Australian Government
Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT
Aviation Occurrence Report – 200600563
Final

Engine Failure
Lake Burbury, Tasmania
5 February 2006
VH-KLP
Cessna Aircraft Company 208

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Pratt & Whitney Canada, Figure 8, PT6 engine cutaway view illustration.

Abstract

On 5 February 2006, at approximately 1725 Eastern Daylight-saving Time, a Cessna Aircraft Company 208 floatplane, registered VH-KLP, departed from Strahan, Tasmania on a chartered tourist flight over Frenchman's Cap with the pilot and ten passengers.

When the aircraft was over Frenchman's Cap at an altitude of 4,500 ft above mean sea level, the pilot observed that a chip detector light on the master caution warning panel had illuminated. The pilot decided to land the plane as soon as possible. During the diversion, five minutes after the chip detector light illuminated, a loud noise was heard and the engine lost power. The pilot immediately feathered the propeller and carried out a forced landing on Lake Burbury.

The pilot reported that the aircraft landed heavily and its forward speed could not be controlled. The aircraft came to a stop on a mud bank on the edge of Lake Burbury with its floats clear of the water. There were no reported injuries.

The engine was removed, disassembled and inspected, revealing damaged components with characteristics consistent with electrical discharge damage. The source of the electrical discharge damage was a starter-generator that was replaced due to a malfunction 18.7 hours prior to the engine failing. This was the forty-third reported starter-generator electrical discharge damage event reported to have taken place on PT6A series engines world-wide since 1992.

As a result of this investigation several safety recommendations have been issued to the aircraft manufacturer, the engine manufacturer, the Civil Aviation Safety Authority, Transport Canada and the US Federal Aviation Administration.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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

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.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, risk controls and organisational influences.

Contributing safety factor: a safety factor that, if it had not occurred or existed at the relevant time, then either: the occurrence would probably not have occurred; or the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or (c) characteristic of an operational environment at a specific point in time.

Safety issues can broadly be classified in terms of their level of risk as follows:

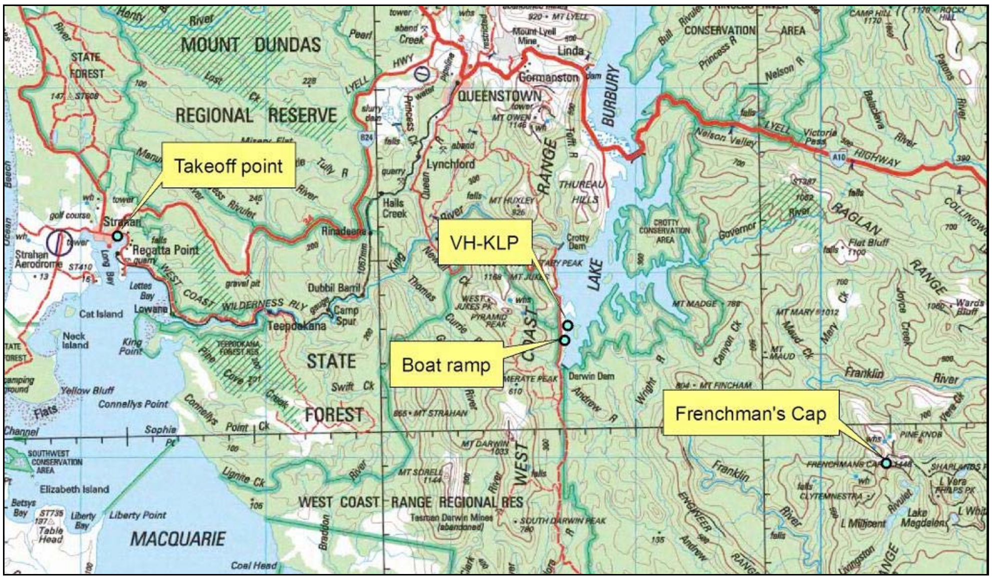
- **Critical safety issue**: associated with an intolerable level of risk.
- **Significant safety issue**: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable.
- **Minor safety issue**: associated with a broadly acceptable level of risk.

FACTUAL INFORMATION

Background information

On 5 February 2006, at approximately 1725 Eastern Daylight-saving Time[1], a Cessna Aircraft Company 208 floatplane, registered VH-KLP, departed from Strahan, Tasmania on a chartered tourist flight over Frenchman's Cap, then returning via the Gordon River and Macquarie Heads. The flight was conducted under the visual flight rules, with a pilot and 10 passengers. When the aircraft was over Frenchman's Cap (Figure 1), at an altitude of 4,500 ft above mean sea level, the pilot observed that the gearbox chip detector[2] light on the master caution warning panel had illuminated.

Figure 1: Map of intended scenic route and actual landing point



The pilot decided to divert and land on Lake Burbury, as it was the closest body of water. The pilot reported that, approximately 5 minutes later, a loud noise came from the area of the engine and a PAN[3] call was made. The pilot feathered the propeller and briefed the passengers that a landing would be made onto Lake Burbury.

The pilot reported that the aircraft landed heavily and that the forward speed could not be controlled. The aircraft came to a stop on a mud bank, with the floats clear of the water (Figure 2).

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1 The 24-hour clock is used in this report to describe the local time of day Eastern Daylight-saving Time (ESuT), as particular events occurred. Eastern Daylight-saving Time was Coordinated Universal Time (UTC) + 11 hours.

2 A device, often a permanent magnet, for gathering and indicating the presence of metallic fragments in lubrication oil.

3 Radio code indicating uncertainty or alert, general broadcast to widest area, not yet at the level of Mayday.

There were no reported injuries and the pilot and passengers were able to walk to a nearby boat ramp and request assistance from the local police.

The aircraft was recovered from the mud bank and towed to a nearby boat ramp. There was no observed damage to the aircraft initially, however, a subsequent inspection of the airframe revealed damage to the engine firewall. The engine was removed and taken to an approved engine overhaul facility.

Figure 2: The Cessna 208's final position on the mud bank

Aircraft chip detector warning system

The aircraft's engine was fitted with two magnetic chip detectors, which were installed on the underside of the reduction gearbox and the accessory gearbox. The chip detectors were electrically connected to an annunciator light located on the pilot's annunciator panel. The chip detector light illuminates when ferrous metal fragments became attached to one or both of the chip detector magnetic poles, completing the circuit to the annunciator light.

A chip detector light illumination warns the pilot that there is abnormal wear occurring inside the engine. The accessory gearbox chip detector warning system was fitted as standard equipment on Cessna 208 aircraft manufactured after 2002. Prior to that date, accessory gearbox chip detectors were optional equipment that were fitted, if required, by the purchaser of the aircraft. Numerous Cessna 208 aircraft have not been fitted with accessory gearbox chip detectors.

Figure 3 is a picture of the accessory gearbox chip detector with metal particles still attached on the left and a clean chip detector of the same type on the right, with the two magnetic poles clearly visible.

Figure 3: Chip detectors

Aircraft manufacturer emergency procedures

The emergency procedures in the C208 aircraft pilot's operating handbook stated that, in the event of an amber gearbox chip detector annunciator light illumination the following procedure should be followed:

1. Engine Gauges--CAREFULLY MONITOR engine gauges for abnormal oil pressure, oil temperature, or power indications.
2. If engine gauges are normal, proceed to destination and determine cause of chip detector annunciator warning prior to next flight.
3. If engine gauges confirm chip detector annunciator warning, proceed in accordance with Engine Failures checklists, or at the discretion of the pilot and consistent with safety, continue engine operation in preparation for an emergency landing as soon as possible.

The pilot in command of VH-KLP reported that the only indication he received from the instruments was the gearbox chip detector light illumination approximately 5 minutes prior to the engine failure. He also stated that had he not diverted to a safe landing area immediately when the chip detector light illuminated, he would have been over mountainous terrain with nowhere to carry out an emergency landing when the engine failed.

According to the aircraft maintenance documentation, there had been no other chip detector annunciator warnings prior to this event from the time the engine was fitted post overhaul.

Engine details

Make	Pratt & Whitney Canada (PWC)
Model	PT6A-114 serial number PCE-PB0508
Total time in service	6,445 hours / 7,855 cycles
Time since last overhaul	1,448 hours / 2,611 cycles
Date of last overhaul	27 November 2003

Engine inspection

The engine was disassembled and inspected in an approved US engine maintenance facility under the supervision of the US National Transportation Safety Board (NTSB) on behalf of the Australian Transport Safety Bureau (ATSB). The inspection revealed that the number-1 engine bearing, which was one of the two support bearings for the compressor rotating section, had collapsed due to mechanical and thermal distress associated with partial seizure (Figure 4).

Figure 4: Failed number-1 bearing

A subsequent technical examination conducted by the ATSB indicated that there was evidence consistent with electrical discharge damage[4] (EDD) from the starter-generator[5] drive gear through to the number-1 bearing. Several damaged components were sent to the ATSB's laboratory for further analysis. The ATSB inspection and analysis confirmed a clear path of EDD from the starter-generator to the number-1 bearing (see Appendix A – ATSB Technical Analysis report BE/200600016).

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4 Thermal damage resulting from localised high temperature produced from electrical arcing. For more information refer to ATSB occurrence report BO/200003399.

5 The starter-generator operates as a starter motor to turn the gas generator section of the engine during start-up. After the engine has started, the starter-generator operates as a generator to provide the aircraft with a continuous supply of 28 volts direct current.

Starter-generator details

Starter-generator inspection

A review of the aircraft maintenance documentation indicated that the starter-generator previously installed on the engine had failed and was replaced with a newly overhauled starter-generator approximately 18.7 hours prior to the engine failure.

The newly overhauled starter-generator that was fitted at the time of the engine failure was inspected and tested when the engine was replaced and was assessed as being serviceable when the engine failed and was returned to service.

The failed starter-generator that was replaced 18.7 hours before the engine failure was taken to an approved starter-generator overhaul facility for disassembly and examination under ATSB supervision (Figure 5).

Failed starter-generator details

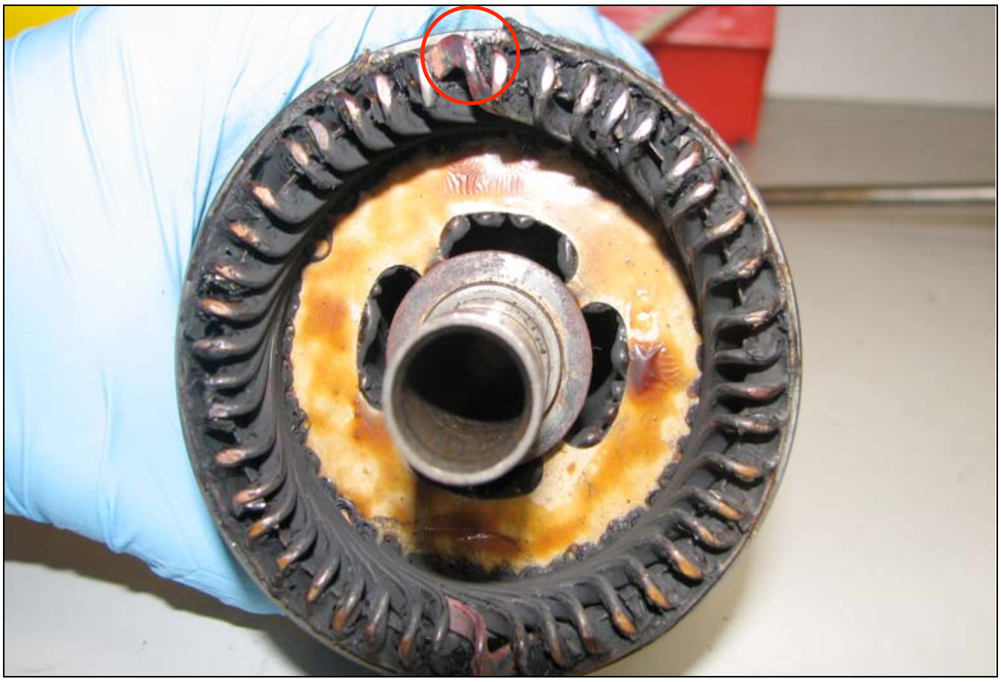
Make	Aircraft Parts Corporation (APC)
Model	Part number 200SGL119Q serial number 2870XL
Time since overhaul	851.5 hours
Time before overhaul	748.5 hours
Time removed before engine failure	18.7 hours
Date last overhauled	19 August 2004

Figure 5: Failed starter-generator assembly

The examination revealed degraded insulation on the starter-generator armature windings. It was evident that the insulation had degraded due to an overheat event taking place during the start mode.

Figure 6 illustrates the point of contact of the armature windings to the forward armature winding retaining band. The area inside the red circle indicates the initiation point for the EDD event.

Figure 6: Starter-generator armature windings



The evidence indicated that, when the exposed armature windings came in contact with the forward armature winding retaining band, a hard short[6] was created. A direct electrical current path then existed between the armature windings and the starter-generator output shaft. This allowed electrical current to discharge into the engine.

Figure 7 is an enlarged view of the area highlighted in Figure 6 and it shows the armature winding and the point of contact with the forward armature winding retaining band. Note the blackened and burnt insulation around the windings and the discoloured metal on the retaining band, indicating the initiation point for the EDD event.

Figure 7: Armature windings

6 A hard short is an unbreaking short circuit which allows electrical current to flow along a different path than the one intended.

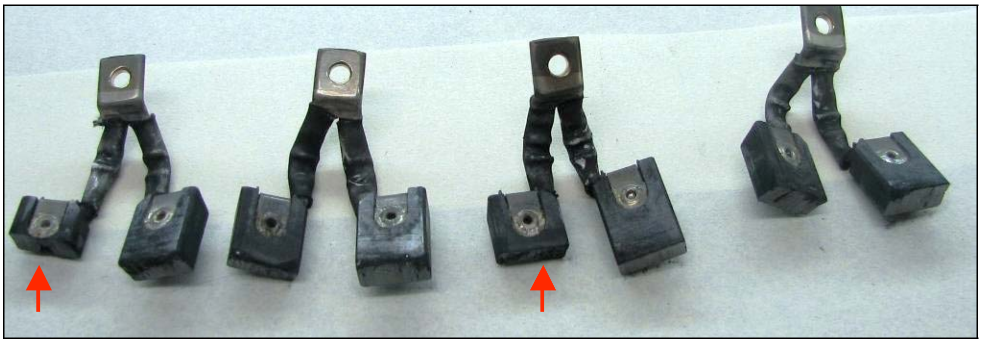
There was evidence of EDD on the starter-generator drive spline in the area highlighted in Figure 8. There was also evidence of EDD on one of the starter-generator armature support bearings.

