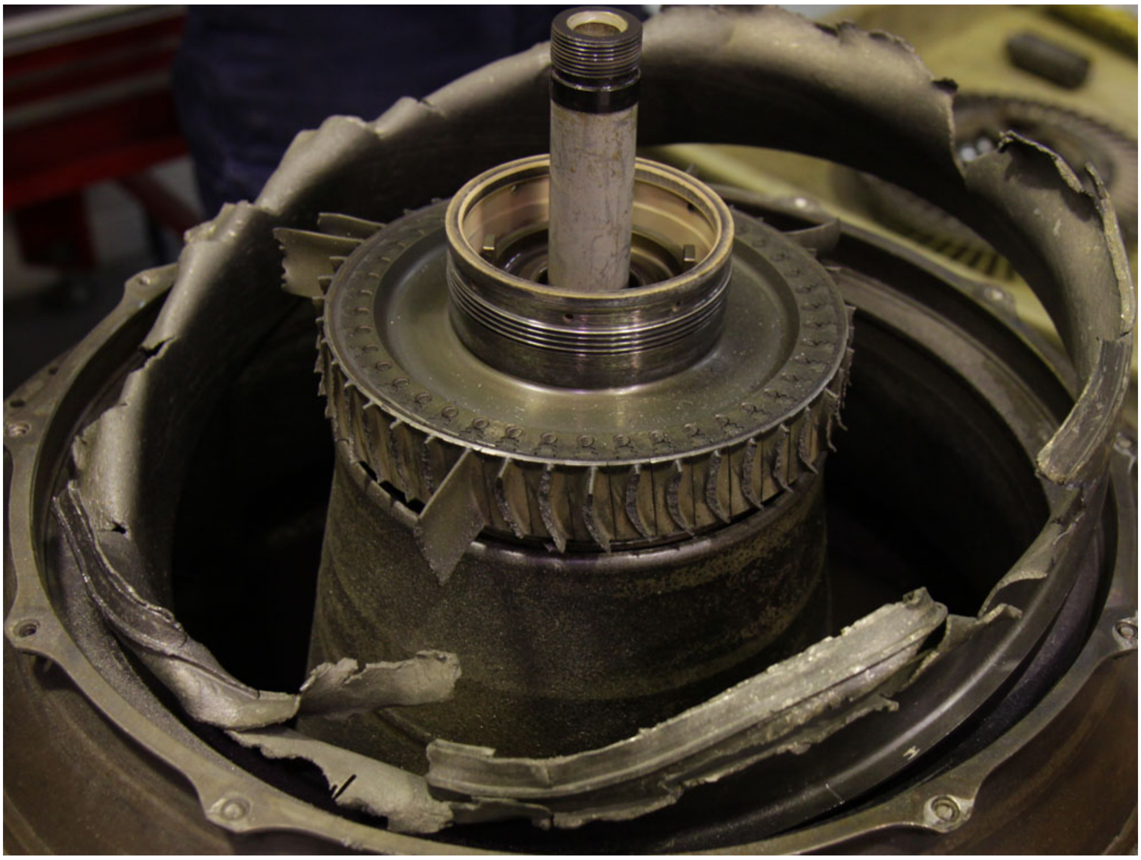
Source: Pratt and Whitney Canada, modified by the ATSB

Engine and component examination

The following significant items were noted during the disassembly and inspection of the failed engine:

