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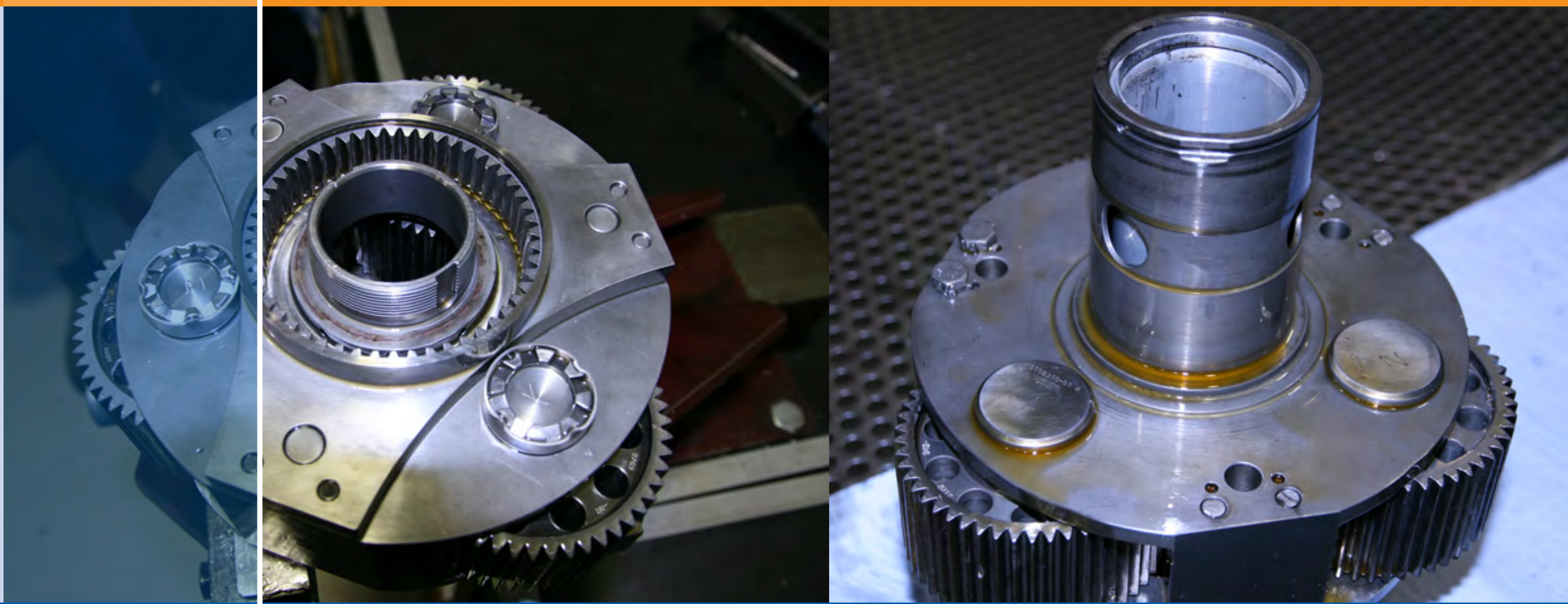

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation
AO-2010-006
Final

Total power loss
11 km NE of Derby Airport, WA
29 January 2010
VH-NWO, Pilatus PC-12/45

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Total power loss, 11 km NE of Derby Airport, Western Australia - 29 Jan 2010
VH-NWO, Pilatus PC-12/45

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Figures 1 and 2: Pratt and Whitney Canada

Abstract

At about 2010 Western Standard Time on 29 January 2010, a single-engine Pilatus PC-12 aircraft, registered VH-NWO, was being operated on a night medical evacuation flight from Derby to Kununurra, Western Australia with four persons on board. The pilot reported that about 56 km after takeoff, as the aircraft was passing through flight level 180, the engine exhibited a number of problems before the pilot turned the aircraft back to the departure airport. The engine failed and the pilot glided the aircraft to land at Derby. There were no injuries. Subsequent inspection confirmed that the engine propeller reduction gearbox had seized.

The investigation found that four of the six first-stage reduction gearbox bolts had failed due to fatigue. As a result of this failure, and a number of previous similar events, the engine manufacturer commenced its own investigation. That investigation included the review of a number of issues relating to engine overhaul practices. Subsequently, the manufacturer recommended withdrawal from service of an engine from one aircraft in the Australia fleet for examination as part of the its investigation.

The manufacturer determined that a quantity of in-service first stage reduction assembly carrier bolts had not undergone cold rolling of the head-to-shank fillet radius during manufacture. As a result, the engine manufacturer issued a number of service bulletins that identified affected gearboxes and provided recommended compliance times for the removal of suspect carrier bolts from service.

A review of the Society of Automotive Engineers (SAE) specification AS7477D found it was ambiguous in respect of the need to cold roll the head-to-shank fillet radius of MS9490-34 carrier bolts. A revised copy of the specification, Revision E, was published by the SAE in October 2011, clarifying the need for cold rolling of the head-to-shank fillet radius of those bolts.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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

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

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

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

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

Developing safety action

Central to the ATSB’s investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

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

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

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, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) 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 in the interests of improved transport safety.

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 characteristic of an operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

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

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

History of the flight

On 29 January 2010, at about 2010 Western Standard Time[1], a single-engine Pilatus PC-12/45 aircraft, registered VH-NWO (NWO), was being operated on a medical evacuation flight from Derby to Kununurra, Western Australia with four persons on board. The night flight was being conducted under the instrument flight rules (IFR) in visual meteorological conditions.

About 56 km from Derby, as the aircraft was climbing through flight level FL 180 (about 18,000 ft), the pilot felt two significant shudders down the airframe and the onset of a loud humming and whining noise. That shudder and noise lasted until the engine was shut down. Seconds later, the engine CHIP caution light illuminated, indicating the detection of metal chips in the engine oil by the engine chip detector[2]. The pilot continued the climb, immediately turned the aircraft back towards Derby and transmitted a PAN[3] call to air traffic control (ATC) to advise of the incident and intention to return to Derby.

The pilot reported that a short time later, the engine oil pressure was lost, the engine torque decreased and the inter-turbine temperature increased. Coincident with those indications, the aircraft's rate of climb began to reduce and the pilot placed the aircraft in level flight. Later, the engine power was reduced further by the pilot.

About 11 km from Derby, the OIL QTY warning light illuminated indicating low engine oil quantity and the pilot shut down the engine. The propeller feathered[4] and stopped rotating immediately. The pilot upgraded the initial PAN call to a MAYDAY[5] and continued the glide approach. ATC requested an aircraft on an international flight, which was overflying the area at the time, to activate the pilot-activated lighting at Derby to assist the pilot of NWO.