Figure 8: Starter-generator drive spline

An inspection of the starter-generator brushes revealed that the brushes had worn unevenly and that two of the brushes were worn well beyond the allowable limits specified in the starter-generator maintenance manual. One of the brushes had worn down to the extent that the spring which keeps the brush in contact with the commutator had reached its stop, which meant the brush was no longer being held in contact with the commutator under positive pressure. It could not be ascertained if that would have contributed to the starter-generator failure. However, the performance of the starter-generator in start mode would have been reduced due to the worn brushes and reduced brush spring tension.

Figure 9 shows the worn starter-generator brushes, and the red arrows indicate the two brushes that were worn beyond limits. The brush springs that hold the brushes in contact with the commutator under a specific tension were checked and all found to be within maintenance manual limits. The brushes were inspected prior to removal and found to be fitted correctly. It could not be ascertained why the brushes were worn at different rates.

Figure 9: Starter-generator brushes



An inspection of the starter-generator maintenance documentation showed that the starter-generator had operated 851.5 hours since it was overhauled. It had 748.5 hours remaining before it was due to be overhauled again, in accordance with the Cessna 208 maintenance manual component limitations.

The starter-generator was last overhauled at a manufacturer approved maintenance facility, using only genuine Aircraft Parts Corporation (APC) parts and procedures during the overhaul.

Aircraft Parts Corporation has an inspection requirement, detailed in Service letter 132, which is a calculation of starter-generator brush life at 300 flight hours. This is a one-off sampling type check to predict brush wear. The inspection is not included in the Cessna 208 maintenance manual, which is used to determine aircraft component inspection and overhaul time limitations.

The Cessna 208 maintenance manual had no inspection requirements for APC type starter-generator brush wear inspections between overhaul periods. This was inconsistent with APC service letter 132 and with other starter-generator types which could be fitted to the same aircraft.

A review of the aircraft maintenance documentation indicated that the starter-generator brushes were not inspected since the last overhaul of the unit.

PT6A starter-generator EDD

PT6A series engine starter-generator EDD occurs when electrical current from the starter-generator output shaft discharges into the engine through the engine accessory drive train.

Figure 10 illustrates the construction of the PT6A engine. The positions of the number-1 bearing and the starter-generator input drive spline are indicated by arrows. The typical starter-generator EDD electrical current path is highlighted in red between the two arrows.

Figure 10: Cross section of a typical PT6A engine

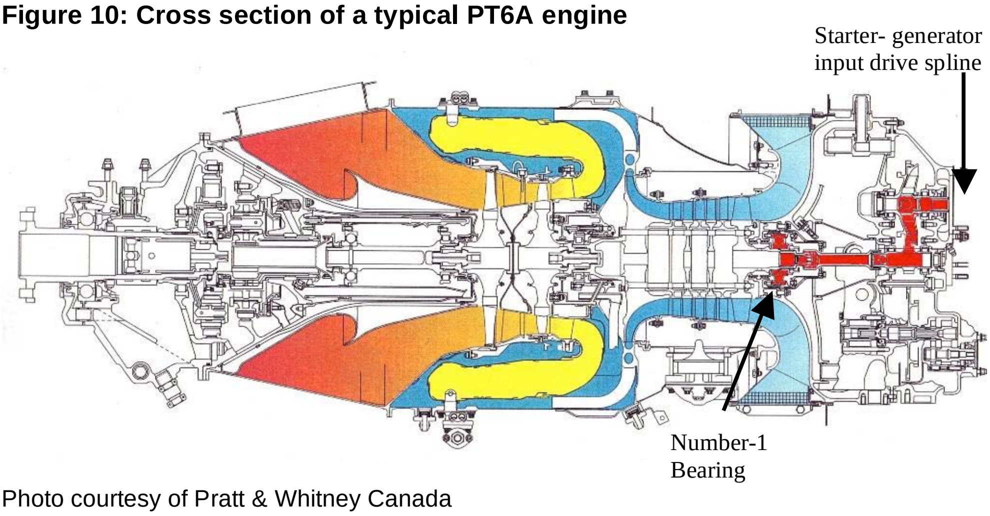


Photo courtesy of Pratt & Whitney Canada

There are two known ways starter-generator EDD can occur. The first type of starter-generator EDD, which is the type found in this event, is a hard short or low resistance to earth, caused by an insulation breakdown in the armature windings or lamination slots. This type of event allows a single high current transient discharge of electricity into the engine resulting in pitting of the number-1 bearing, leading to its eventual failure. This type of event damages the number-1 bearing almost instantaneously. The Generator Control Unit[7] (GCU) senses a fault and disconnects the starter-generator electrically when this event occurs, however this may not occur until it after the damage has already occurred to the engine.

The second type of starter-generator EDD is armature leakage from a build up of brush dust in the starter-generator. The brush dust can provide a track for current flow between the commutator and the output shaft. This type of event can cause an intermittent flow of electric current into the engine, resulting in pitting of the number-1 bearing and eventually resulting in its failure. In a previous ATSB investigation into EDD, the GCU's intermittently sensed faults with the starter-generator and on occasion would disconnect the starter-generator electrically.

Previous PT6A starter-generator EDD events

According to the engine manufacturers documentation there have been a total of forty-two PT6A starter-generator EDD events recorded world-wide since October 1992 to February 2006. In the vast majority of those cases, the starter-generator EDD events led to number-1 bearing failure. Up to February 2006, the aircraft and engine types which are known to have been affected by starter-generator EDD engine failures are as follows:

Aircraft Type	Engine Type	Number of Events
Raytheon Beechcraft 1900C/D	PT6A-65B/67D	19
Shorts Bros 330/360	PT6A-65R/67R	11
Raytheon Beechcraft Kingair 90/200/300	PT6A-21/41/60A	4
Pilatus PC 12	PT6A-67B	3
Air Tractor AT 502/602/802	PT6A-34/60/67AG	3
Raytheon Beech 99	PT6A-36	1
Cessna Caravan 208	PT6A-114	2

Previously, it was only the larger PT6A series of engine (-60 and higher) utilising Lear Seigler (TRW Lucas) P/N 23078 or P/N 23085 starter-generators that were known to be at risk of EDD. However, information provided by the engine manufacturer has shown that the small and medium sized PT6A engines are also vulnerable to starter-generator EDD.

This is the second known event to have occurred with a PT6A-114 engine. Prior to publishing this report, the ATSB became aware of another Cessna 208 PT6A-114 starter-generator EDD event. The engine was sent to an engine overhaul facility for a scheduled overhaul in 2003. An engine condition report described starter-generator EDD type damage sustained in the engine. The damage had not progressed to the point of engine failure before the engine was removed for overhaul.

7 The Generator control unit monitors and controls the electrical power system, sequencing system operation from starting the engine through to generator operation, the unit is also utilised for system protection, it will electrically disconnect the starter-generator if it senses a problem.

The PT6A-114 engine is considered to be a medium sized PT6A engine. There have been eight known starter-generator EDD events in single engine aircraft fitted with PT6A engines, five of these aircraft being capable of Instrument Flight Rules (IFR) operations.

Six such events have been recorded in Australia. An investigation was carried out by the ATSB following the last known event in Australia. For more information, on the previous investigation, which encompassed five engine failures on Shorts Bros. 360 aircraft utilising PT6A-67R engines, refer to the ATSB investigation report BO/200003399 and technical analysis report BE/200000014, available on the ATSB web site http://www.atsb.gov.au.

An investigation into a Pilatus PC12 accident was carried out by the NTSB in 2002. The investigation identified PT6A starter-generator EDD pitting in the number-1 bearing as the initiator to the engine failure. The EDD event was identified to have taken place approximately 700 hours prior to the engine failing.

PT6A EDD detection

When a starter-generator malfunction occurs due to a hard short, an inspection of the starter-generator drive spline with a 10 times magnifying glass could identify evidence of electrical arcing (Figure 7). If electrical arcing damage is present on the starter-generator drive spline, then an inspection of the engine accessories and number-1 bearing would likely reveal EDD.

The engine manufacturer introduced a maintenance manual requirement in 2002 to carry out patch checks and Spectrographic Oil Analysis Programs (SOAP) in an effort to detect EDD affected engines before they failed.

A relevant extract from the PT6A-114 maintenance manual amendment of February 2005 Chapter 72-00-00 page 649/650 was as follows:

> (1) If the starter-generator is replaced in order to rectify a reported engine starting or electrical generation defect, that is suspected as an electrical fault or bearing distress of the starter-generator, inspect the main oil filter as follows:
>
> (a) Do a main oil filter patch check (Ref. Chapter 79-20-02). The results of the filter patch analysis should be reviewed within the next 25 flight hours. If non allowable debris is found, follow the recommended maintenance actions (Ref. Chapter 79-20-02).
>
> (b) Regardless of the results of the patch analysis, repeat step (a) every 100 hours, for the next 700 flight hours.
>
> (c) If bearing material (AMS 6440/6444 or AMS 6490/6491, Ref. Chapter 79-20-02) is found, remove the engine/gas generator module and send to an approved overhaul facility for repair.

According to the aircraft maintenance documentation, a patch check was carried out when the failed starter-generator was replaced with no anomalies detected.

The function of SOAP and patch checks is to identify the presence of material that has been liberated from the internal components of the engine accessory and drive gear assemblies. SOAP is a trending technique that looks for changes in the entrained metallic element content of lubrication oil. Filter patch checks use procedures to identify larger material particles and pieces that have lodged in the oil filter element. SOAP looks for periodic changes in the metallic elements within the oil (i.e. iron, copper, aluminium), whereas patch checks can identify specific alloys such as bearing material within the material collected by the oil filter element.

During the NTSB investigation into the Pilatus PC12 starter-generator EDD engine failure and subsequent accident in October 2002, the following findings were noted:

> The operator of the Pilatus PC12 was conducting a spectrometric oil analysis program (SOAP) checks at 100 hour interval, concurrent with 100 hour inspections. Records from SOAP tests performed from January 2000, through to September 2002, thirty two point six hours before the engine failure were reviewed. The PC12 engine had sustained starter-generator EDD prior to the SOAP checks being carried out, yet there was no discernable trend for metal in the oil that was tested.

At the time of writing this report, the engine manufacturer was unable to identify any example of SOAP or patch check which indicated starter-generator EDD prior to engine failure.

ANALYSIS

Aircraft manufacturer emergency procedures

Emergency procedures in the aircraft manufacturer's information manual and the pilot's operating handbook provided the procedures to be followed in the event of a chip detector light illuminating in-flight.

The pilot in command stated that the only indication he received from the instruments, was the gearbox chip detector annunciator light illumination 5 minutes prior to the engine failure. He also stated that, had he not diverted to a safe landing area immediately when the chip detector light illuminated, he would have been over mountainous terrain with nowhere to carry out an emergency landing.

The emergency procedures in the aircraft manufacturer's information manual in regard to chip detector warnings presume that the engine is serviceable to continue unless an adverse engine indication is noted. The statement 'proceed to destination…' could mean flying for an extended period to the destination when a suitable alternative place to land could be closer.

This event has shown that an adverse engine indication does not necessarily precede engine failure when a chip detector annunciator light illuminates. The emergency procedures contained in the pilot's information manual did not sufficiently highlight the possibility of imminent engine failure after the illumination of an engine chip detector light.

Starter-generator

Examination of the failed starter-generator revealed evidence of electrical arcing on the drive spline, armature and one of the armature support bearings. The source of the electrical arcing was an armature winding that came in contact with the armature winding retaining band, due to armature winding insulation degradation. This created a hard short, allowing electrical current to discharge from the armature to the starter-generator drive shaft and then into the engine.

The degradation of the armature winding insulation indicated that the starter-generator had overheated during a start, or several start cycles, burning and dislodging the insulation material, rendering it ineffective.

The starter-generator brushes had worn unevenly for reasons that could not be established. Two of the eight starter-generator brushes were worn well beyond the manufacturer's allowable limits. The starter-generator was approximately half way through its 1,600 hour overhaul life.

A review of the Cessna 208 maintenance manual showed no requirement for a brush condition inspection to be carried out between overhaul periods. This is inconsistent with other starter-generator types that can be fitted to the same aircraft, which are checked at 500 hour intervals. A requirement to inspect the starter-generator brushes at regular intervals would have revealed the abnormal brush wear.

It is not known if the starter-generator brush wear contributed to the starter-generator overheat and failure. However, the two brushes that were worn beyond limits would have caused the spring tension on those brushes to be reduced to an unacceptable level, which in turn would have reduced the starter-generator performance.

The Cessna 208 maintenance manual does not contain any information to highlight the possibility of Electrical Discharge Damage (EDD) occurring when a starter-generator fails. It also does not refer to the relevant information in the Pratt & Whitney PT6A maintenance manual.

This is the first known PT6A EDD event to have occurred with an APC type starter-generator. Previous starter-generator events have occurred with Lear Seigler (TRW Lucas) P/N 23078 or P/N 23085 starter-generators. This event shows that it is possible for PT6 EDD to occur with various types of starter-generators fitted.

Engine failure

The technical examination of the failed engine components determined that mechanical failure of the number-1 main shaft bearing was the principal contributing factor that led to the in-flight engine failure. The failure was initiated by a starter-generator malfunction which caused EDD in the engine that remained undetected for 18.7 hours, at which point the number-1 bearing collapsed, resulting in the engine failure.

The only warning indicated to the pilot of an impending engine failure was an accessory gearbox chip detector annunciator light illumination on the annunciator panel, 5 minutes prior to the number-1 bearing failure. No other adverse engine indications were noted prior to the engine failure.

Information provided by the engine manufacturer has highlighted the fact that all PT6A engines are vulnerable to starter-generator EDD, not just the larger series engines (-60 and up) as earlier thought. The number of previously reported PT6A engine failures (forty two since 1992, and one subsequently reported) due to starter-generator EDD has highlighted the PT6A series engines predisposition to failure after a starter-generator malfunction has occurred. Records of starter-generator EDD begin in 1992. It is not unreasonable to consider that a number of other EDD events would have taken place prior to 1992.

This event and previous PT6A EDD engine failures have shown the PT6A series engine design is such that the lowest resistance to ground (earth) from the starter-generator input drive spline is through the number-1 bearing, which is one of two main bearings supporting the engine compressor rotating section.

When the electrical current grounding occurred through the number-1 bearing, it caused pitting type damage. Previous events have shown that depending on the severity of the pitting damage after EDD, the engine can continue to run between 18.7 to 700 hours before the number-1 bearing fails, resulting in engine failure with very little or no prior warning.