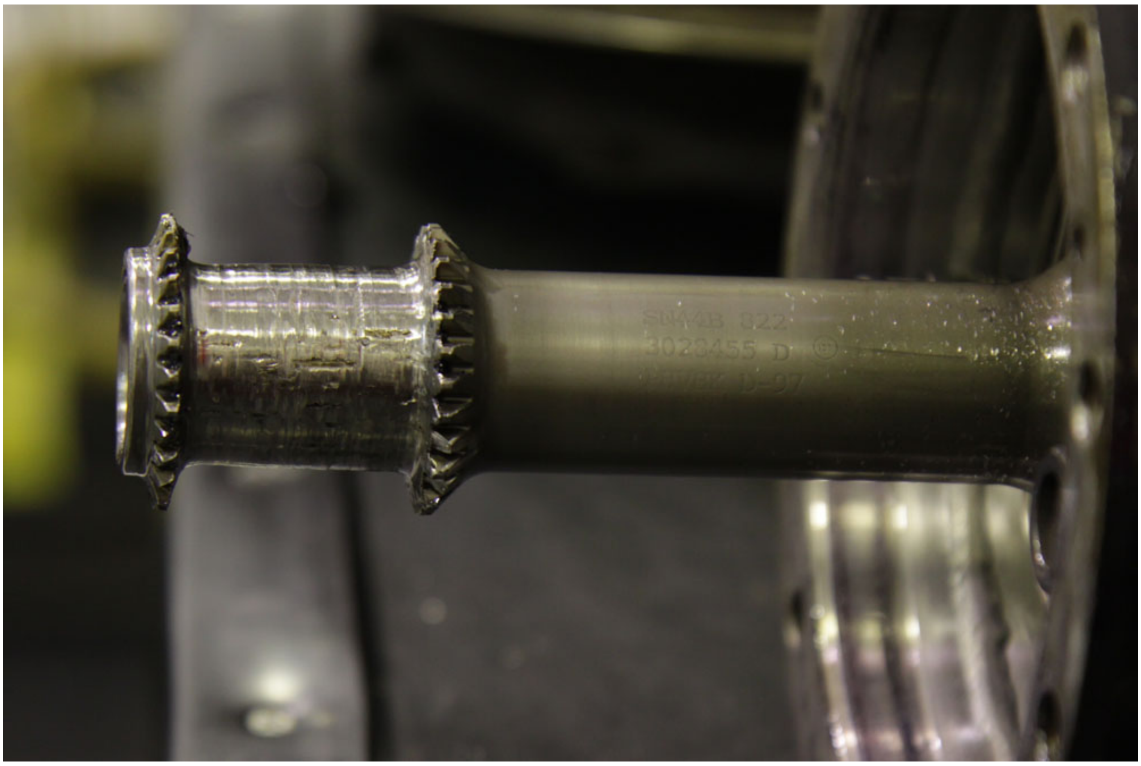
- Most of the blades from the second-stage power turbine disk had fractured and released at their base at the blade platform (Figure 3). The fracture surfaces of the remnant blade stubs were consistent with failure by overstress with no evidence of any pre-existing defects or progressive crack growth. The power turbine housing successfully contained the released blades.
- Within the reduction gearbox:
  - All of the teeth on the first-stage sun gear had been effectively 'machined' from the shaft (Figure 4).
  - All three first-stage planet gears showed significant deformation and chipping of the gear teeth, some of which had fractured by a fatigue cracking mechanism (Figure 5 and Figure 6).
  - The plain bearings from each of the planet gears were in good condition and showed no evidence of distress.
  - There was no evidence to indicate that the oil supply to the reduction gearbox had been disrupted.
  - The reduction gearbox magnetic chip detector and sump screen had captured a significant quantity of metallic debris (Figure 7). Subsequent analysis revealed the captured debris to be similar in composition to the alloy used in the reduction gear set.