The aircraft landed safely at Derby Airport a short time later.

Personnel information

The pilot held the appropriate licence, ratings, and medical certificate for the flight.

The pilot had experience as a standards instructor and as an approved testing officer (ATO). That experience involved issuing approvals for other pilots to conduct instrument and multiengine training and testing.

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1 Western Standard Time was Coordinated Universal Time (UTC) +8 hours.

2 A magnetic device that gathers metallic slivers, usually from lubricating oil. Those slivers complete an electrical circuit that illuminates a cockpit warning light.

3 Radio transmission indicating uncertainty or alert, in the form of a general broadcast to the widest area but not yet at the level of a Mayday.

4 The propeller blades are rotated parallel to the airflow to reduce drag in case of an engine failure

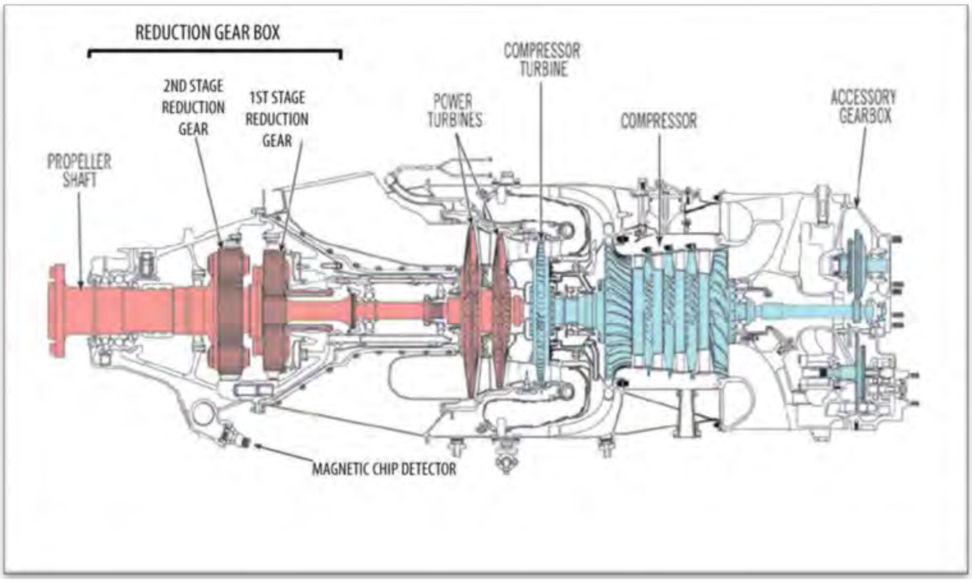
5 International call for urgent assistance.

Aircraft information

The aircraft was manufactured in 2001 and was approved for unrestricted day or night operations under the IFR and for operations in the aerial work[6] category.

The aircraft was fitted with a Pratt and Whitney PT6A-67B engine (Figure 1), serial number PCE-PR0092. The engine was manufactured in Canada in June 1998 and had a total time in service of 5,619 hours. The engine's power section, which included the propeller reduction gearbox, had accumulated 1,120 hours since its last overhaul, which was carried out on 23 May 2007.

Figure 1: Schematic of the PT6A-67B engine



Meteorological information

The pilot reported that the power loss occurred in visual meteorological conditions, with smooth air and a few clouds.

Engine and gearbox examination

Preliminary examination of the engine by the operator's maintenance personnel confirmed that there had been an internal seizure of the propeller reduction gearbox. Other than the seizure of the gearbox, no other anomalies affecting the engine or any of its components were identified at that time. The engine was then shipped from Derby to an approved engine overhaul workshop in Brisbane, Queensland for detailed examination under the supervision of the Australian Transport Safety Bureau (ATSB).

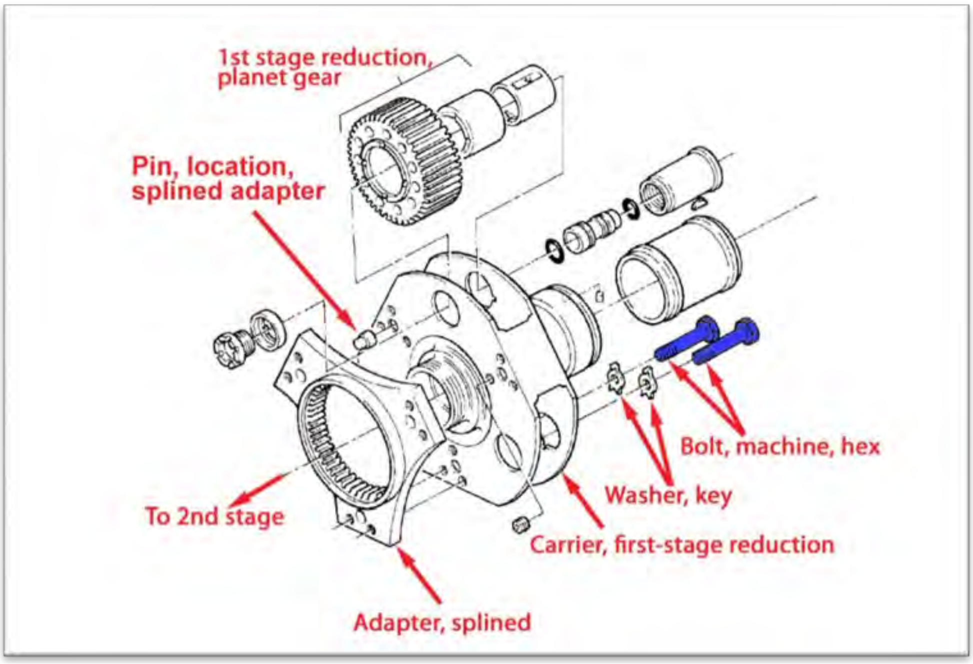
The examination of the gearbox found that four of the six first stage reduction assembly carrier bolts (part number MS 9490-34) had failed due to fatigue cracking

6 Civil Aviation Regulation 206 *Commercial purposes* prescribed aerial work as including: aerial surveying, spotting and photography; agricultural operations; advertising; and ambulance functions.

at the head-to-shank fillet radius[7] (Figure 2). Debris from the failed bolts was released into the first stage sun and planet gears, causing significant damage.

A fifth carrier bolt had fractured through the threaded area as a result of overstress, with the threaded portion remaining in the splined adapter.

Figure 2: Schematic of the first stage reduction assembly, showing a closer location view of the failed bolts



In addition to the carrier bolts, the splined adapter was aligned and held in position by three locator pins adjacent to the carrier bolts.