The ATSB considers that a condition exists in the PT6A series engine design which allows it to sustain damage to the number-1 bearing from a starter-generator malfunction. This condition has resulted in a number of in-flight engine failures.

EDD detection and prevention

Spectrographic Oil Analysis Program (SOAP) and patch checks were the only means the engine manufacturer had advised to identify EDD in PT6A engines. Each have inherent difficulties in terms of their ability to provide a reliable and sufficiently advanced indication of pending engine failure stemming from EDD. Predominantly, the problems arise from the frequency with which the filter patch checks and SOAP sampling can be practically carried out. Both tests rely on detecting the wear material products generated from breakdown mechanisms initiated from EDD damaged areas.

In the case of EDD to bearing and gear contact surfaces, the initial mode of breakdown is the development and growth of areas of rolling-contact fatigue cracking, which produces the spalling[8] of material from the contact surfaces, which then enters the lubricant and can be detected. The difficulty arises from the fact that the degradation develops at an exponential rate. In the case of the critical component, the number-1 bearing, by the time the breakdown has developed to a point where it would be reasonable to expect a positive detection via SOAP or patch check, the component is likely to be at risk of imminent total failure.

The engine from VH-KLP only released a sufficient amount of internal component material to bridge the poles of the accessory gearbox chip detector, illuminating the warning light approximately five minutes before the number-1 bearing failed. A review of the aircraft maintenance documentation indicated there had been no previously reported chip detector warnings during the time that the engine was fitted since being overhauled.

At the time of writing this report, the engine manufacturer was unable to identify any example of SOAP or patch check which indicated starter-generator EDD prior to engine failure.

The investigation identified a means of detecting EDD from a starter-generator hard short by inspecting the starter-generator drive spline with a 10 times magnifying glass. If the inspection revealed electrical arcing type damage to the starter-generator drive spline, a further disassembly and inspection of the engine would likely reveal EDD in the engine accessories and the number-1 bearing.

The basic starter-generator and PT6A engine designs have remained the same for some time. With this in mind, it would be reasonable to assume that PT6A starter-generator hard short EDD events will continue to occur at the same rate until modifications are carried out on the starter-generator and engine design to address the issue.

The conclusions of this investigation are consistent with previous investigations that indicated that electrical isolation of the starter-generator from the engine remains the most effective solution to prevent engine failures as a result of EDD events.

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8 Spalling - The cracking and flaking of particles out of a surface.

FINDINGS

Contributing safety factors

- The in-flight failure of the engine was due to the failure of the number-1 bearing.
- The failure of the number-1 bearing was due to the passage of electrical current through the bearing, causing electrical discharge damage (EDD) to its rolling elements, finally leading to its failure.
- The source of the EDD was the starter-generator that failed and was removed 18.7 hours prior to the engine failure.
- The evidence indicated that the previously installed starter-generator had failed due to an overheat during a start or several start cycles, causing armature winding insulation breakdown, this led to a hard short being created, allowing electrical current to discharge into the engine.
- The absence of any effective means to detect EDD when it occurred meant the damaged engine continued in-service without the operator's knowledge that an engine failure was imminent.
- The absence of electrical isolation between the starter-generator drive shaft and the engine allowed discharge of electrical current into the engine.
- PT6A series engines are susceptible to failure of the number-1 bearing, as a result of EDD sustained from a starter-generator malfunction.

Other safety factors

- The emergency procedures in the aircraft manufacturer's information manual with regard to chip detector warnings presume that the engine is serviceable to continue unless an adverse engine indication is noted. This event has shown that an adverse engine indication does not necessarily precede engine failure when a chip detector annunciator light illuminates.
- The Cessna 208 maintenance manual has no requirement to inspect the starter-generator brushes of Aircraft Parts Corporation (APC) extended life (XL) type starter-generators during the time between overhauls.
- The starter-generator manufacturer has only a limited requirement to inspect the starter-generator brushes of APC XL type units during the time between overhauls, which has not been incorporated in the Cessna 208 maintenance manual.
- The Cessna 208 maintenance manual does not contain any information to highlight the possibility of EDD occurring when a starter-generator fails. It also does not cross reference the relevant Pratt & Whitney maintenance manual for the information.

Other key findings

- The accessory gear-box chip detector warning system fitted to the incident aircraft was instrumental in providing a prior warning of impending engine failure, allowing the pilot time to select a safe place to land.
- The pilot immediately initiated an emergency landing when the chip detector annunciator light illuminated which ensured the safety of those on board.
- Accessory gear-box chip detector systems are not a mandatory requirement for aircraft fitted with PT6A series engines, although they have been fitted as standard equipment in the Cessna 208 since 2002.

SAFETY ACTIONS

Previous Safety Recommendations

During the course of the Australian Transport Safety Bureau's (ATSB) previous investigation into PT6A EDD events the following relevant recommendations were issued (Refer to ATSB report BO/200003399 and technical analysis report BE/200000014 for more details).

ATSB Recommendation R20020121

Issued to the FAA on 12 June 2002

The Australian Transport Safety Bureau recommends that the United States Federal Aviation Administration [FAA] examine the circumstances of electrical discharge damage to the number-1 bearing of the Pratt and Whitney (Canada) PT6A engine models equipped with TRW Lucas starter-generators and develop an appropriate safety assurance strategy.

Response from the Federal Aviation Administration on 23 February 2003

Safety Recommendation 02.207 recommended that the FAA examine the circumstances of electrical discharge damage to the number one bearing of the Pratt & Whitney Canada (PWC) PT6A engine models equipped with TRW Lucas (now Goodrich) starter-generator models 23078 and 23085 and develop an appropriate safety assurance strategy.

As discussed in the Australian Transport Safety Bureau Air Safety Occurrence Report (200003399) which resulted in FAA Safety Recommendation 02.207, the issue has to do with failure of the number one bearing in certain PWC PT6A-60 series engines (causing engine failure) apparently due to electrical discharge damage (EDD). Evidence suggests that an electrical current from the starter-generator gear shaft passes through the accessory gear train and the compressor splined coupling. It appears that the electric current initiates spalling damage to the engine number one bearing.

At the time of the Australian Report there had been seventeen engine failures on the worldwide PT6A fleet attributed to EDD, according to the engine manufacturer. Five of these involved an Australian operator of Shorts 360 aircraft. Other failures occurred on Beech 1900 and Beech King Air aircraft. These are all twin-engine aircraft. In addition, there has been a recent failure of a PT6A-67B engine apparently due to EDD in a single-engine Pilatus PC-12/45 aircraft which resulted in an accident.

The Chicago Aircraft Certification Office (ACO) has discussed this matter with Goodrich (TRW Aeronautical Systems, Lucas Aerospace), Transport Canada, and with ANE-142 which has cognizance of the PWC PT6A engines. We were unable to ascertain the root cause of the problem. These starter-generators (and other similar design Goodrich starter-generators) used in other aircraft installations have not experienced the EDD bearing problem. Accordingly, the FAA has decided to publish a Special Airworthiness Information Bulletin (SAIB) with general information directed to owners and operators of aircraft with the specified PWC PT6A-60 series engines. It alerts them to the condition and recommends that the existing instructions regarding starter-generator maintenance, proper grounding of the starter-generator, and periodic checking of engine oil for possible early detection of bearing deterioration be followed. A copy of this SAIB is attached. It is possible that investigation of the Pilatus PC-12/45 accident mentioned above will lead to more specific and detailed guidance.

ATSB Response Status: Monitor

ATSB Recommendation R20020120

Issued to the Civil Aviation Safety Authority on 12 June 2002

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority [CASA] continue to examine the circumstances of electrical discharge damage to the number-1 bearing of the Pratt and Whitney (Canada) PT6A engine models equipped with certain TRW Lucas starter-generators and develop an appropriate safety assurance strategy to ensure the continuing airworthiness of Australian registered aircraft fitted with similar engine and starter-generator combinations.

Response from CASA on 16 August 2002

As acknowledged in the report, the Authority has undertaken a number of actions to ameliorate the mechanical failure. These include monitoring the airworthiness of PWC PT6A engines incorporating a starter-generator that is known to require maintenance additional to that detailed in the aircraft manufacturer's maintenance schedule.

In addition, CASA is liaising with the engine manufacturer on the development of an insulated starter-generator drive train, with the aim of eliminating the problem.

ATSB Response

Subsequent to the Federal Aviation Administration response to the ATSB recommendation R20020120 the Civil Aviation Safety Authority was asked for comment.

Response from CASA on 20 March 2003

I refer to your note of 25 February 2003 to [CASA officer] regarding the response by the Federal Aviation Administration (FAA) to the issue of Air Safety recommendation R20020121.

In addition to the information supplied by the FAA, CASA advises the following:

CASA has already published a lengthy article on this subject in Flight Safety Australia. A copy of this article is attached for the information and consideration of the ATSB.

CASA has also issued a CAR 38 (1) Direction to commercial operators of PT6A-60 series engines and an information letter to all other PT6A operators.

ATSB Response Status: Monitor

Previous US National Transportation Safety Board (NTSB) recommendations

The US NTSB investigated a Pilatus PC-12/45 accident in 2002 which involved a PT6A EDD engine failure. The text below is the background information and subsequent recommendations issued to the US Federal Aviation Administration (FAA) which are still awaiting response.

NTSB recommendations to the FAA

Background Information

On October 16, 2002, a Pilatus PC-12/45 airplane, N96WF, overran the runway during a forced landing at Trenton Mercer County Airport (TTN), Trenton, New Jersey... The pilots reported that shortly after takeoff from TTN, they heard "bangs" coming from the single engine, a Pratt & Whitney Canada (PWC) PT6A-67B turbopropeller, and that there were flames and sparks coming from the engine’s left-side exhaust. The pilots turned back toward the airport, extended the landing gear and flaps, shut down the engine, and feathered the propeller... The airplane landed long, about two-thirds down the 4,800-foot-long runway, and fast, with a 20-knot tailwind, on a wet runway. The airplane overran the runway and continued for about 300 feet before impacting a chain link fence; the airplane sustained substantial damage.

NTSB recommendation issued to the FAA on 7 January 2004

Recommendation number A-03-058

The National Transportation Safety Board recommends that the Federal Aviation Administration: Require that Pratt & Whitney Canada PT6A-60 series engine starter-generators be electrically isolated from the rest of the engine.

NTSB Status: Open - Await Response

NTSB recommendation issued to the FAA on 7 January 2004

Recommendation number A-03-059

The National Transportation Safety Board recommends that the Federal Aviation Administration: Require that Pilatus PC-12 and PC-12/45 airplanes up to serial number (SN) 231 be equipped with a central advisory and warning system that will display engine magnetic chip detector warnings during all phases of flight.

NTSB Status: Open - Await Response

NTSB recommendation issued to the FAA on 7 January 2004

Recommendation number A-03-060

The National Transportation Safety Board recommends that the Federal Aviation Administration: Require on Pilatus PC-12 and PC-12/45 airplanes the installation of a magnetic chip detector, in accordance with Pilatus Service Bulletin No. 79-005, or an equivalent device, in the accessory gear box oil-drain to monitor the Pratt & Whitney Canada PT6A-67B engine's entire oil system, as soon as the necessary parts become available.

NTSB Status: Open - Await Response

NTSB recommendation issued to the FAA on 7 January 2004

Recommendation number A-03-061

The National Transportation Safety Board recommends that the Federal Aviation Administration: Evaluate all single-engine, turbopropeller, normal-category airplanes to ensure that the magnetic chip detectors (MCD), or equivalent devices, are installed to monitor the engine's entire oil system, and that warnings are enabled during all phases of flight.

NTSB Status: Open - Await Response

NTSB & FAA correspondence post recommendations

Response from the FAA on 23 February 2004

Letter Mail Controlled 3/1/2004 1:17:42 PM MC# 2040099 The Federal Aviation Administration (FAA) is evaluating the technical feasibility of implementing these safety recommendations. The FAA is also asking for input from Pilatus Aircraft Ltd. and the Swiss Federal Office for Civil Aviation since they have the design authority for the Pilatus PC-12. It is anticipated that the evaluation will be completed in May 2004. I will inform the Board of the FAA's proposed actions to address these recommendations once the evaluation is completed.

Response from the NTSB on 10 May 2004

The FAA states that it is evaluating the technical feasibility of implementing these safety recommendations, to be completed in May 2004, and that it is asking for input from Pilatus Aircraft Ltd. and the Swiss Federal Office for Civil Aviation. The Safety Board appreciates the FAA's initial evaluation of these recommendations. Safety Recommendation A-03-60 will require input from the manufacturer, and A-03-61 will need an evaluation of the scope and technical issues involved. With regard to Safety Recommendation A-03-59, the modification to the central advisory and warning system exists now in Canadian-registered aircraft. The Board notes that 25 percent of U.S.-registered aircraft (that is, 74 out of 276 airplanes) are pre-231-serial-numbered aircraft and that these aircraft operators deserve the same level of safety as the other 75 percent. The Board urges the FAA to complete the evaluation and initiate action by May 2004 as indicated. The Safety Board also notes that no mention is made of consultations with Pratt & Whitney Canada concerning electrical isolation of starter-generators on PT6A-60, as requested in Safety Recommendation A-03-58. The Board asks that the FAA advise what actions are being taken with respect to isolating the starter-generators from the remainder of the PT6A-60 engine. Pending specific information as to the FAA's proposed actions to address these recommendations, Safety Recommendations A-00-58 through -61 are classified "Open--Await Response."

Previous ATSB Safety Advisory Notices

During the course of the ATSB’s previous investigation into PT6A EDD events the following safety advisory notices were issued.

ATSB SAN 20020122

Issued to Transport Canada on 12 June 2002

The Australian Transport Safety Bureau suggests that Transport Canada should note the deficiencies identified relating to electrical discharge damage to the number-1 bearing of the Pratt and Whitney (Canada) PT6A engine models equipped with TRW Lucas, model 23078 and 23085, starter-generators.

Response From: Transport Canada on 12 July 2002

Transport Canada has noted the deficiencies identified by the ATSB and has been working with the engine manufacture, Pratt & Whitney Canada, regarding the source of the electrical discharge damage (EDD) - TRW Lucas Starter Generator models 23078 and 23085. It is expected that it will be necessary for a coordinated effort on the part of: Transport Canada, the FAA and the CAA U.K. as the respective State of Design Authorities responsible for the PWC PT6A engine group, the Lucas starter-generator and the Shorts & Harland SD3-60 aircraft. At this time, Transport Canada awaits the proposed corrective action from the FAA and TRW Lucas to electrically isolate the starter-generator output shaft from the engine starter generator.