Figure 3: Second-stage power turbine disk



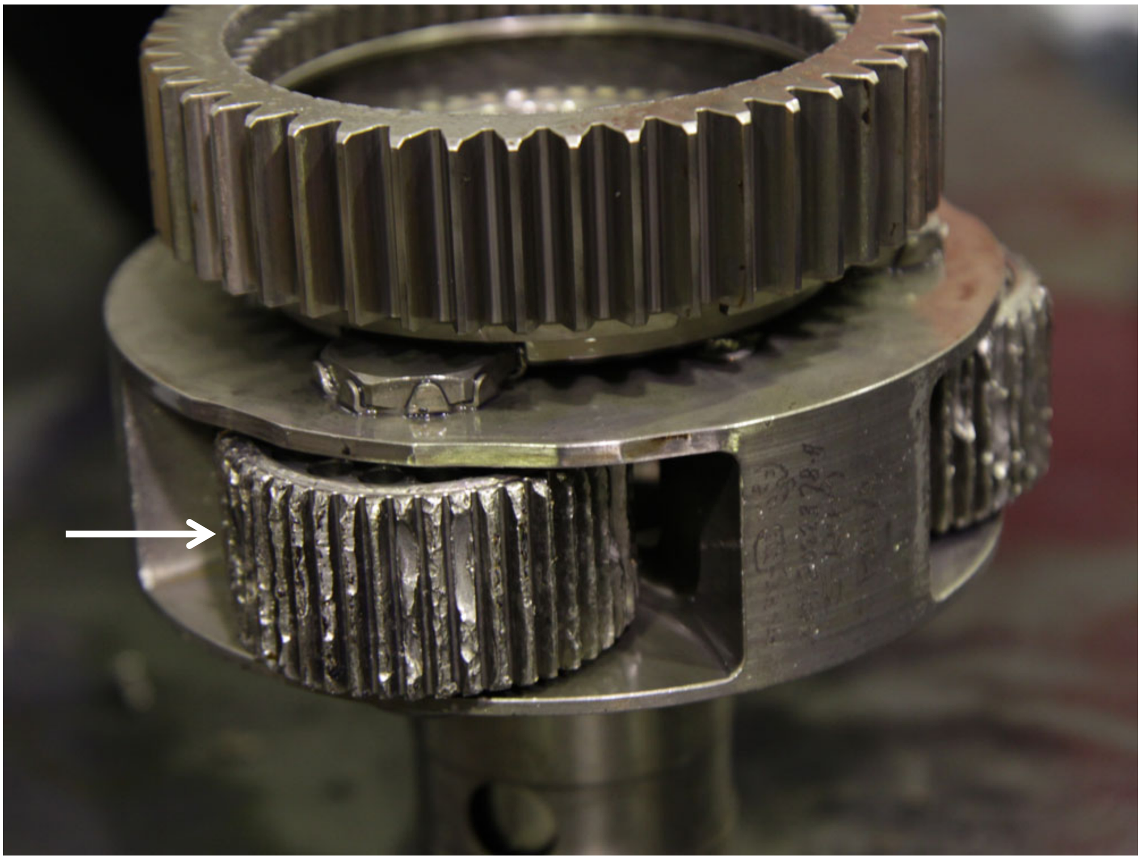
Source: ATSB

Figure 4: Remnant first-stage sun gear



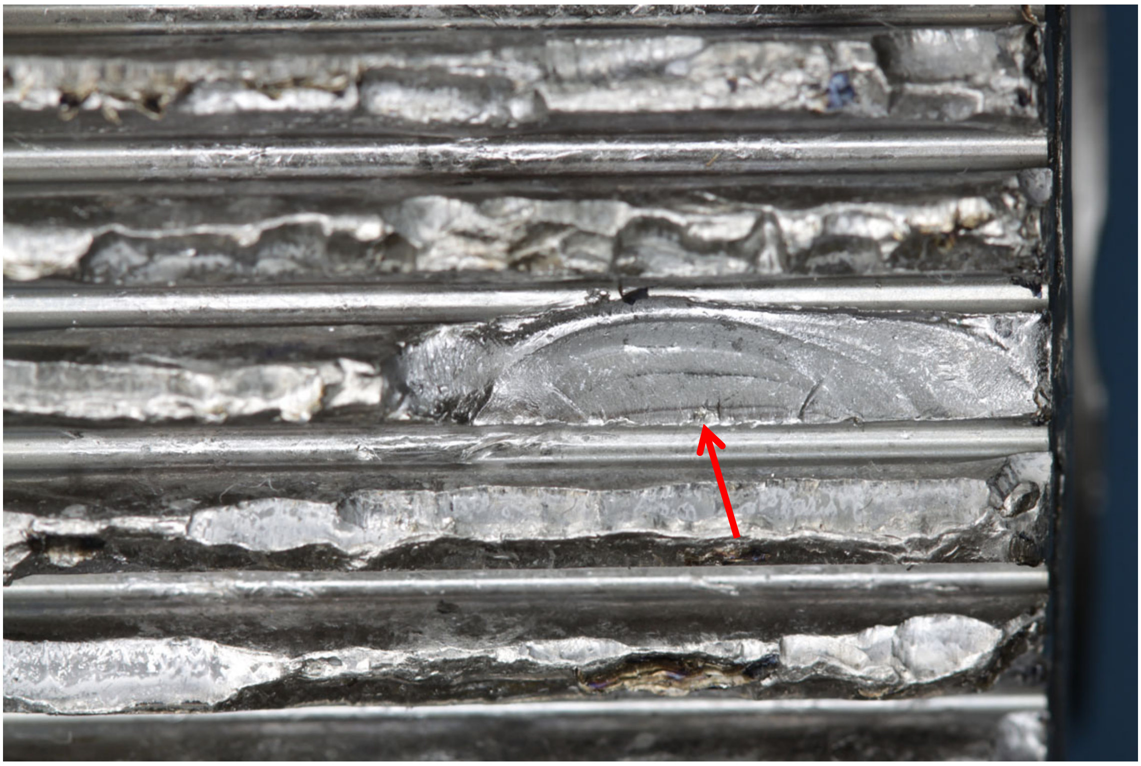
Source: ATSB

Figure 5: A damaged first-stage planet gear (arrowed) in situ within the gear carrier