Figure 3: Carrier plate assembly showing the location of the fractured bolts (Figure 3a) and the position of the splined adapter (Figure 3b).

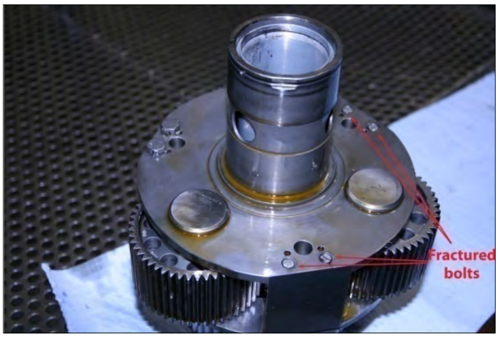


Figure 3a: First stage reduction carrier, showing the location of the fractured bolts.

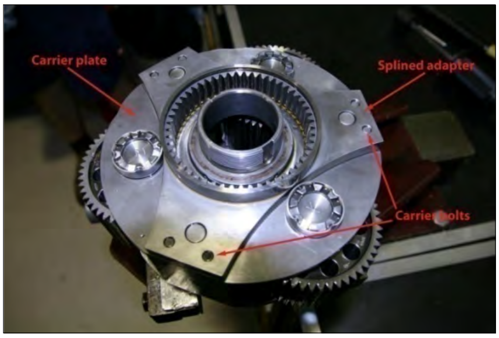


Figure 3b: Underside of the first stage reduction carrier, showing the splined adapter.

The six carrier bolts, the first stage carrier and the splined adapter were retained by the ATSB for further examination. That examination confirmed the mode of failure as reverse bending fatigue below the head of four of the bolts (Appendix A).

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[7] Fillet radius. The area where the head of a bolt transitions to the shank or shaft of a bolt.

Carrier bolt failure

The material properties (chemistry, hardness and dimensional checks) of the failed bolts and the splined adapter were consistent with their designation in the engine manufacturer's illustrated parts catalogue.

In October 2010, the engine manufacturer advised the ATSB of the identification of a number of in-service carrier bolts that had not been cold rolled[8] at the head-to-shank fillet radius. That would have reduced the bolts' fatigue resistance, and increased the likelihood for the initiation of fatigue cracking at the head-to-shank fillet radius.

An MS 9490-34 bolt, which was confirmed as having undergone cold rolling of the head-to-shank fillet radius during manufacture was examined by the ATSB. A comparison of the cold rolled bolt and the intact bolt from the aircraft's reduction gearbox revealed a significant difference between the surface microstructure at the respective bolt's head-to-shank fillet radius (Figure 4). That difference was consistent with the intact bolt not being cold rolled.

Figure 4: Comparison of one of the failed bolts (Figure 4a) – not cold rolled - and a cold-rolled bolt (Figure 4b)

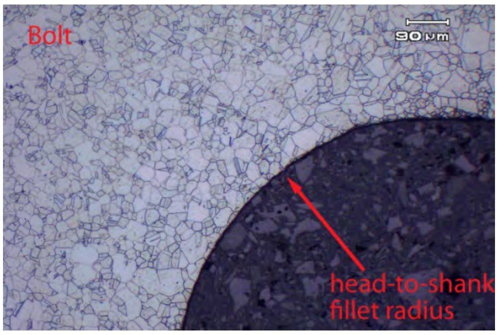

Figure 4a: Head-to-shank fillet radius of one of the failed bolts, with no evidence of cold rolling.

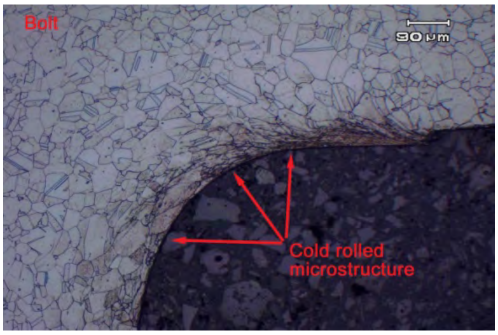

Figure 4b: Head-to-shank fillet radius exhibiting a cold-rolled microstructure.

It was reported that the bolt manufacturer only cold rolled the head-to-shank fillet radius when it was considered necessary to remove evidence of grinding or tool marks on bolts during the manufacturing process. The bolt manufacturer believed that this was in accordance with the fabrication instructions described in SAE[9] Aerospace Standard (AS) 7477 Revision D, which advised the following with regard to cold rolling:

> The head-to-shank fillet radius of parts having the radius complete throughout the circumference of the part shall be cold worked sufficiently to remove all visual evidence of grinding or tool marks.

The application section of the Standard called for good fatigue resistance. The heat treatment and surface hardening sections of the Standard implied that the head-to-shank fillet radius would be cold rolled.

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8 Action to harden and increase the strength of steel at the expense of its ductility.

9 Society of Automotive Engineers.

Reduction gearbox failure history for PT6A-65 and 67 series engines

The investigation found that, between 2000 and the incident involving NWO in January 2010, there were a total of 27 failures of the larger variants of the PT6A series engines due to failure of the first stage carrier bolts at the head-to-shank fillet radius. The engine variants affected included the PT6A-67A/67AF/67AG/67B/67D/67P/67R and 65AR. During that period, there were 2,029 of these engines in service worldwide.

Between January 2010 and October 2010, there were two further PT6A reduction gearbox failures, bringing the total number of failures since 2000 to 29.

Of the 29 reported reduction gearbox failures, 27 were in overhauled engines and two in newly-manufactured engines. Fifteen of the events resulted in in-flight shutdowns.

On 10 July 2008, Transport Canada, the Canadian regulatory authority issued Service Difficulty Advisory (SDA) AL 2008-05 titled *Pratt and Whitney Canada - PT6A-65 & 67 series reduction gearbox, 1st stage carrier bolts fractured*. The SDA advised the number of known fatigue fractures sustained by reduction gearbox P/N MS9490-34 first stage carrier bolts up to the date of publication. Five of the bolt failures led to in-flight shutdowns.

Engine manufacturer's reduction gearbox investigations

In 2007, the engine manufacturer began an engineering study to improve its understanding of the reasons for the reduction gearbox carrier bolt failures on PT6A-67 series engines. As a result, the following service changes were implemented by the engine manufacturer:

- In January 2008, an 'All Shop Message' PT6A-2008-01 was issued to all approved overhaul facilities. The message emphasised the then standard practices for the lubrication of the bolts and for applying torque to critical components.
- In January 2009, the engine Overhaul Manual (OHM) was revised to introduce new torque procedures for the first stage carrier bolts as follows:
  - Lubricate bolts MS9490-34 prior to their installation at overhaul.
  - Apply torque twice during the assembly procedure to remove any washer elastic reaction from the true bolt preload.