ATSB SAN 20020123

Issued to Pratt & Whitney Canada on 12 June 2002

The Australian Transport Safety Bureau suggests that Pratt and Whitney Canada should note the deficiencies identified relating to electrical discharge damage to the number-1 bearing of the Pratt and Whitney (Canada) PT6A engine models equipped with TRW Lucas, model 23078 and 23085, starter-generators.

ATSB SAN 20020124

Issued to UK Civil Aviation Authority on 12 June 2002

The Australian Transport Safety Bureau suggests that the United Kingdom Civil Aviation Authority should note the deficiencies relating to electrical discharge damage to the number-1 bearing of the Pratt and Whitney (Canada) PT6A engine models equipped with TRW Lucas, model 23078 and 23085, starter-generators.

New safety action

As a result of this investigation (VH-KLP, BO/200600563) the following safety actions have been implemented.

Civil Aviation Safety Authority

The Civil Aviation Safety Authority (CASA) has advised the ATSB of the following safety actions:

CASA will review the circumstances of electric discharge damage (EDD) to No 1 bearing on P&WC PT6A series engines with the view to developing mandatory maintenance instructions which will provide the ability to detect if an EDD event has occurred. The aim of those instructions would be to detect engine damage caused by electrical discharge and require follow up actions to prevent an engine in-flight shut down (IFSD) due to Number-1 bearing failure.

These instructions will require the periodic cleaning of brush dust in conjunction with inspection for brush wear, a detailed visual inspection of starter shaft gear teeth using a 10 times magnifying glass and further engine inspection if warranted by the initial inspection findings.

CASA maintenance instructions are an interim measure until engine or starter manufacturers assume the responsibility and address the core problem from a design point of view.

CASA first notified operators and maintenance organisations about PT6A engine EDD through the November – December 2001 issue of Flight Safety Australia (FSA) magazine in an article entitled “Electrical Discharge”. The article may be viewed on the following link:

http://www.casa.gov.au/fsa/2001/nov/36-39.pdf

CASA has advised that it will publish another FSA article on the subject, which will emphasise that the problem of EDD is not limited to only a few PT6A engine models. In addition to the proposed maintenance direction(s), CASA intends to simultaneously produce an Airworthiness Bulletin providing detailed guidance on how and what to look for during the required inspections.

Engine manufacturer

Pratt & Whitney Canada (P&WC) has advised the ATSB of the following safety actions:

P&WC reports that it is pursuing the incorporation of a non-conductive insert in the design of its new engines (PT6A-68). As this feature requires an extensive re-design of the gear, the oil seal, and the accessory housing, it is not practicable to be incorporated into the existing fleet of engines.

In P&WC’s earlier review of this issue, it was determined that the more practical solution was to incorporate a non-conductive element into the shaft of the starter-generator unit. While the Starter-Generator manufacturer (Lear Seigler/TRW

Lucas) proposed several designs, P&WC is not aware that any have been developed to the production stage.

To increase aircraft operators awareness, P&WC issued Service Information Letter S.I.L No. Gen-PT6-024 on 24 May 2007.

Aircraft manufacturer safety action

The Cessna Aircraft Company has advised the ATSB of the following safety actions:

Cessna has submitted a Service Information Request to issue a Service Newsletter to remind operators of P&WC PT6A maintenance manual inspection requirements outlined in the PT6A-114A Engine Maintenance Manual Section 72-00-00.

Cessna is also aware of the P&WC Service Information Letter S.I.L No. Gen-PT6-024 that was issued on 24 May 2007. Cessna is also evaluating the need to place a note in the Cessna 208 Aircraft Maintenance Manual to reference the relevant P&WC Maintenance Manual.

Safety Recommendations

During the review of the draft ATSB report into this occurrence, a number of Directly Involved Parties responded to proposed safety recommendations contained in the draft. Where appropriate, those comments are included in this section.

As a result of this occurrence the ATSB issues the following safety recommendations:

Engine manufacturer

Recommendation 20070015

The Australian Transport Safety Bureau recommends that Pratt & Whitney Canada, in conjunction with Transport Canada, incorporate measures to electrically isolate the starter-generator gear-shaft input coupling spline and the engine number-1 main shaft bearing of all Pratt & Whitney Canada PT6A series engines.

Pratt and Whitney Canada response

Pratt and Whitney responded to this proposed safety recommendation (draft recommendation A) in the ATSB draft report by stating:

> P&WC is pursuing the incorporation of a non-conductive insert in the design of our new models of PT6A engines. As this feature requires an extensive re-design of the gear, the oil seal, and the accessory housing, it is not practicable to be incorporated into the existing fleet of engines.
>
> In our earlier review of this issue, it was determined that the more practical solution was to incorporate a non-conductive element into the shaft of the starter-generator unit. While the Starter-Generator manufacturer proposed several designs, P&WC is not aware that any have been developed to the production stage.

ATSB comment:

The ATSB does not accept that P&WC's response to the draft recommendation is adequate and believes that P&WC should take a pro-active role and work in conjunction with Transport Canada to develop an effective method to electrically isolate starter-generators in the existing fleet of PT6A series engines in order to eliminate the possibility of engine failure due to EDD. As such the ATSB now formally issues safety recommendation R20070015.

Recommendation 20070016

The Australian Transport Safety Bureau recommends that Pratt & Whitney Canada, in conjunction with the aircraft and starter-generator manufacturers, incorporate a suitable inspection of the starter-generator gear shaft input coupling spline for any evidence of Electrical Discharge Damage (EDD), if the starter-generator is replaced in order to rectify a reported engine starting or electrical generation defect.

Pratt and Whitney Canada response

Pratt and Whitney responded to this proposed safety recommendation (draft recommendation B) in the ATSB draft report by stating:

> This subject was extensively reviewed in the course of the earlier investigation of the EDD incidents. The decision taken at that time was that the engine gear has an internal spline, and as such, is very difficult to examine in-situ to arrive at a meaningful result. P&WC would support a recommendation that consideration be given to an AMM revision that would call for an inspection of the external spline of the starter-generator, as it is our understanding that this would be practical and effective.

ATSB comment:

The ATSB accepts P&WC's response and agrees that the starter-generator external spline is the most practical and effective method to determine if there has been an EDD event. As such the ATSB has reworded and now formally issues safety recommendation R20070016.

Recommendation 20070017

The Australian Transport Safety Bureau recommends that Pratt & Whitney Canada consider requiring the removal of any PT6A series engine from service where there is evidence of an EDD event.

Pratt and Whitney Canada response

Pratt and Whitney responded to this proposed safety recommendation (draft recommendation C) in the ATSB draft report by stating:

> As noted above, P&WC does not believe that the examination of the engine's internal spline on-wing will accurately determine the presence or absence of EDD, however an examination of the starter-generator spline may be warranted.
>
> As the nature of EDD damage is progressive, P&WC would seek to minimize operator disruption by a recommendation that the engine should be reworked within an appropriate time frame (say 50 hours) and that operation within this period would be subject to repetitive filter patch inspections per the existing engine EMM.

ATSB comment:

As stated above, the ATSB accepts P&WC's response and agrees that the starter-generator external spline is the most practical and effective method to determine if there has been an EDD event. However, the ATSB does not accept that continued operation of the engine following an EDD event is without risk. Additionally, it has been shown through this investigation that filter patch checks are not a reliable means to predict an engine failure following an EDD event. It is the ATSB's view that, where evidence of EDD is detected, the engine's continued reliability should be considered suspect. As such the ATSB has reworded and now formally issues safety recommendation R20070017.

Aircraft manufacturer

Recommendation 20070018

The Australian Transport Safety Bureau recommends that Cessna aircraft company, consider revising the Cessna 208 series aircraft Pilot Information Manual for emergency procedures on chip detector and pilot warnings.

Cessna response

Cessna Aircraft Company responded to this proposed safety recommendation (draft recommendation F) in the ATSB draft report by stating:

> Cessna continues to support our previous stance on this subject. A chip detector annunciation can identify a minor to a major problem. This is the reason Cessna has elected to leave the checklist somewhat up to the pilot's discretion. The pilot is the only one in a position to assess whether he has a minor or major problem and the potential effects. It would be equally bad to lead the pilot into a premature off airport landing when a minor problem would have allowed the engine to run normally to a safe airport landing.
>
> Prior to this occurrence, Cessna and APC records show that there has never been an electrical discharge damage (EDD) failure on an APC starter generator installed on 208 aircraft. A review of the Lucas starter generator maintenance history, that Cessna had access to, reveals no incidents of any EDD or electrical short problems on Lucas units during the past five years. (Five years is as far as the easily accessible records go back.) Based on the above information, Cessna does not believe a change to the emergency procedures is warranted.

ATSB comment:

The ATSB does not accept Cessna's comment in relation to the information contained in the pilot's emergency procedures. While acknowledging that the pilot is best placed to evaluate any abnormal situation, the emergency procedures statement "if engine gauges are normal, proceed to destination…" can be misleading if the number-1 engine bearing is becoming distressed. This investigation has shown that this process can take only a few minutes from chip detector light illumination to complete engine failure.

It is the ATSB's view that the Cessna emergency procedures should consider this scenario and include a statement such as "land at the nearest suitable location" irrespective of engine gauge readings. This does not mean the pilot should carry out an off airport landing as stated in the Cessna response. As such, the ATSB now formally issues safety recommendation R20070018.

Recommendation 20070019

The Australian Transport Safety Bureau recommends that Cessna aircraft company, revise its procedures in the Cessna 208 aircraft maintenance manual to include the starter-generator manufacturer's recommended brush inspection requirements.

Cessna response

Cessna Aircraft Company responded to this proposed safety recommendation (draft recommendation G) in the ATSB draft report by stating:

> Cessna has discussed this recommendation with an APC repair facility. Reservations have been voiced concerning the customers checking of brushes, as they might chip the brushes, or put them back incorrectly. If APC elects to change the current maintenance procedures regarding the inspection or overhaul of their starter-generators, Cessna will pass the information on to our customers and consider changing the aircraft maintenance manual, if deemed necessary.

ATSB comment:

The ATSB does not accept that Cessna's response to draft recommendation G is adequate. The ATSB believes that Cessna should incorporate the starter-generator manufacturer's inspection requirement, APC Service Letter 132, as a minimum inspection requirement in the Cessna 208 maintenance manual. Service letter 132 is a brush life calculation check which should be carried out at 300 hours after a starter-generator is installed. As such, the ATSB now formally issues the safety recommendation as R20070019.

Transport Canada

Recommendation 20070020

The Australian Transport Safety Bureau recommends that Transport Canada, as the state of design for PT6A engines, review the continued airworthiness of PT6A series engines, with regard to its susceptibility to failure of the number-1 bearing, as a result of EDD sustained from a starter-generator malfunction.

Transport Canada response

Transport Canada responded to this proposed safety recommendation (draft recommendation I) in the ATSB draft report by stating:

> TC continually monitors the continuing airworthiness of the PT6A engine. According to the latest P&WC data (1Q/2007), the 12 months in-flight shut down (IFSD) rate for the PT6A series engines is 0.004 per 1000 hours (0.011 for the PT6A-114/-114A series engines), which is well within the acceptable certification requirement of 10E-5. The IFSD rate due to EDD would be expected to be much lower than the above IFSD rate. TC suggests that the TSB or ATSB request P&WC provide the in-flight shut down rate due to electrical discharge damage (EDD) problems.

ATSB comment:

The ATSB does not accept Transport Canada's suggestion that either the Transportation Safety Board of Canada or the ATSB should seek further EDD related IFSD rates from the engine manufacturer. As the responsible airworthiness authority, the ATSB believes that TC should actively seek any data required to review the continued airworthiness of the PT6A series engines in relation to potential failures as a result of EDD. That review should consider not only the IFSD rate, but also the potential serious consequences of sudden engine failure in single-engine, passenger-carrying operations. As such, the ATSB now formally issues the safety recommendation as R20070020.

Recommendation 20070021

The Australian Transport Safety Bureau recommends that Transport Canada require that Pratt & Whitney Canada incorporate measures to electrically isolate the starter-generator gear-shaft input coupling and the engine number-1 main shaft bearing of all Pratt & Whitney Canada PT6A series engines.

Transport Canada response

Transport Canada responded to this proposed safety recommendation (draft recommendation J) in the ATSB draft report by stating:

> Larger PT6A-68 series engines now incorporate a “Vespel” (Polyimide composite) coupling to isolate/protect the number-1 bearing from electrical discharge damage. Small PT6A-114 series engines (such as the one involved in the current investigation) have space limitations affecting the insertion of an insulating material for protection of the engine number-1 bearing from electrical discharge damage emanating from a malfunctioning starter-generator.
>
> Modification of the starter-generator to electrically isolate the shaft has been previously identified as the terminating action to mitigate the issue of EDD. Attached you will find a copy of a letter dated May 25, 2001 to the Federal Aviation Administration, New York Aircraft Certification Office (FAA NYACO) requesting a status update on the work done by the TRW Lucas and the FAA position on this matter.
>
> This work included a modification to electrically isolate the shaft to mitigate this issue. A copy of this letter was also forwarded to the FAA Engine Certification Office in October 2002. TC suggests that the TSB or the ATSB contact the FAA in regards to this issue.

ATSB comment:

The ATSB does not accept Transport Canada’s suggestion that either the Transportation Safety Board of Canada or the ATSB should contact the FAA in regard to this issue. As the responsible airworthiness authority, the ATSB believes that TC, in conjunction with the engine manufacturer, actively pursue any methods available to electrically isolate PT6A series engines to eliminate the possibility of EDD damage. As such, the ATSB now formally issues the safety recommendation as R20070021.

Federal Aviation Administration

Recommendation 20070022

The Australian Transport Safety Bureau recommends that the US Federal Aviation Administration, as the state of design for Lear Seigler (TRW Lucas) and Aircraft Parts Corporation (GE Unison) type starter-generators, examine the circumstances of electrical discharge damage to the number-1 bearing of Pratt & Whitney Canada PT6A series engines and develop an appropriate safety assurance strategy, to reduce the risk of engine failure resulting from the effects of EDD to the number-1 bearing.

Recommendation 20070023

The Australian Transport Safety Bureau recommends that the US Federal Aviation Administration consider the benefits of implementing the fitment of accessory gearbox chip detectors on all Cessna 208 aircraft.