Source: ATSB

Figure 6: Example of fatigue cracking (arrowed) on a first-stage planet gear tooth



Source: ATSB

Figure 7: The contaminated magnetic chip detector plug

Source: ATSB

Engine maintenance

The failed engine, serial number PCE-81564, was manufactured in 1980 and was initially installed on the aircraft in 2003. At the time of the occurrence, the engine had accumulated 12,426 hours total time in service and 10,216 cycles. It had been 3,431 hours since the most recent overhaul (TSO), which was conducted in 1995. The engine was being maintained on 5,000 hour service intervals according to the *PT6A Enhanced Maintenance Program* requirements, as detailed in Civil Aviation Safety Authority (CASA) Airworthiness Directive AD/ENG/5 Amdt 9 – *Turbine engine continuing airworthiness requirements*. There were no records of any significant engine anomaly in the engine maintenance logs or aircraft maintenance release, and there was no indication of impending engine failure in the engine condition trend monitoring data.

Magnetic chip detector

AD/ENG/5 Amdt 9 Appendix A required that the reduction gearbox oil filter element and chip detector 'be inspected for contamination, or continuity' at least every 220 hours of service. The most recent chip detector inspection was in December 2012 at 3,260 hours TSO (171 hours prior to the engine failure). No anomalies were noted during that inspection. A small amount of metallic fuzz was noted during an earlier inspection in April 2011 at 2,889 hours TSO, however, the subsequent five inspections were clear of any defects.

The aircraft incorporated a press-to-test button to check the functionality of the cockpit annunciator lights during pre-flight checks, but no method for testing the continuity of the chip detector circuit from the cockpit. Pre-flight checks also included an inspection of the circuit breaker panels for any circuits that had popped.

Reduction gearbox

The first-stage reduction gears were all P&WC parts. Engraved identifiers on the flanks of each planet gear indicated that they had been installed together as a matched set. There was no record in the engine maintenance logs to indicate that the gears had ever been replaced during the life of the engine.

AD/ENG/5 Amdt 9 requirement 1.3 provided three options for compliance with the inspection and overhaul requirements for PT6A series engines (other than those installed in aerial agricultural or firefighting operations):

> a) PT6A series engines shall be overhauled at periods as listed in, and subject to the requirements of, the appropriate Pratt and Whitney Canada Service Bulletin detailing Pratt and Whitney Canada PT6A operating time between overhaul and hot section inspection frequency; or
>
> b) At periods not to exceed 5,000 hours time in service, subject to compliance with the maintenance requirements detailed in Appendix A of this Directive; or
>
> c) As detailed in an approved system of maintenance.

The operator's maintenance documentation indicated that the engine had been maintained in accordance with option b) above.

A Pratt and Whitney Canada Service Bulletin, SB 3003, prescribed the operating time between overhaul and hot section inspections for PT6A-38, -41, -42 and -42A engines. The SB provided recommendations for basic time between overhaul (TBO) inspections. Any extension to the basic TBO required approval from the operator's airworthiness authority. Engine specific TBO extensions were set at a maximum of 5,000 hours or 12 years per SB 3003 Revision 25 and required that a record be kept of the total hours since new for the first-stage sun and planet gears. Furthermore, to be eligible for a TBO extension, the first-stage sun and planet gears must have no more than 12,000 hours' time since new at any time during the program. The 12,000-hour limit was not a requirement for engines maintained on the baseline TBO recommendations per SB 3003.

AD/ENG/5 Amdt 9 Appendix A did not specifically reference the first-stage reduction gears, but required that 'all life-limited components shall be replaced at engine manufacturer's published life limits per AD/ENG/7', which in turn required that, 'Unless otherwise directed by the Authority, [operators should] replace life limited engine components in accordance with the latest issue of the applicable engine manufacturer's service document that details such life limits'*.* P&WC SB 3002 was the applicable document that detailed the life limits of engine components; however, there was no reference to the first-stage reduction gears. Therefore, at the time of the most recent overhaul (in 1995), the first-stage sun and planet gears did not have a life limit, unless operating under the manufacturer's TBO extension program.

P&WC service information letter (SIL) No. PT6A-078 (released September 1999), mandated the replacement of first-stage sun and planet gears at overhaul, regardless of condition. Furthermore, it became a requirement that if the first-stage planet gears are replaced for any reason, the first-stage sun gear must also be replaced. This information was also incorporated into revised engine overhaul manuals at this time. The SIL indicated that the requirement was introduced to enhance the reliability of the first-stage reduction gear train after an increasing rate of unplanned engine removals due to first-stage sun and planet gear distress. The distress of the gears was associated with re-installation of the original sun and/or planet gears at the previous overhaul.