Following the publication of those service changes, the engine manufacturer continued to investigate the bolt distress mechanism. Overhaul processes were implicated as being the primary contributing factor, which led to further changes to the OHM in September 2010. Those changes included the:

- triple torquing of the bolts
- alignment of a tabbed washer prior to tightening the assembly.

Following the occurrence involving NWO, the engine manufacturer requested the removal from service of one low-time Australian engine for closer inspection of the carrier bolts. In particular, the manufacturer sought an engine that had been overhauled prior to the 2009 amendments to the OHM. No defects or discontinuities of the carrier bolts were identified in that engine.

Ongoing work by the engine manufacturer subsequently revealed that many of the carrier bolts in service may not have been cold rolled at the head-to-shank fillet radius during bolt manufacture. The engine manufacturer advised that their investigations into the bolt failures had been based on the assumption that all bolts underwent cold rolling in the head-to-shank fillet radius. The discovery that many of the in-service bolts had not been cold rolled meant that those bolts had lower strength and fatigue resistance than was necessarily the case.

Organisational and management information

Approved single–engine, turbine-powered aeroplane operations

The reliability of turbine engines, including turboprop engines, has continued to increase over time.[10] However, turboprop engines can and do fail. A forced landing at night in IFR conditions is about 2.2 times more likely to result in a fatality when compared with a forced landing during daylight[11].

In 2001, the Civil Aviation Safety Authority (CASA) introduced Civil Aviation Regulations (CAR) 174B and 175A to permit passengers to be carried for hire or reward in a single engine aeroplane under the IFR and at night under the visual flight rules subject to CASA approving the operator and aeroplane type in writing. Prior to that time, those operations required an aircraft to have a minimum of two engines.

The CASA requirements for an approved single-engine turbine-powered aeroplane (ASETPA) operation, including the approval of an aeroplane type, are based on a similar philosophy to that required for extended range operations for twin-engine aeroplanes (EROPS)[12]. The ASETPA requirements stipulated enhanced operational, pilot training and aircraft design standards, including that:

- the aeroplane shall meet a certain design standard
- the aeroplane shall meet a documented level of reliability
- the aeroplane shall have an enhanced level of essential operating equipment redundancy
- an enhanced level of engine condition monitoring shall be applied to the operation
- an enhanced level of crashworthiness shall be incorporated into the aeroplane
- the aeroplane shall comply with the operational equipment requirements for commercial passenger carrying IFR operations
- the operator shall have an enhanced level of pilot qualifications and operational and maintenance control.

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[10] Aviation Week, *When the Engine Goes Bang*, Patrick R. Veillette, Ph.D, Aug 2006

[11] NTSB Annual Review of aircraft accident data, U.S. General Aviation Calendar year 2006.

[12] Refer to Appendix B for a full description of the ASETPA requirements.

Currently, there are only two single turbine-engine aircraft types approved for ASETPA operations in Australia. Those are the Cessna 208 and the Pilatus PC-12 aircraft. Pilatus has advised that all PC-12 aircraft comply with the ASETPA design standards from manufacture.

Although the night medical evacuation flight was not carried out under ASETPA, the engine failure sustained in NWO is relevant to ASETPA operations in Australia. That relevance relates to the inclusion of the failure in CASA's PT6A-67B statistics that, in turn, affects CASA's consideration of the reliability of the PT6A-67B engine for the ASETPA program.

Aircraft operator

The aircraft operator was approved to conduct unrestricted day or night IFR operations in the aerial work category.

The operator was not required to comply with the requirements of ASETPA, because it was not a fare-paying passenger operation. Additionally, the nature of their operations was such that the operator was unable to comply with all aspects of the ASETPA requirements. In particular, they were unable to remain within gliding distance of a suitable landing area in the event of an engine failure. While not ASETPA approved, the operator advised that they used the ASETPA requirements as a baseline for their maintenance regime and operational training because of the perceived additional safety value. That operational training included practice of emergency procedures twice a year.

The operator also provided additional information in its PC-12 aircraft's global positioning system (GPS) equipment to assist flight crews in an emergency, including:

- The operator's aircraft's GPS equipments were programmed with the majority of the aircraft landing areas (ALAs)[13] and registered or certified aerodromes in Western Australia that were used by its flight crews.
- All aerodromes, whether certified, registered or ALAs could be displayed on a multi-function display and the MAP page of each aircraft's GPS system.
- The aircraft's GPS systems were programmed with a one-touch function for the location of 'nearest to' aerodromes in the event of an engine failure.

The operator's flight crews reported that that information significantly enhanced their situational awareness and reduced pilot workload in a stressful situation.

PT6A-67 series engine failure rates

The ASETPA requirements specified that the engine type shall have documented evidence of an acceptable world fleet reliability with an in-flight shut down (IFSD) rate of not greater than 0.01 per 1,000 hours.

As part of its function in gathering engine failure rates to inform the ASETPA requirements, CASA monitored the PT6A-67B engine failure rate by examining

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[13] A place that may be suitable for the landing and takeoff of an aircraft of appropriate certification and performance, but that may not fully meet formal standards of construction, marking, maintenance or reporting.

worldwide IFSD events, and maintaining a rolling average[14] of those failures. That average was used to monitor the engine's failure rate and ensure that they remained within the specified tolerances. There were 27 occurrences worldwide involving failures of the first stage carrier bolts in PT6A series engines at the head-to-shank fillet radius between 2000 and that involving NWO. However, that failure rate was low given the large number of such engines in service, and the accumulated hours of those engines. Further, of the 27 reported failures, only that affecting NWO occurred in Australia, and two (including NWO) involved PT6A-67B engines. The majority (14) involved PT6A-67D engines that were predominantly installed in twin-engine aircraft.

[14] A rolling average is the averaging of a set of variables over a set time period.

ANALYSIS

Introduction

The meteorological conditions at the time and the aircraft's maintenance were not a factor in the occurrence.

It was likely that the pilot's experience as a standards instructor and approved testing officer routinely exposed the pilot to simulated total power loss. That, and the application by the operator of elements of the approved single-engine, turbine-powered aeroplane (ASETPA) program, including emergency preparedness and pre-flight planning, would have enhanced the pilot's proficiency in the management of such failures.