Civil Aviation Safety Authority

Recommendation 20070024

The Australian Transport Safety Bureau recommends that the Civil Aviation Safety Authority consider the benefits of requiring the fitment of AGB chip detectors on all Australian registered Cessna 208 aircraft used in commercial passenger operations.

CASA responded to this proposed safety recommendation (Recommendation O) in the ATSB draft report by stating:

> The proposed mandatory maintenance instruction is aimed at capturing an EDD event before an engine IFSD occurs due to bearing failure. If the EDD events are captured through starter-generator shaft inspection and follow-on maintenance actions are carried out before engine failure, fitment of accessory gearbox (AGB) chip detector indication system in the cockpit may prove to be of marginal benefit, if any. The time between chip detector indication and the actual failure is known to be a few minutes.
>
> CASA maintenance instructions are an interim measure until engine or starter manufacturers assume the responsibility and address the core problem from a design point of view. CASA does not believe that the fitment of [an] AGB chip detector indication system in the cockpit will bring the safety benefits anticipated by ATSB recommendation O [R20070024]. CASA will, however, continue monitoring the effectiveness of mandatory maintenance instructions.

ATSB comment:

The ATSB does not accept CASA's suggestion that accessory gearbox chip detector systems are of marginal benefit. As indicated in this investigation, the accessory gear-box chip detector warning system fitted to the incident aircraft was instrumental in providing a prior warning of impending engine failure, allowing the pilot time to select a safe place to land. As such, the ATSB now formally issues the safety recommendation as R20070024.

APPENDIX A: TECHNICAL ANALYSIS REPORT

ATSB TECHNICAL ANALYSIS
BE200600016

Examination of Accessory Gearcase and Engine Bearing Components – Pratt & Whitney Canada PT6A-114 Turboprop Engine

Cessna Aircraft Co. 208, VH-KLP

5 February 2006

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Released in accordance with section 25 of the *Transport Safety Investigation Act 2003*

FACTUAL INFORMATION

Introduction

On 5 February 2006, a float-equipped Cessna Aircraft Company 208 'Caravan' aircraft, registered VH-KLP, was conducting a scenic charter flight over the Queenstown region of western Tasmania, when the pilot reported the illumination of an engine chip detector annunciator light, and subsequently, a loud noise and loss of power from the engine. After shutting down the engine and feathering the propeller, the pilot carried out a forced landing on Lake Burbury, where the aircraft came to rest upon the lake shore.

Initial disassembly and examination of the engine was conducted at the workshops of Dallas Airmotive, Dallas, Texas, USA, under the supervision of an investigator from the US National Transportation Safety Board (NTSB), acting on behalf of the Australian Transport Safety Bureau (ATSB). On the basis of observations made during that examination, it was apparent that the rear main shaft (number-1) bearing had failed, resulting in the partial seizure of the rotor assembly. Associated with the bearing damage were several indications of localised electrical discharge (arcing) over the bearing rolling-contact surfaces. Following completion of the disassembly, the remnants of the number-1 bearing and selected components from the auxiliary gearcase were forwarded to the ATSB's Canberra laboratories for further detailed technical study.

During flight, approximately 20 operating hours prior to the engine in-flight failure event, the aircraft operator reported the failure of the starter-generator (SG) unit. Information received indicated that the SG was subsequently replaced and the failed item retained for later overhaul. As part of the ATSB's examination into the engine failure occurrence, the failed SG unit was obtained and examined concurrently with the engine componentry.

Scope

The scope of the requested technical examination included the identification of the factors contributing to the failure of the number-1 shaft bearing, including the confirmation of the existence and source of electrical discharge damage (EDD) within the accessory gearcase assembly.

Initial examination

The subject engine was a Pratt & Whitney Canada PT6A-114 turboprop, serial number PCE-PB0508, and had operated for 6,445 hours / 7,855 cycles since new. The engine had accrued 1,448 hours / 2,611 cycles since last overhaul in January 2003. The preliminary engine disassembly overseen by the US NTSB included the written and photographic documentation of the condition of the primary engine components. ATSB analysis of the teardown findings found that the number-1 bearing breakdown was the primary factor contributing to the in-flight engine power loss 'Pitting indicative of EDD' was reported on elements of the number-1 bearing, the starter-generator gear-shaft, input coupling shaft and the number-1 bearing flexible support.

Component examination

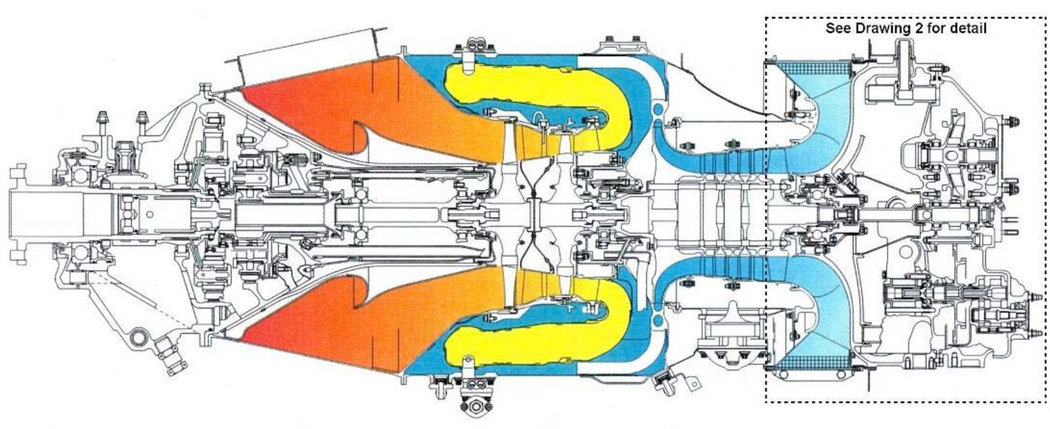
The following items were examined.

Table 1: Component identification

ID	Item	Part number	Serial number
A	Bearing, No. 1 main shaft	3101864-01	A000324
B	Housing, No. 1 bearing	3004517	21232
C	Flexible support, No. 1 bearing	3004555	108
D	Rear hub & coupling, compressor	3013111, 3013175	Unknown, 295
E	Coupling shaft, gearcase input	3011405	FN0797
F	Gear shaft, gearcase input drive	3011406	1153-26
G	Gear shaft, starter-generator	3017609	1123-03
H	Bearings, input coupling shaft	3112368-01	FA9609244, FA9609245
I	Bearings, starter-gen gear shaft	3112368-01	FA9609241, FA9609237
J	Plugs, chip detector, AGB & RGB[9]	3045915-02	ABA978, unknown
K	Armature, starter-generator	200SGL1064-1	838A1
L	Drive shaft, starter-generator	Unknown	Unknown
M	Bearings, starter-generator	Barden 153	C6656, Unknown

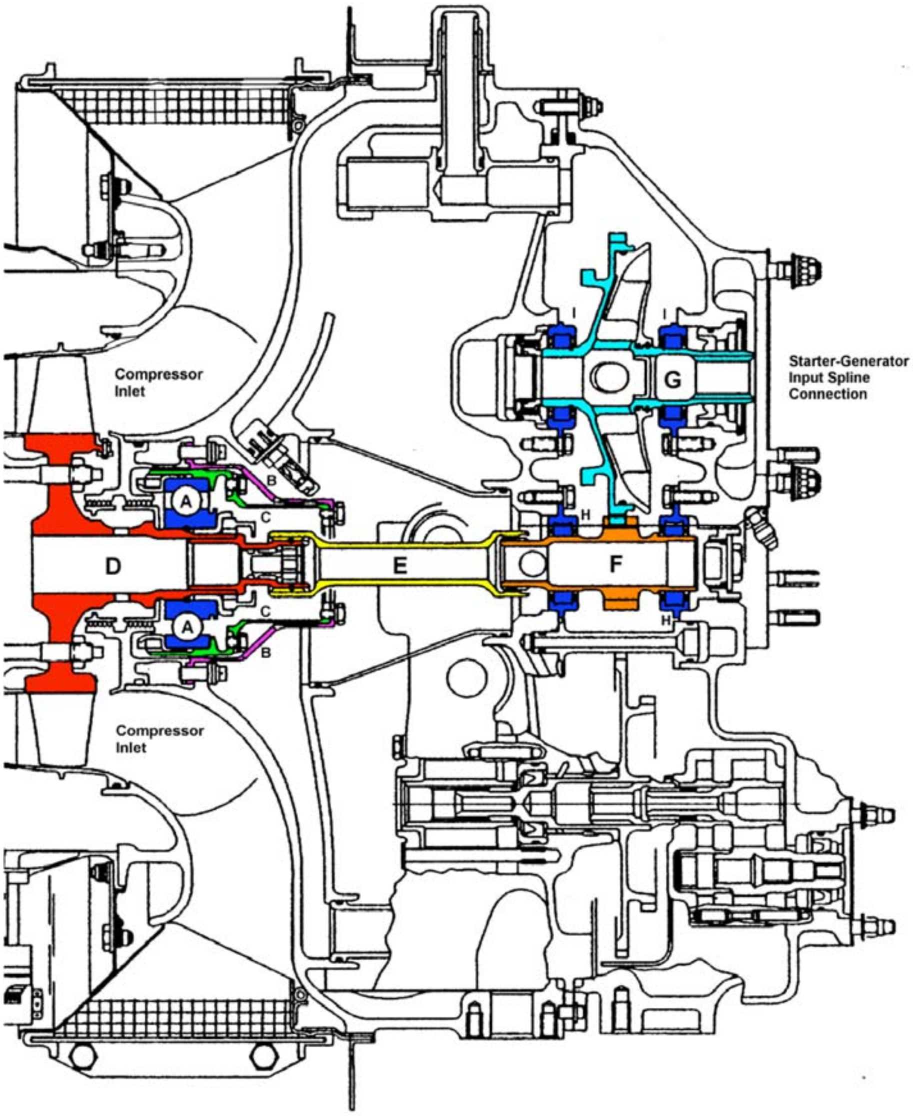
Drawing 1 presents a representative cross-sectional view of the PT6A engine, with Drawing 2 showing the arrangements of the components referred to above within the engine compressor inlet and accessory gearcase.

Drawing 1: Sectional view of a typical PT6A engine – accessory gearbox and number-1 main shaft bearing area enclosed



9 'AGB' – Accessory Gearbox, 'RGB' – Reduction Gearbox

Drawing 2: Engine accessory gearcase and number-1 bearing. Components examined are identified with reference to Table 1



Number-1 main shaft bearing

The engine number-1 shaft bearing was an externally lubricated, split inner race ball bearing unit, manufactured by SNFA France and allocated P&WC part number 3101864-01.

Outer race identification:

SNFA Made in France
SP 33077
Δ7 S92F3K17
01895 SNFA 0003246
02N M CPW 3101864-01A

Inner race identification:

01895 SNFA 0003246
*5V94D9M34

As-received, the bearing exhibited extensive abrasive wear of the rolling elements (balls), with the associated wear and break-up of the cage, see Figure 1. The single plane of wear and metal loss on each ball was indicative of complete seizure of the assembly and a transition from rolling to sliding contact between the races and ball elements. In addition to the sliding wear, many of the ball elements presented spalling and flaking of the surface material, producing an irregular distribution of surface pitting, see Figure 2. Frictional heating associated with the sliding had produced oxidation and chromatic tinting of the exposed surfaces.

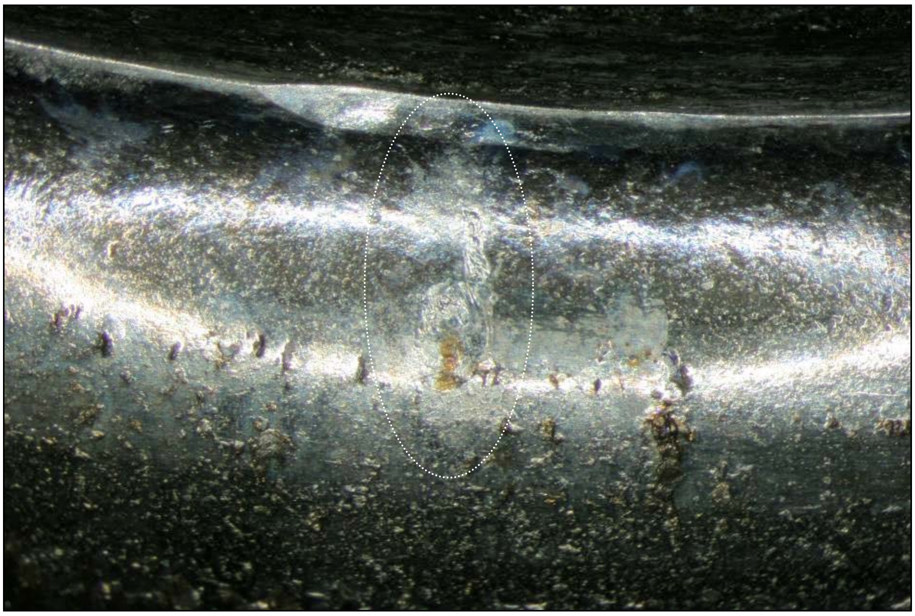
Figure 1: Remnants of the engine number-1 bearing unit

Figure 2: Rolling elements showing typical surface spalling damage

Similar pitting and spalling damage was noted around the contact surfaces of the bearing outer race, with accompanying surface bruising and indentation damage, see Figure 3. Amongst the paths of surface spalling, several localised areas presented a rounded and flowed appearance, atypical of the surrounding surface morphology. The region shown in Figure 4 was characteristic of these features.