Related occurrences

Reduction gearbox failure

ATSB investigation AO-2006-007 involved the in-flight failure of a PT6A-41 engine that had damage to the second-stage power turbine and damage to the first-stage reduction gears that was very similar to that of the occurrence engine. That investigation found that the first-stage sun gear had been replaced some 5,000 hours prior to the failure, without corresponding replacement of the first-stage planet gears. Mismatched sun and planet gear sets had previously been identified by the engine manufacturer as a contributing factor in reducing the reliability of the reduction gearbox. It was also noted that the planet gears had likely accumulated 13,882 hours of service at the time of failure.

Chip detector light illumination

A search of the CASA Service Difficulty Report (SDR) database found two instances of momentary, in-flight illumination of the RGB chip detector light on Beech 200 aircraft. In both instances the engine subsequently failed. The ATSB is also aware of a previous occurrence where the circuit breaker popped without a corresponding warning light. The popped circuit breaker in that occurrence was attributed to a large piece of metallic debris that had short-circuited against the gearbox casing.

In August 2012, the ATSB received a report through their confidential reporting scheme (REPCON), regarding momentary or intermittent chip detector light illumination. The reporter expressed a safety concern that the current non-normal checklist procedure, to monitor the engine indications and shut down the engine if further abnormal indications are observed, is inadequate for this scenario and should be amended to include checking if the circuit breaker has popped and also to warn the pilot that engine failure may still be imminent.

As a result of this occurrence, the ATSB contacted CASA, requesting comment in relation to the abovementioned chip detector circuit concerns. CASA reported that they had discussed the incident with the aircraft manufacturer and was advised:

> …that on this occasion, the engine experienced an accelerated rate of failure, resulting in a large volume of liberated engine material to bridge the chip detector warning terminals. This scenario caused the aircraft's circuit breakers to short out, extinguishing the crew's indication light.
>
> Hawker Beechcraft also advised that the aircraft flight manual requires the pilot to monitor the other engine indications for abnormal readings in a case such as this. The pilot should also, at their

> discretion, perform a precautionary engine shutdown if engine indications show the safety of flight may be affected.

CASA reported that they had not received any further reports of this type of occurrence and would not be undertaking any further action unless new information is provided.

Safety analysis

Engine failure

During the normal operation of a free-turbine engine, such as the PT6A-41, the load applied by the hot airstream as combustion gases pass through the power turbine is transferred via a stub shaft and sun gear to the propeller reduction gearbox. The power turbine will rotate at a constant speed when there is a balance between the gas load applied to the turbine and the air loads applied to the propeller.

When a drive shaft component such as the sun gear fails, the mechanical interconnection between the propeller reduction gearbox and the turbine is removed. The system is no longer balanced. This condition, known as a 'loss of load', results in a decrease in propeller reduction gearbox speed and an increase in turbine speed as the combustion gases are still applying a load to the now unloaded turbine.

When a turbine disk is rotating, there is a radial expansion of the disk and span wise elongation of the turbine blades as a result of centrifugal forces generated. The greater the rotational speed, the greater the applied stresses to the rotating components. Permanent deformation results when the increase in speed is such that those stresses exceed the yield strength of the disk or the blades. An overstress failure may occur as the rotational speed of the turbine approaches its terminal speed, exceeding the ultimate strength of the disk or its blades, and can result in fragmentation of the disk or shedding of the blades.

The fatigue failure and subsequent breakdown of the first-stage sun and planet gear teeth in the reduction gearbox from the occurrence engine resulted in the above-described disconnection between the power turbine and propeller reduction gearbox. This led to an immediate 'loss of load' of the power turbine, allowing it to accelerate and shed its blades due to the resulting overstress.

Reduction gearbox failure

A metallurgical examination of the recovered engine components showed that several teeth from each first-stage planet gear within the reduction gearbox had failed due to the initiation and propagation of fatigue cracking. The examination also showed that virtually no remnants of the contact portion of teeth from the mating sun gear remained. No identifying features that could have initiated the cracking, such as corrosion pitting, excessive wear or mechanical damage, were observed around the fatigue crack origins from the planet gears. The appearance and location of the fatigue cracks in the tooth fillet radius was consistent with exposure to cyclic bending loads.