Similarly, the high level of awareness and acceptance of the requirements of the ASETPA program, and their application by the operator, directly affected the route and height flown, and the general conduct of the flight. The location and height at which the total power loss took place, within gliding distance of a suitable airport, and the pilot's proficiency in the management of such failures, would also have increased the likelihood of a safe outcome.

This analysis will examine the factors that contributed to the total loss of engine power and the potential for identifying similar failure mechanisms in the worldwide fleet of PT6A-series engines.

The total power loss

An ambiguity in the Society of Automotive Engineers (SAE) specification for the cold rolling of MS9490-34 bolts used in the manufacture of PT6A-series engines led to some of them not being cold rolled at the head-to-shank fillet radius and therefore being more susceptible to fatigue crack initiation than they would otherwise have been. Bolts that had not been cold rolled were installed in the aircraft's engine during overhaul and, during the engine's service, fatigue cracks initiated at the head-to-shank fillet radius. Those fatigue cracks led to the failure of the bolts, resulting in the seizure of the reduction gearbox and subsequent engine failure.

While the wording in the first section of SAE AS 7477 Rev D may have been ambiguous, the application section of the standard mentioned that bolts manufactured to this specification were intended to have good fatigue resistance. As such, best practice should dictate that the bolts were cold rolled under the head to improve fatigue resistance. Additionally, there were several other locations in the standard where cold rolling of the head-to-shank fillet radius was implied.

Approved Single Engine Turbine Powered Aeroplane

The continuing improvement in the reliability of turbine engines, including turbopropeller engines has lead to the possibility of single-engine operations under the instrument flight rules (IFR). That includes Approved Single Engine Turbine Powered (ASETPA)-type operations.

The operational ASETPA requirements reflected an attempt to minimise the consequences of an engine failure. This is especially important in the case of a forced landing in unsuitable terrain, particularly at night. The application by the operator of a number of those operational requirements afforded the pilot the greatest chance of a successful forced landing.

Monitoring of engine failure rates

The methods used for monitoring engine failure rates showed that the engine failure data being gathered and analysed by the manufacturer was the most reliable indicator of failure events across all PT6A-series engines. That included the failure rates of components such as the carrier bolts installed in a number of the engine variants, which amounted to 27 failures over a 10-year period.

In contrast, the ASETPA program methodology for assessing engine reliability only monitored the in-flight shut down rate for the PT6A-67B engines. That meant that only two engine failures were identified over the 10-year period, possibly delaying the identification of an emerging airworthiness trend, such as the failure of the carrier bolts.

The engine manufacturer’s awareness of all similar failures in the PT6A-series engine explained the manufacturer’s efforts, including a number of service bulletins, to eliminate the failures.

FINDINGS

From the evidence available, the following findings are made with respect to the total power loss that occurred 11 km north-east of Derby Airport, Western Australia on 29 January 2010 and involved Pilatus PC-12/45, registered VH-NWO. They should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The first stage reduction gear box seized following the failure of four of the six MS9490-34 reduction gear assembly carrier bolts.
- The reduction gear assembly carrier bolts failed as a result of fatigue cracking at the head-to-shank fillet radius.
- The carrier bolts had not undergone cold rolling of the head-to-shank fillet radius during manufacture.
- The Society of Automotive Engineers specification AS7477 was ambiguous in relation to the requirement to cold roll the head-to-shank fillet radius of MS9490-34 bolts. *[Minor safety issue]*
- The bolt manufacturer's interpretation of Society of Automotive Engineers International specification AS7477 resulted in the inconsistent manufacture of bolts that were cold rolled at the head-to-shank fillet radius.
- A number of non-cold rolled bolts were installed on PT6A-67-series engines during manufacture and overhaul. *[Minor safety issue]*

Other key findings

- The application by the operator of the requirements of the approved single-engine, turbine-powered aeroplane program to its operations, and the pilot’s ongoing exposure to the management of practice engine failures optimised the potential for a safe landing after the total power loss.

SAFETY ACTION

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

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

Society of Automotive Engineers International

Bolt manufacturing specification

Minor safety issue

The Society of Automotive Engineers (SAE) International specification AS7477 was ambiguous in relation to the requirement to cold roll the head-to-shank fillet radius of MS9490-34 bolts.

Action taken by SAE International

The engine manufacturer reported that it had advised SAE International standards division committee SAE E-25 of the possibly ambiguous wording of sections of SAE International specification AS7477 in respect of the requirement to cold roll the under head fillet radius. The engine manufacturer further advised that committee SAE E-25 had unanimously agreed that specification AS7477 bolts required cold rolling of the under head fillet radius, and that the standard required revision to provide a clearer set of requirements in that regard. Revision E was issued by the SAE in October 2011, and expressly stated that the fillet shall be cold rolled, even if there is no evidence of grinding or tool marks.

ATSB assessment of action

The ATSB is satisfied that the action taken by SAE International adequately addresses this safety issue.

Pratt and Whitney Canada

Lack of cold rolling of head-to-shank fillet radius on first stage reduction gear box carrier bolts

Minor safety issue

A number of non-cold rolled bolts were installed on PT6A-67 series engines during manufacture and overhaul.

Action taken by the engine manufacturer

Following the discovery that the bolts had not been cold rolled at the head-to-shank fillet radius, the engine manufacturer issued two service bulletins (SB). Those bulletins, P&WC SB No. 14444 and P&WC SB No. 14446 specified the need to replace the first stage carrier bolts in PT6A-67 series engines. The service bulletins allowed for the scheduled replacement of all affected bolts with components that had a JB or an X stamped on the bolt head, which indicated that the replacement bolts had undergone cold rolling.

The engine manufacturer also conducted a value stream mapping exercise to review all standard parts used in their engines to identify any parts used in critical areas of the engine. Such parts would be considered critical, and be given a 3 million part number, meaning that the part had to be designed and inspected to the engine manufacturer's specifications. The engine manufacturer believes that this action will ensure quality assurance and minimise the risk of non-conforming parts.

The engine manufacturer advised that all of its previous incremental actions to enhance the assembly processes for the reduction gearbox would remain as a standard overhaul or rebuild requirement.

ATSB assessment of action

The ATSB is satisfied that the action taken by Pratt and Whitney Canada adequately addresses this safety issue.

Civil Aviation Safety Authority

No organisational or systemic issues were identified that might adversely affect the future safety of aviation operations for which the Civil Aviation Safety Authority (CASA) might have ownership. However, as a result of this occurrence, CASA has taken the following proactive safety action to improve the monitoring of specific engine failure types:

> The Airworthiness and Engineering Branch is working closely with our colleagues in Safety Analysis who are in the process of establishing relevant safety reports based on data, including [Service Difficulty Report] SDR data, held by the Authority. Moreover, we are working with our Information Technology (IT) people in an order to improve the capability of the current SDR data base. This work should include an alert function, which I am confident will address the specific issues raised in the ATSB report in terms of ensuring we capture and action systemic issues, as has occurred in the case of these P&W PT 6 bolt failures.