Figure 3: Outer race of number-1 bearing showing spalling damage along the contact path

Figure 4: Atypical area on outer race surface (enclosed)



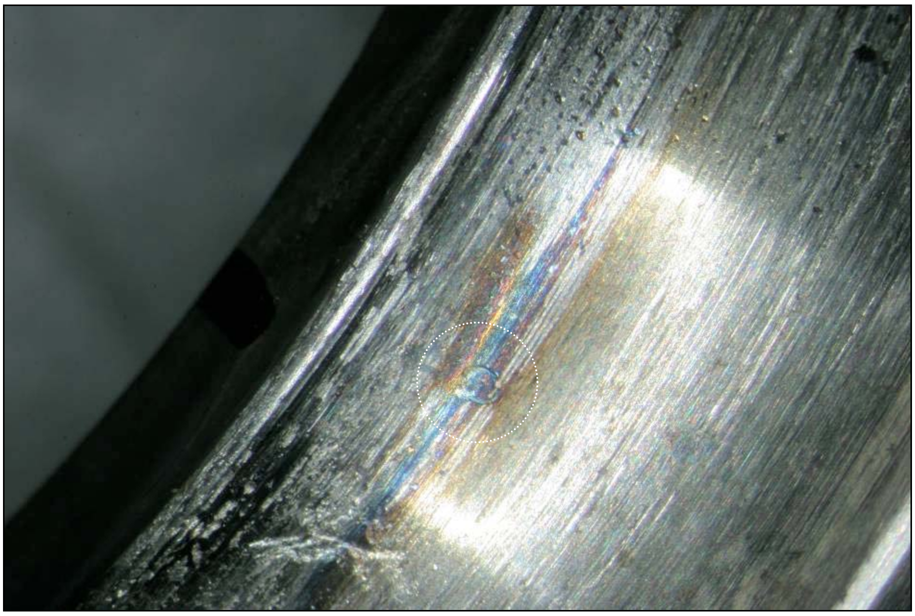
Of the two inner race halves, the forward (thrust) element showed severe scoring and abrasive metal loss of a nature similar to the ball elements, see Figure 5. The rear (non-thrust) race half showed distress predominantly toward the innermost areas of the contact path, with scoring, frictional heat-tinting and metal smearing effects, see Figure 6. As had been noted on the outer race, several unusual localised features were observed – presenting as isolated rounded depressions that had been over-scored by the passage of the ball elements, see Figure 7.

Figure 5: Forward section of the number-1 bearing inner race – heavily scored

Figure 6: Rear section of the number-1 bearing inner race

The external surfaces of the bearing races showed no abnormal characteristics, other than regions of oxide tinting associated with the elevated surface frictional heating resulting from the seizure event. The journal mounting faces showed no indication of looseness, movement or misalignment of the bearing within the housing or upon the rotor shaft.

Figure 7: Isolated area of atypical damage on the rear section of the number-1 bearing inner race (circled)



Bearing surface examination and metallography

To further characterise the nature of the anomalous areas identified on the inner and outer bearing race elements, the areas shown in Figures 4 and 7 were examined under the scanning electron microscope (SEM), before being transversely sectioned and prepared for metallographic study. Figures 8 and 9 present the surface form of the areas under the SEM – both showed rounded features, with some evidence of surface metal flow, possibly characteristic of localised melting.

Figure 8: SEM image of inner race area shown in Figure 7

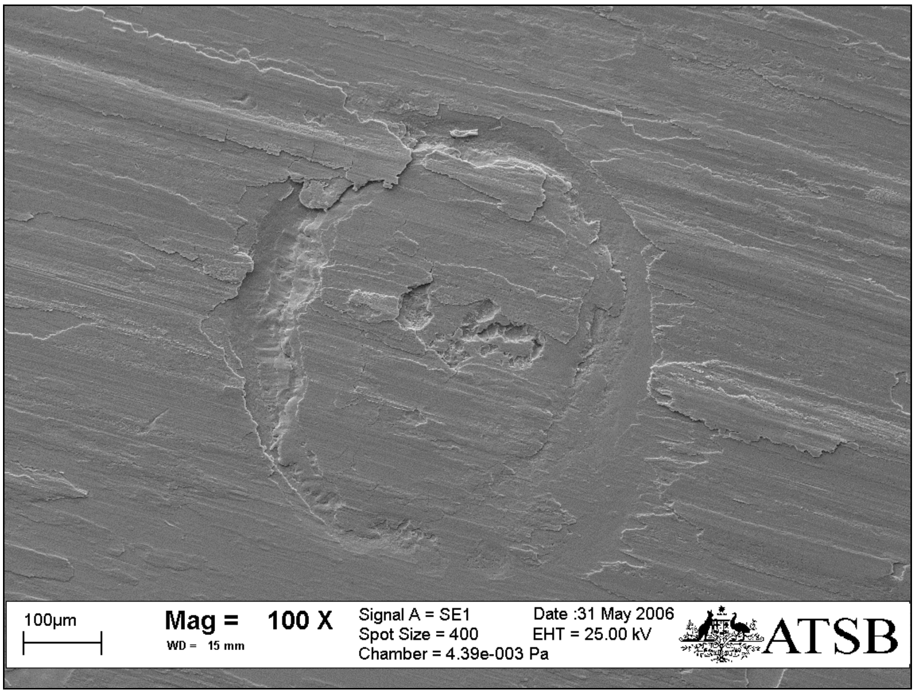
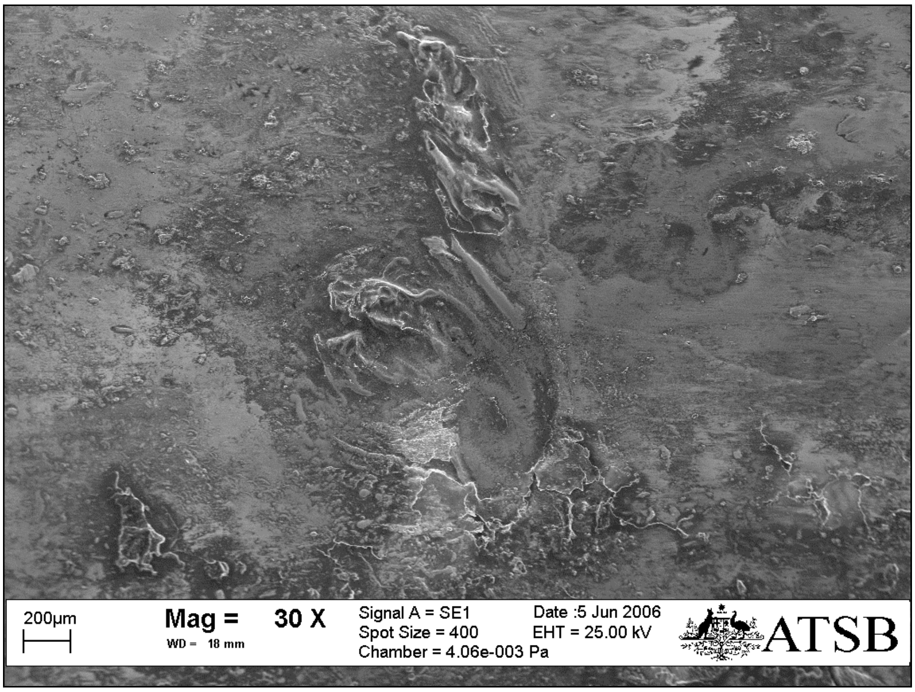


Figure 9: SEM image of outer race area shown in Figure 4



Microscopic study of transverse metallographic sections prepared through the areas of interest found notable zones of thermally affected microstructure (heat affected zones, HAZ) associated with and surrounding the surface features, see Figures 10 and 11. While many areas over the race surfaces exhibited thermal effects from frictional heating, such areas tended to present as broad bands or zones of affected material oriented along the axis of bearing rotation. The local areas in question, however, showed heat affected zones that were limited to the periphery of the surface feature and were inconsistent with having been formed by a frictional mechanism. Figure 12 illustrates the HAZ transition and parent material microstructure.

Figure 10: Transverse micro-section through the inner race area identified in Figures 7 and 8. Note the localised heat-affected zones (2% Nital etch)

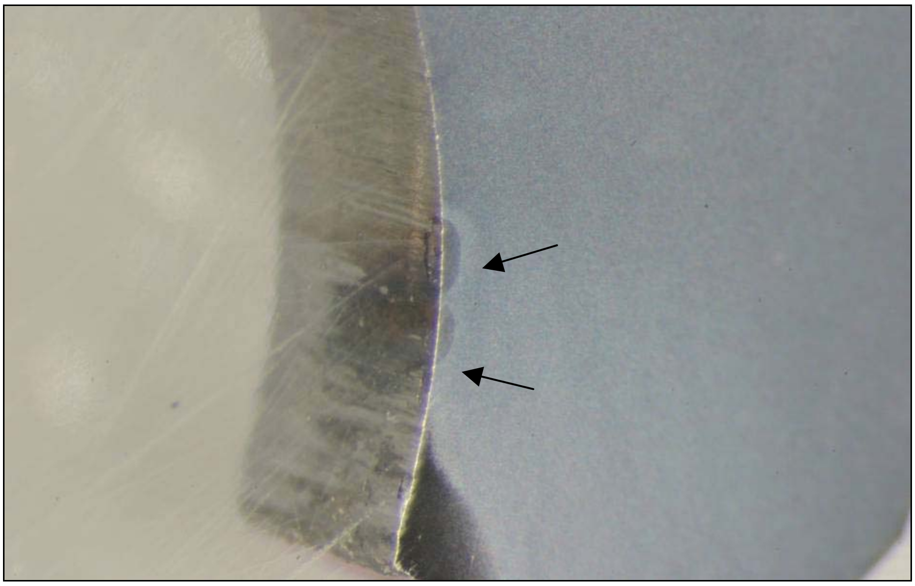


Figure 11: Transverse micro-section through outer race area shown in Figures 4 and 9. Shallow heat-affected zone. (2% Nital etch)

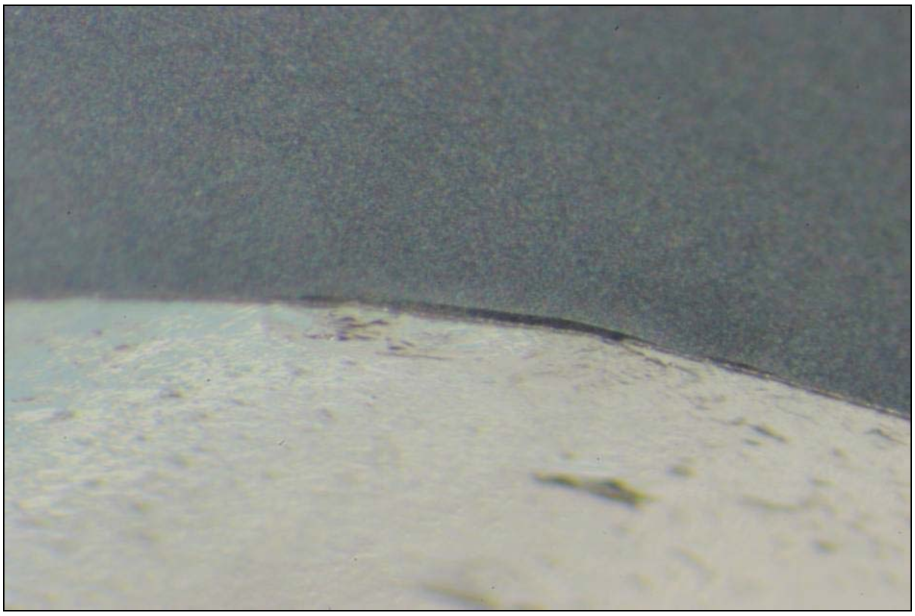
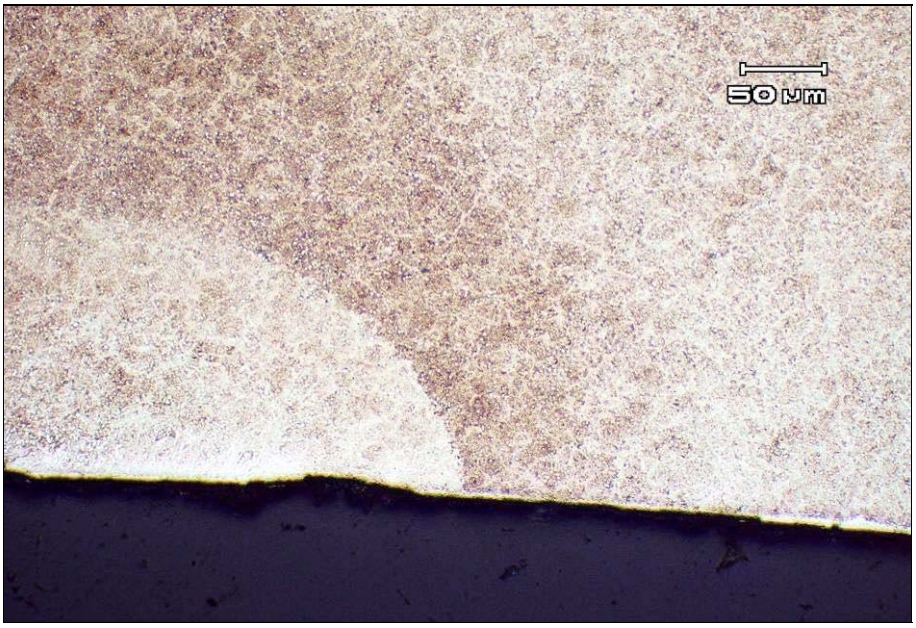


Figure 12: Heat affected zone microstructure of the inner race region shown in Figure 10 (2% Nital etch)



The general microstructure of the bearing race material was typical of a modern high-speed rolling element bearing – comprising a distribution of fine spheroidal carbides within a tempered martensitic[10] matrix. The non-metallic inclusion content, distribution, and form was also consistent with that expected of a bearing of that type.

Rear hub and coupling, compressor

Drive to the accessory gearcase of the engine was transferred from a splined coupling integrated into the stage-1 compressor hub, see Figure 13. The coupling splined connection adjacent to the number-1 bearing mount showed a small circular region of localised pitting damage on the face of a single spline tooth, see Figure 14. The surrounding surfaces showed no other anomalous features or damage associated with service or maintenance. The uniform, circular and isolated nature of the pitted region was consistent with the effects of localised surface re-melting, produced by a transient electrical discharge event, with current flow across the coupling connection.

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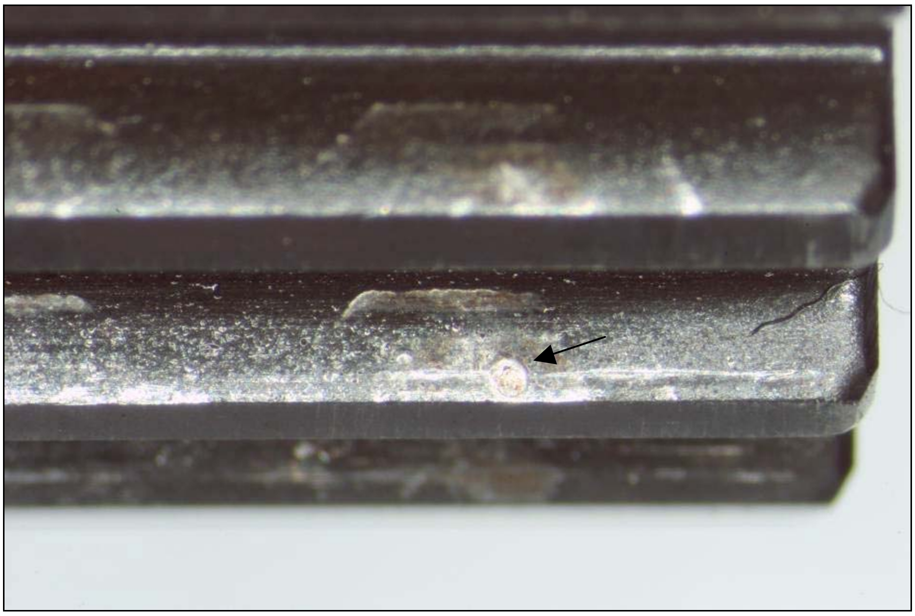
10 *Martensite* is the hard microstructural constituent produced when some metallic alloys (commonly hardenable steels) are cooled from the hardening temperature at a speed greater than the alloys' critical cooling rate.