A comprehensive review of the available maintenance documentation for the engine revealed that the failed first-stage sun gear and planet gear set had accumulated 12,426 hours total time in service and 10,216 cycles. In the absence of any identified contributory defect, maintenance or operational issues, it was probable that the development of the fatigue cracking was related to their high time in service and that the gears had reached the end of their fatigue life.

Replacement of first-stage reduction gears

At the time of the most recent engine overhaul in 1995, there was no requirement to replace the first-stage reduction sun and planet gears for PT6A engines maintained under Civil Aviation Safety Authority Airworthiness Directive AD/ENG/5 Amdt 9 requirement 1.3(b) or for engines maintained per the manufacturer's basic time between overhaul (TBO) interval recommendations listed in Service Bulletin (SB) 3003 R25. This was in contrast to the 12,000 hour life limit recommended by the engine manufacturer in SB3003 R25, to qualify for their TBO extension program.

The discrepancy in first-stage reduction gear service life was subsequently addressed by the manufacturer's September 1999 introduction of the mandatory requirement to replace the first-stage reduction gears at every overhaul. However, engines that have not been overhauled since 1999 (including the subject engine) could still be operating with first-stage reduction gears in excess of the 12,000 hour life limit, while still complying with AD/ENG/5 Amdt 9 and the manufacturer's baseline TBO requirements. Pratt and Whitney Canada (P&WC) have indicated that, based on the current rate of in-flight shut downs (one per 10,000,000 flight hours) relating to reduction gear deterioration, and provided that the engine is maintained in accordance with P&WC's instructions for continuing airworthiness, there is no immediate action required in these situations. Nevertheless, the ATSB encourages operators and maintainers of affected engines to review their maintenance records and give consideration to the replacement of high-time gearsets.

Magnetic chip detector

Evidence indicated that the magnetic chip detector cockpit warning light and circuitry was functional at the time of the most recent maintenance check and there were no issues reported with the cockpit annunciator lights or circuit breakers.

Engines experiencing an accelerated rate of failure may trigger momentary or intermittent illumination of chip detector warning lights, or popped circuit breakers with no associated chip detector light, resulting from the rapid build-up of large amounts of metallic debris. This scenario was considered a likely explanation for the lack of an otherwise expected chip detector warning light prior to the subject engine failure.

Findings

From the evidence available, the following findings are made with respect to the engine failure involving Beech Aircraft Corporation 200, registered VH-ZMP, which occurred 155 NM (277 km) north-north-west of Marshall Islands International Airport (Majuro Atoll), on 12 September 2013. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing factors

- The engine failure resulted from fatigue cracking and accelerated breakdown of the first-stage sun and planet gears in the propeller reduction gearbox that led to a subsequent loss of load and consequential overspeed of the second-stage power turbine.

Other factors that increased risk

- Pratt and Whitney Canada PT6A-38, -41, -42 and -42A engines, last overhauled prior to September 1999, may be operating with first-stage reduction sun and planet gears in exceedance of the 12,000 hour life limit required for the manufacturer’s time between overhaul (TBO) extension program, while still complying with the requirements of Civil Aviation Safety Authority Airworthiness Directive AD/ENG/5 Amdt 9 and the manufacturer’s baseline TBO program.
- The reduction gearbox chip detector cockpit warning light circuit breaker had popped, preventing the flight crew from receiving a visual warning prior to the engine failure.

General details

Occurrence details

Date and time:	12 September 2013 – 1040 MHT[1]	
Occurrence category:	Serious incident	
Primary occurrence type:	Engine failure	
Location:	155 NM (277 km) NNW of Marshall Islands International Airport (Majuro Atoll),	
	Latitude: 07° 11.90' N	Longitude: 171° 34.02' E

Aircraft details

Manufacturer and model:	Beech Aircraft Corporation Model 200	
Registration:	VH-ZMP	
Serial number:	BB-259	
Type of operation:	Charter	
Persons on board:	Crew – 2	Passengers – 1
Injuries:	Crew – 0	Passengers – 0
Damage:	Substantial	

[1] Marshall Islands Time (MHT) was Coordinated Universal Time (UTC) + 12 hours.

Sources and submissions

Sources of information

The sources of information during the investigation included:

- the pilot in command of VH-ZMP
- the aircraft operator
- an engine maintenance provider
- the engine manufacturer
- the Civil Aviation Safety Authority (CASA).

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), 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 pilot in command, the aircraft operator, the engine manufacturer, CASA and the Transportation Safety Board of Canada. No significant submissions were received from those parties.

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

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 identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, 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 initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred 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 to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept 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.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.