APPENDIX A: TECHNICAL ANALYSIS REPORT

ATSB TECHNICAL ANALYSIS
AO-2010-006

Total power loss
11 km NE of Derby Airport, Western Australia
29 January 2010
VH-NWO, Pilatus PC-12/45

Carrier bolt failure examination

FACTUAL INFORMATION

Introduction

On 29 January 2010, at approximately 2010 Western Standard Time (WST), a single-engine Pilatus PC-12 aircraft, registered VH-NWO, was being operated on a medical evacuation flight from Derby to Kununurra, Western Australia with four persons on board.

After departure, when the aircraft was about 56 km from Derby, the pilot reported engine problems and turned the aircraft back to the departure aerodrome. The engine subsequently failed and the pilot glided the aircraft to the aerodrome and landed safely with no reported injuries. A subsequent inspection confirmed that the engine's propeller reduction gearbox had seized.

Following workshop disassembly of the PT6A-67B engine (S/N PR0092), the examination found that a number of reduction-gearbox first-stage carrier bolts had failed. Several of the gearbox components were retained by the ATSB for closer examination in the ATSB's Canberra laboratories.

The following components were examined;

- Carrier, first-stage reduction – P/N 3107995-01
- Adapter, splined, first-stage reduction – P/N 3108312-01
- Bolt, machine, hexagon head – MS9490-34 (6 in total)

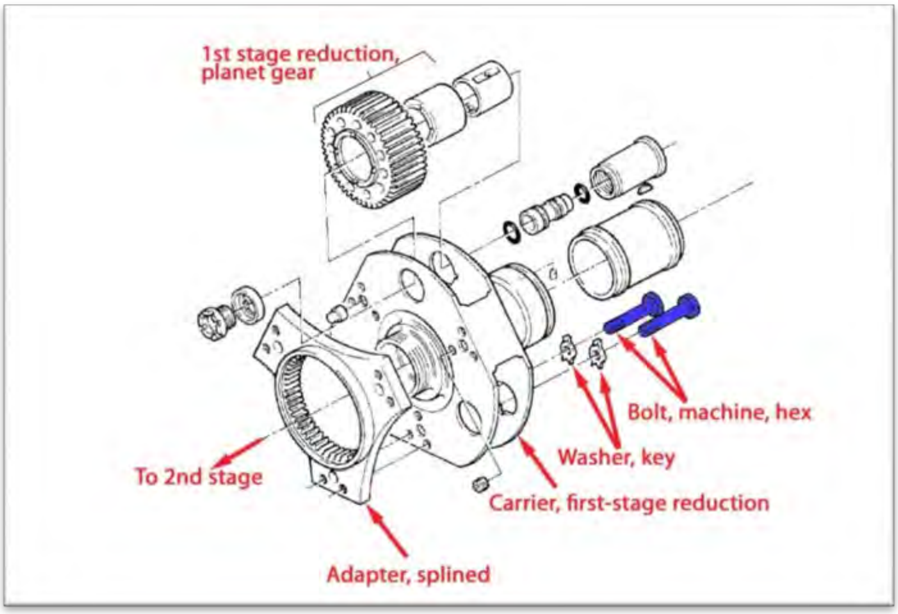
Scope of the examination

The scope of the examination was to analyse the failed bolts for a probable fracture mechanism; to verify the material properties of the bolt, and to critically examine the carrier plate design in the context of the bolt failures.

Examination of the assembly

Seizure of the reduction gearbox was attributed to the fracture of the carrier bolts. These bolts provided a clamping force between the carrier plate and the splined adapter (Figure A1).

Figure A1: Schematic of the first stage reduction assembly



The assembly contained six bolts (Figure A2); four of the bolts had failed underneath the bolt head, one of the bolts had failed in the threaded region at a location between the carrier plate and splined adapter (Figure A3) while the final bolt remained intact.

Figure A5: Overview of carrier plate assembly showing location of the under-head fractured bolts (left) and position of splined adapter (right)

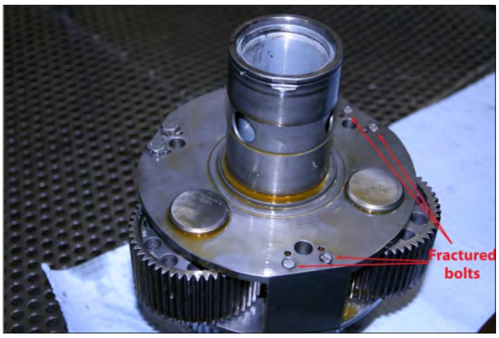


Figure A2a: First stage reduction carrier showing the location of the under-head fractured bolts.

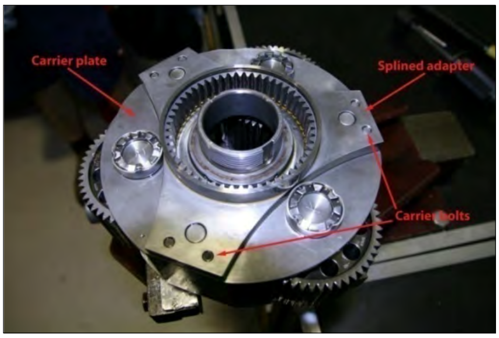
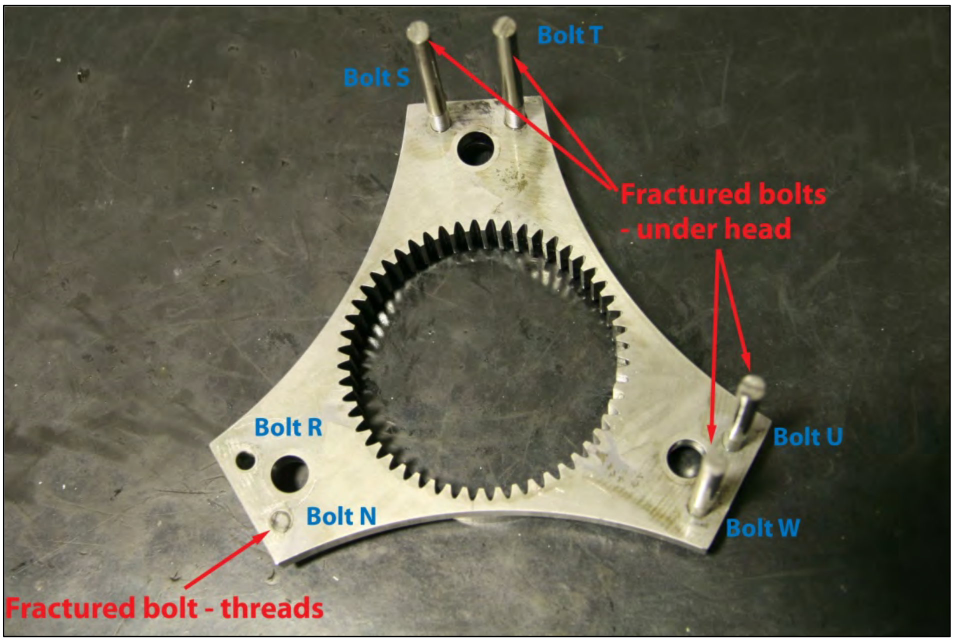