Figure 13: Compressor rear hub and coupling spline

Figure 14: Pitting damage on the surface of a spline tooth (arrowed)



Accessory gearcase input coupling shaft

Multiple discoloured and slightly eroded spots of surface pitting and remelting damage were noted within the splined coupling connection at both ends of the shaft, see Figures 15 – 17. The appearance of the damage mirrored that presented by the mating male spline connections of both the compressor hub and the accessory gearcase input gear-shaft. With the exception of the identified damage, both connections appeared to be in sound condition.

Figure 15: Input coupling shaft

Figure 16: Internal spline tooth pitting and re-melting (input drive gear shaft end)

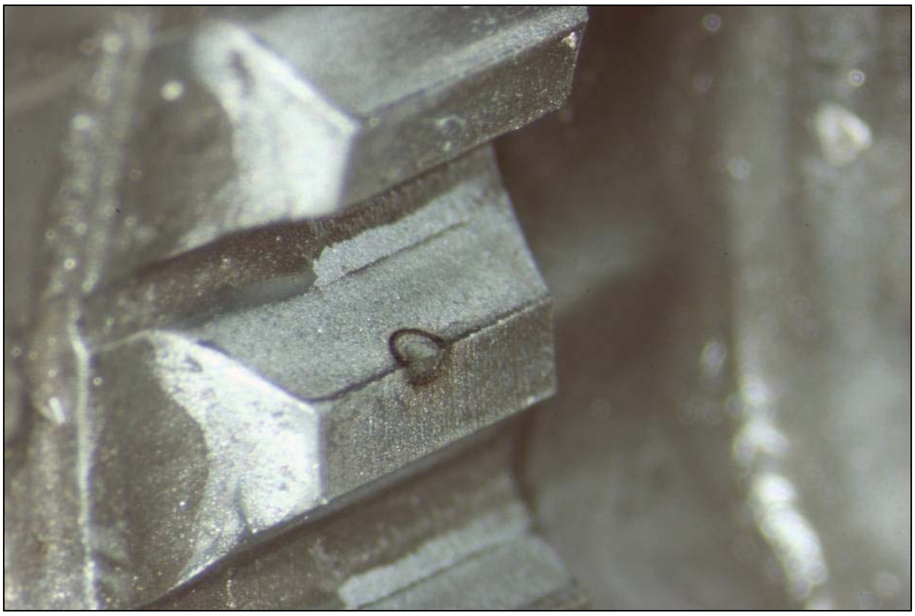
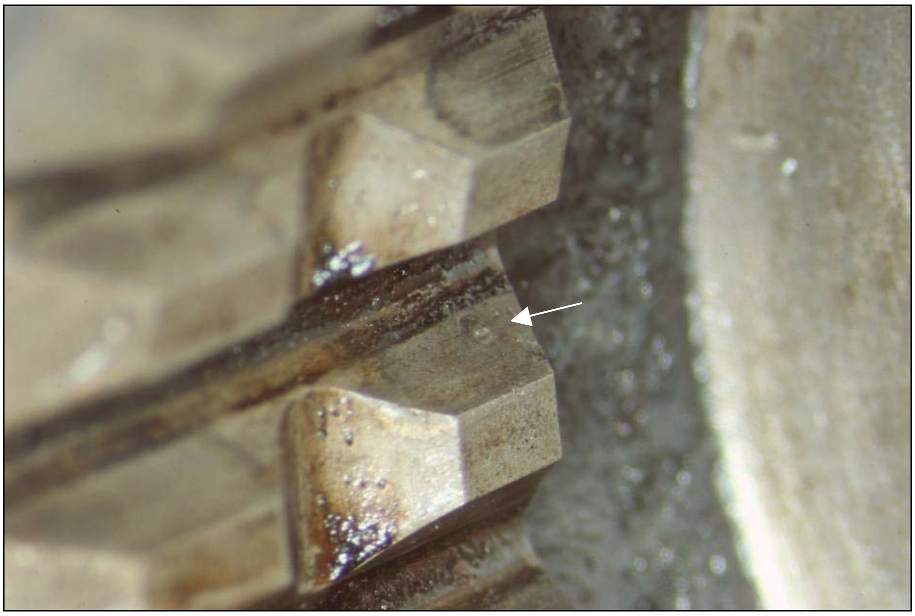


Figure 17: Internal spline tooth pitting and re-melting (compressor rear hub coupling end)



Gearcase input drive gear shaft

Figures 18 – 20 show the accessory gearcase input drive shaft and the similar pitting damage found on both coupling splines and gear teeth. Being particularly evident on the gear teeth, the damage showed the classic features associated with electrical arc re-melting. The gear contact surfaces showed no other evidence of mechanical breakdown, contact-fatigue spalling or indications of lubrication deficiencies.

Figure 18: Input drive gear shaft – accessory gearcase

Figure 19: Pitting and re-melting damage to a gear tooth

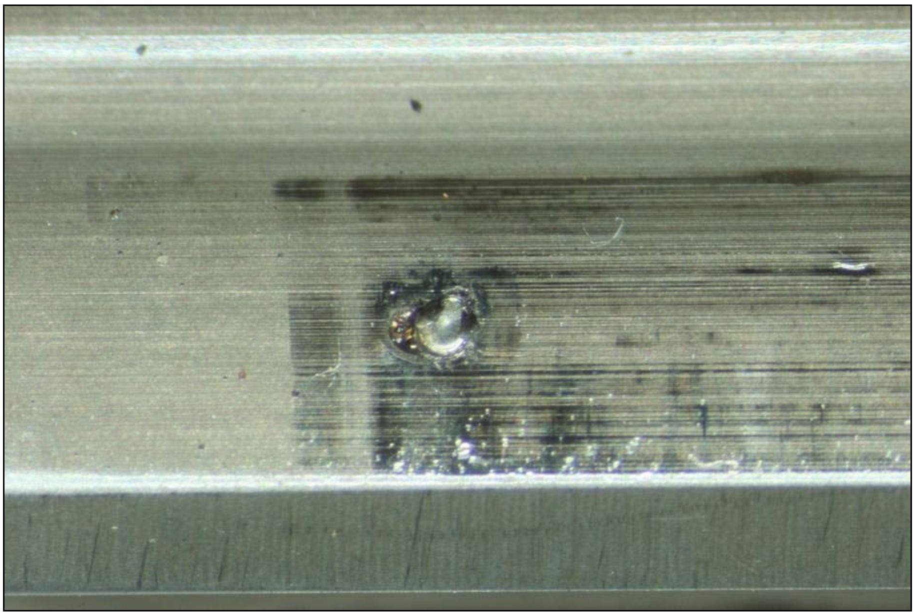
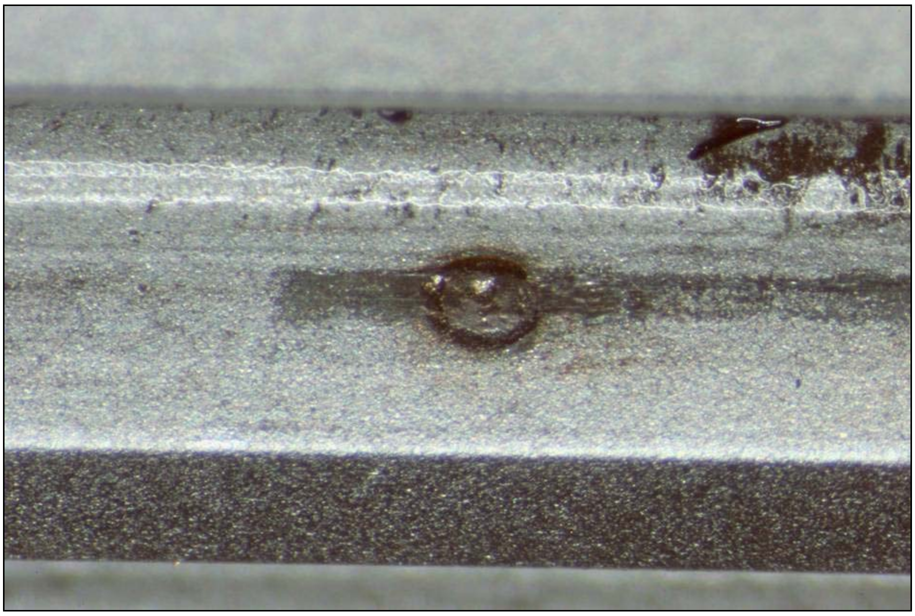


Figure 20: Pitting and re-melting damage to a tooth from the input drive gear shaft coupling



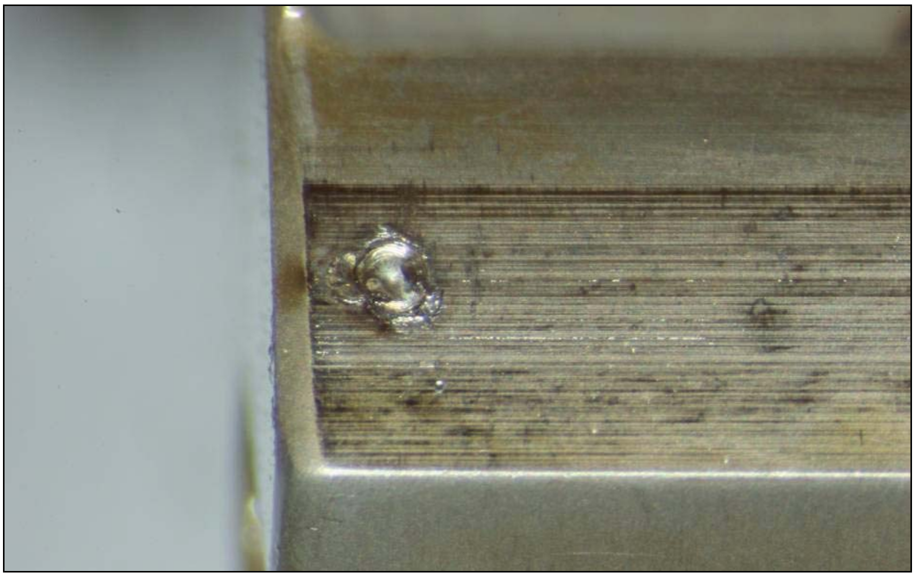
Starter-generator gear-shaft

Providing for power transfer and speed reduction between the engine main-shaft and the starter-generator (SG) input shaft, the SG gear-shaft, see Figure 21, on examination, also showed clear evidence of an electrical arc discharge event, with two opposing areas of pitting and re-melting on the large gear wheel teeth, with associated heat tinting of the immediate surrounding surfaces, see Figures 22 and 23. The gear tooth surfaces were otherwise in sound condition, as were the bearing journal surfaces.

Figure 21: Starter-generator gear shaft

Figure 22: Prominent pitting and thermal tinting on a gear shaft tooth

Figure 23: More pitting on the gear shaft teeth – adjacent to the area shown in Figure 22



Gear-shaft bearings

Both input drive and SG input gear-shafts were supported by high-speed roller bearings, secured using an integral flange mounting arrangement. General examination of the four assembly bearings showed no evidence of electrical discharge damage (EDD) or other damage, induced mechanically or otherwise.

Starter-generator drive shaft

The starter-generator unit that had failed while in service on VH-KLP, was an APC model 200SGL, part number 200SGL119Q, serial number 2870XL. To support the engine failure mode investigation, the SG central splined drive shaft, see Figure 24, and the armature assembly were received and examined to identify and characterise any anomalous damage or unusual appearance. Under low power examination, the drive spline teeth showed several areas of pitting and surface re-melting, again typical of EDD, see Figures 25 and 26. Otherwise, the drive shaft appeared sound and showed no evidence of premature breakdown or damage.