Figure A2b: Underside of first stage reduction carrier showing the splined adapter.

In addition to the carrier bolts, the splined adapter was aligned and held in position by the presence of three locator pins, located adjacent to the carrier bolts. Following removal of the remaining intact bolt, the splined adapter was separated from the carrier plate. The bolts were identified by the letter designation stamped on the side of the splined adapter (N, R, S, T, U and W, as shown in Figure A3).

Figure A6: Splined adapter following removal from the carrier plate. Note the locations of the fractured bolts and their designations



The length of the exposed thread was measured on the bolts that had fractured under the head (S, T, U and W), prior to their removal from the splined adapter. All four bolts exhibited a similar level of engagement (Figure A3 and A6). The bolt that had fractured in the threaded region (Bolt N) showed slightly less thread engagement when viewed from the underside, when compared against the bolts that had fractured beneath the head.

Evidence of fretting wear and scuff marks was observed on the mating surfaces between the carrier plate and the splined adapter (Figures A4 and A5). The wear appeared to be slightly greater towards one side of each of the three carrier plate arms. This was consistent with the torsionally-induced movement of the splined adaptor with respect to the carrier plate during service.

Figure A7: Carrier plate after removal of the splined adapter. Note the fretting wear adjacent to bolt pairs

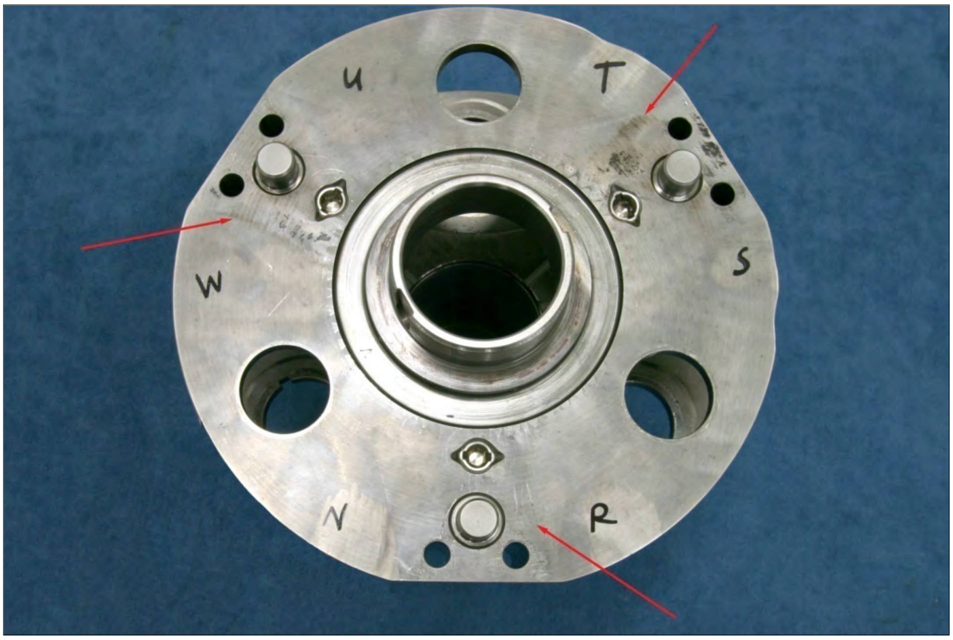
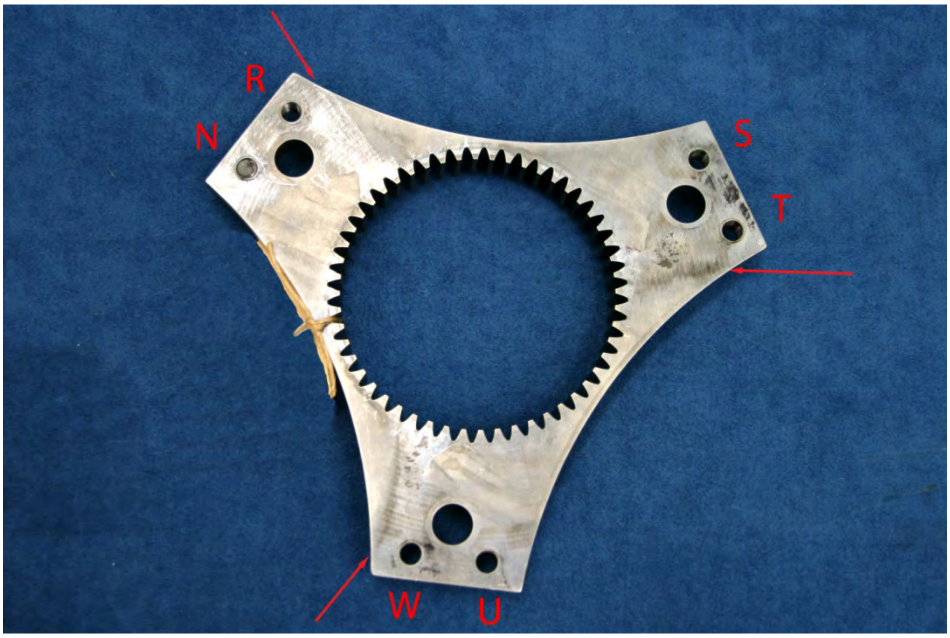


Figure A8: Splined adapter, following removal from the carrier plate, showing the face in contact with the carrier plate



Examination of the carrier bolts

The engine illustrated parts catalogue indicated that the carrier bolts were part number MS9490-34 (Military Standard 9490 *Bolt, machine – hexagon head, full shank, AMS5731, 0.250-28 UNJF-3A*). The specified bolt material (AMS5731) was a corrosion and heat-resistant, precipitation-hardenable stainless steel. Bolt manufacture was to be in accordance with AMS 7477 (*SAE AS7477, Bolts and Screws, Steel, UNS S6628 – Tensile Strength 130 ksi, Procurement Specification*), which specified that the bolt be solution treated and aged per AMS2759/3.