Figure 24: Starter-generator drive shaft and coupling spline

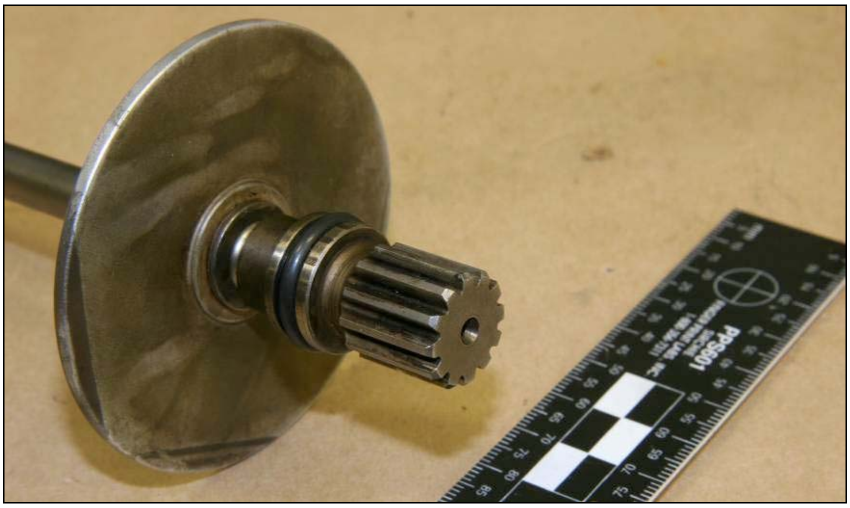


Figure 25: Spline tooth pitting damage

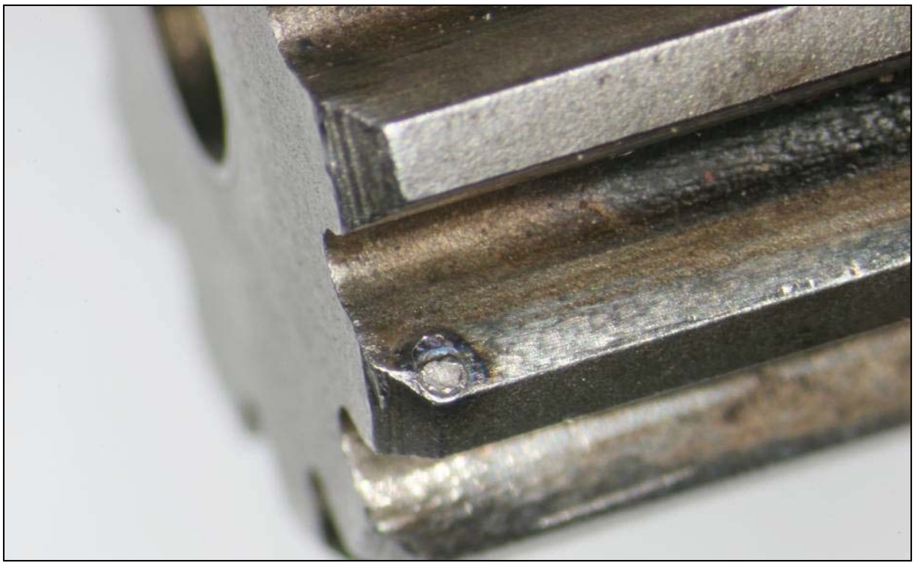
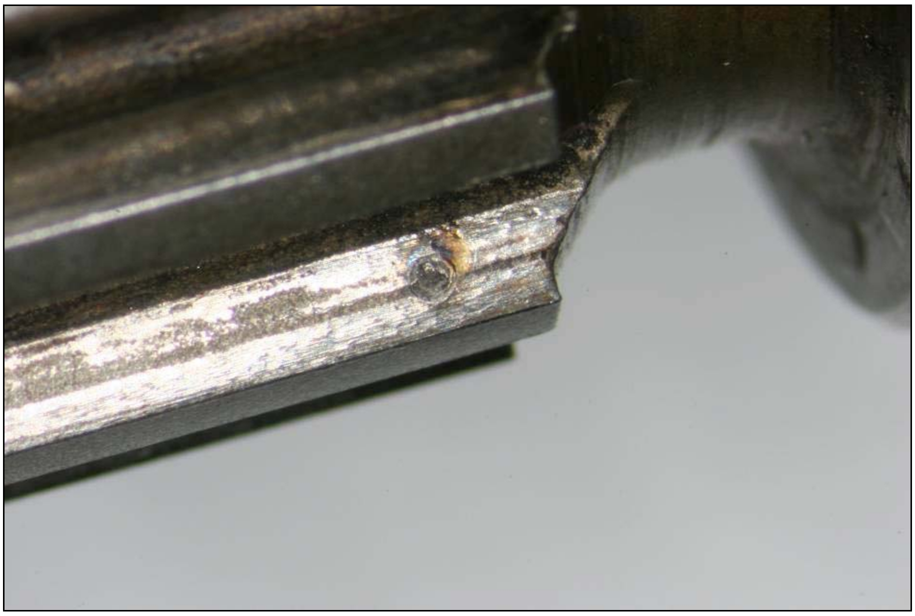


Figure 26: Pitting toward inner end of starter-generator drive spline



Starter-generator armature

Upon examination, the SG armature unit, see Figure 27, showed clear evidence of the electrical shorting of a single core winding against the drive-end ring, see Figure 28. The insulating material between windings and end ring had been charred and lost in the area of the short, and the point of physical contact was characterised by the thermal tinting of the ring surface. The affected winding itself appeared discoloured and oxidised, when compared against the adjacent windings, with the discolouration also evident at the opposite (commutator) end of the armature core, see Figure 29. Laboratory measurements showed a negligible electrical resistance between the affected winding and the body of the armature core.

Figure 27: Armature / commutator body

Figure 28: Shorted winding at the forward (drive) end of the armature core

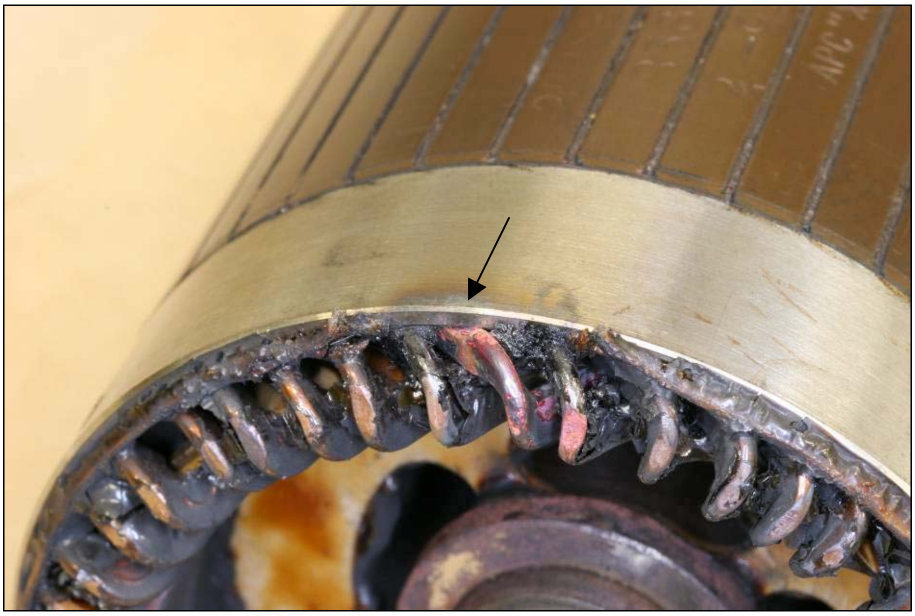
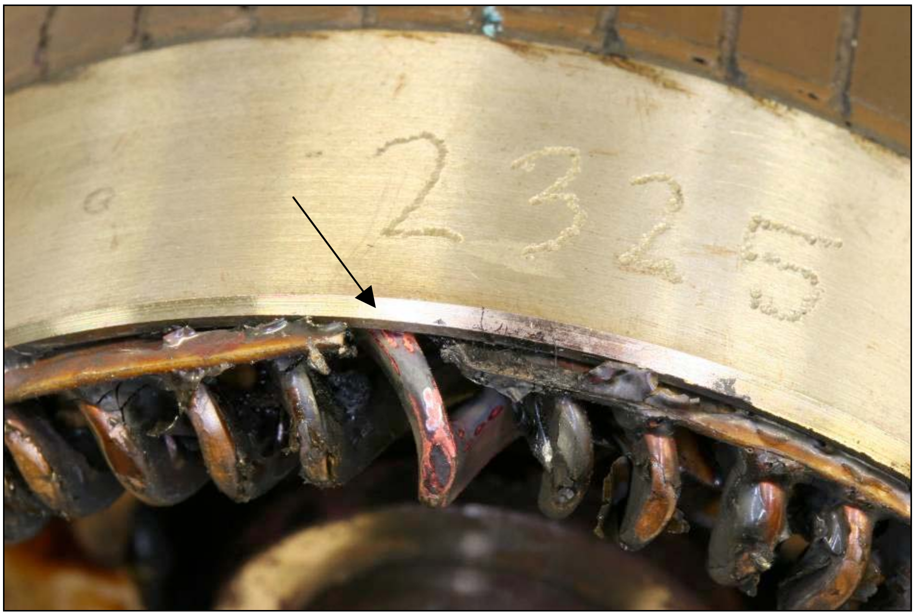


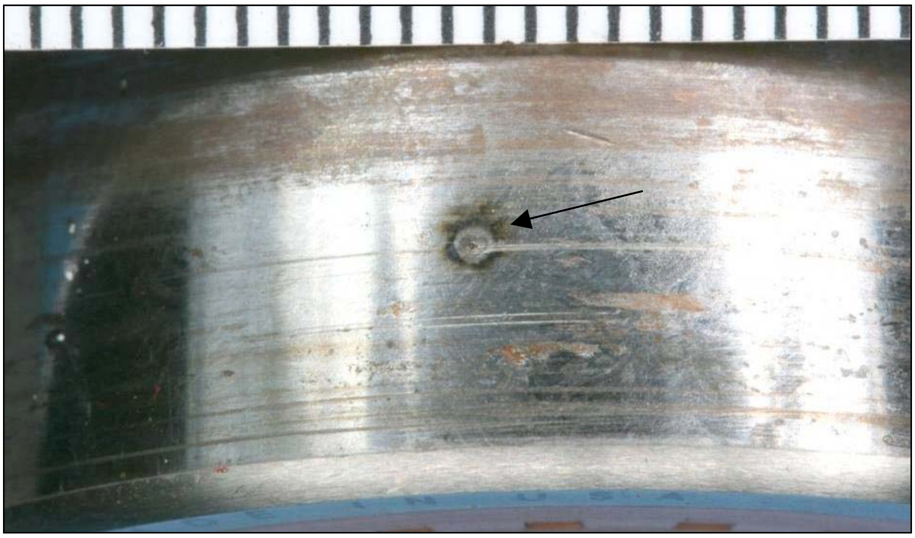
Figure 29: The shorted turn at the rear (commutator end) of the armature body



One of the two armature bearings, see Figure 30, showed multiple electrical arcing indications on the external cylindrical surface, see Figure 31. The affected surfaces of that bearing also showed circumferential scoring and light fretting damage, consistent with rotation and movement within the housing. The opposing bearing showed no evidence of external electrical arcing, nor did it exhibit any evidence of looseness or rotation within its housing.

Figure 30: Starter-generator shaft bearings – note damage at arrow

Figure 31: Typical pitting / re-melting damage as observed on the other accessory gear case components



ANALYSIS

Engine failure

The technical examination of the failed engine from VH-KLP determined that the mechanical failure of the number-1 main shaft bearing was the principal contributing factor that led to the reported in-flight loss of power and engine failure. The damage sustained by the bearing was indicative of a progressive transition from the normal rolling-contact between bearing elements, to a sliding, skidding contact, with the consequent marked increase in friction and the eventual seizure of the assembly.

Bearing failure

Laboratory examination of the failed bearing remnants found several indications of localised thermally affected material over the bearing rolling contact faces – the features of such being consistent with production by a transient electrical discharge. The surface disruption and microstructural alteration that results from such an event would lead to the development of rolling-contact fatigue cracking and spalling of material from the race and rolling element surfaces during continued bearing operation. Consequently, as a combination of the increased friction associated with the degraded bearing surfaces and the compromised bearing clearances, the assembly would begin to seize and eventually fail in the manner observed.

Electrical discharge damage

The investigation established clear evidence of an electrical discharge path extending between the previously-fitted starter-generator armature winding, and the engine number-1 main shaft bearing. Each connecting/contacting surface showed single or groups of several points of arcing damage, consistent with a single, high-current transient discharge event. The evidence suggested that this was initiated by the contact and shorting of the armature winding against the armature core. An absence of effective insulation between the armature core and output/drive shaft allowed the flow of current into the engine accessory gearcase and consequently, through the gear train and couplings, into the number-1 bearing.

The flow of current through the gear train and bearing implied the absence of an alternative path of lower resistance between the armature shaft and ground (earth) potential. While the formation of EDD on the contact surfaces of gears and splined connections in the accessory gearcase is undesirable and likely to lead to a reduction in assembly life, the primary threat to the continued operation of the engine arises from EDD sustained by the engine main-shaft bearings. It was evident from this investigation that such damage can lead to rapid breakdown and failure of rolling-element bearings as a result of the premature development of rolling-contact fatigue spalling from the EDD affected areas.

FINDINGS

Contributing safety factors

The ATSB technical investigation identified the following factors as being directly contributory to the in-flight engine failure of the PWC PT6A-114 engine installed in VH-KLP.

- The starter-generator that was removed from the engine approximately 20 hours prior to the in-flight failure had sustained an electrical short between an armature winding and the armature core.
- The absence of electrical isolation between the starter-generator armature and the drive shaft allowed the transient passage of current into the accessory gearcase during that shorting event.
- The absence of electrical isolation between the starter-generator coupling and the accessory gearcase input coupling, allowed the subsequent passage of electrical current into the engine number-1 main shaft bearing.
- The passage of electrical current across bearing, coupling and gear surfaces created localised areas of electrical arcing and the consequent metallurgical damage to the material in the vicinity of the arc discharges (electrical discharge damage, EDD).

The formation of EDD within the number-1 engine main shaft bearing precipitated the development of internal rolling-contact fatigue spalling and the subsequent breakdown and seizure of the bearing.

APPENDIX B: MEDIA RELEASE

Investigation of Cessna 208 engine failure and forced landing on Lake Burbury

The ATSB has found that a Cessna 208 engine failure and forced landing onto a lake in a remote part of south-western Tasmania last year was due to a previous generator failure, has praised the pilot's actions in landing the aircraft and ensuring passenger safety, and has made a number of safety recommendations to prevent a similar failure.

The Australian Transport Safety Bureau's final investigation report states that the aircraft, a single engine Cessna 208 floatplane was being operated on a commercial scenic flight over rugged terrain with a pilot and 10 passengers. The occupants were fortunate to escape unharmed, due to the pilot's prompt actions in diverting to Lake Burbury when an engine chip-detector warning light came on. Within minutes of the warning light illuminating, the engine failed completely and the pilot was able to conduct a forced landing onto the lake. The aircraft ended up on a mud bank on the edge of the lake and the occupants were able to walk away unharmed.

A previous generator failure led to electrical discharge damage (EDD) to the engine, resulting in its failure in-flight. EDD is a known problem with the Pratt and Whitney Canada PT-6 series turbo-prop engines fitted to this aircraft type. The ATSB has investigated similar events in Australia previously and the ATSB report cites 43 similar events reported worldwide since 1992. Some of these events have also been investigated by the US National Transportation Safety Board.

As a result of the ATSB investigation into this serious incident, a number of safety actions have been implemented by the aircraft and engine manufacturers as well as Australia's Civil Aviation Safety Authority (CASA). CASA has advised the ATSB that it will issue mandatory aircraft maintenance instructions and Airworthiness Bulletins to reduce the possibility of EDD occurring and will highlight the issue to the Australian aviation industry through its Flight Safety Australia magazine.

While the safety actions of all parties are to be commended, the ATSB remains concerned that there remain safety issues that need to be addressed to eliminate the possibility of EDD events leading to engine failures of this engine type. The ATSB final report therefore contains a number of safety recommendations to the aircraft and engine manufacturer, the Canadian and US airworthiness authorities, Transport Canada and the Federal Aviation Administration and CASA.