Visual examination

The physical dimensions (length, diameter & thread characteristics) of the bolts were measured and were found to be consistent with the MS9490-34 standard.

Bolts S, T, U and W had all fractured at the head-to-shank fillet radius (Figure A6) while bolt N failed through the threaded section.

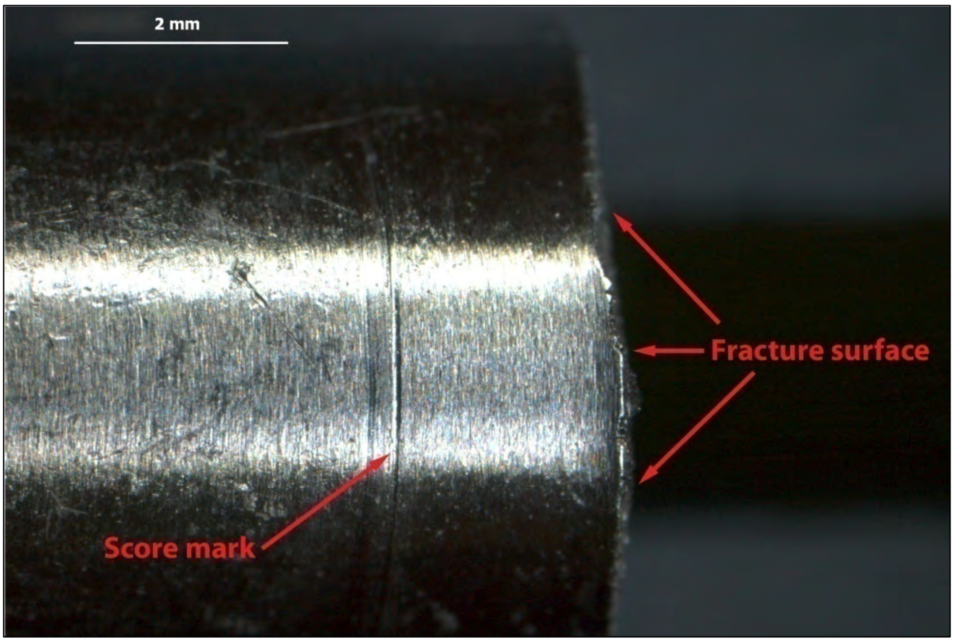
Figure A9: Carrier bolts following disassembly of the first stage reduction carrier. Note that Bolts S, T, U and W failed under the bolt head, Bolt N failed through the threaded section, while Bolt R remained intact

The fracture faces of Bolts S, T, U and W also exhibited similar features. In all cases, the surface was smooth, flat, and perpendicular to the principal axis of the bolt. Evidence of cyclic fatigue crack growth in the form of beach marks was observed. Beach marks (indicative of reverse bending fatigue cracking) extended radially from opposite sides of the bolt towards the centre, and extended across a significant proportion (>⅔) of the fracture surface area (Figure A7). A small region across the centre of the bolt exhibit features consistent with an overstress failure mode.

Figure A10: Fracture face of Bolt S showing evidence of reverse bending fatigue

A circumferential score mark, located approximately 2mm from the fracture surface, was identified on all six carrier bolts (Figure A8). The score mark was coincident with a location between the carrier plate and the tabbed key washer (refer Figure A1).

Figure A11: Shank of a fractured bolt showing the typical score mark 2mm from the under-head fracture



The fracture face of Bolt N exhibited different features to the other four fractured bolts. While the surface was smooth, flat and oriented perpendicular to the length of the bolt, no evidence of fatigue failure was observed. The fracture face was coincident with a thread root and appeared to be consistent with a bending overstress failure.

Figure A12: Fracture face of Bolt N

Non-destructive examination – penetrant inspection

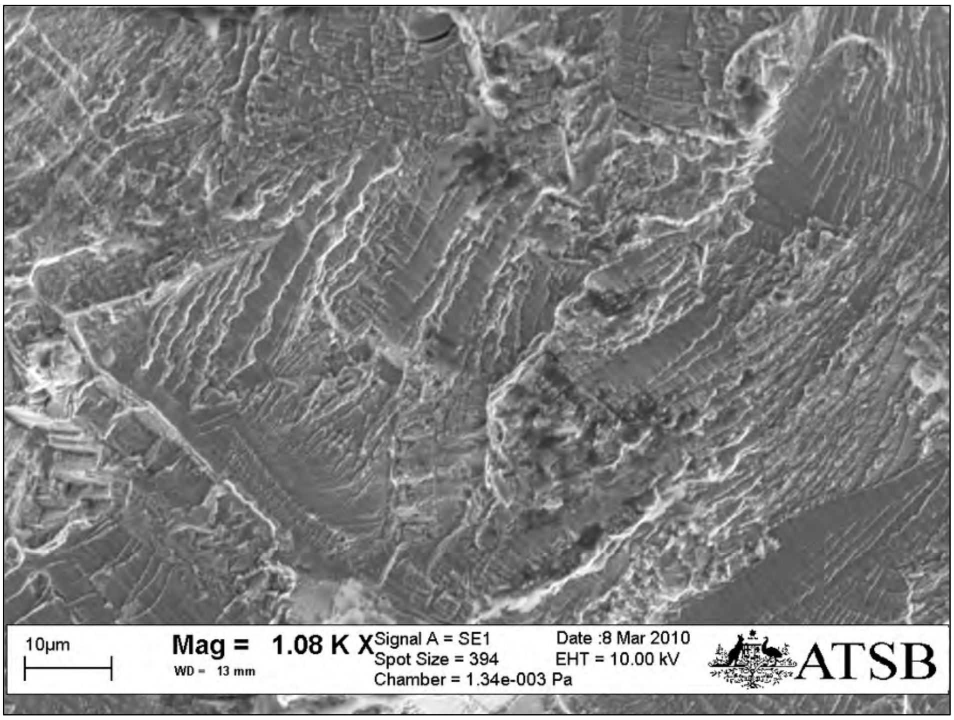
Bolt R (intact) and Bolt N were examined using a fluorescent dye-penetrant inspection technique. No defect/crack indications were observed along the length of the bolt, under the bolt head, or in the thread roots.

Scanning electron microscopy

The fracture face removed from Bolt S, and the bolt head removed from the intact Bolt R, were examined using a scanning election microscope (SEM).

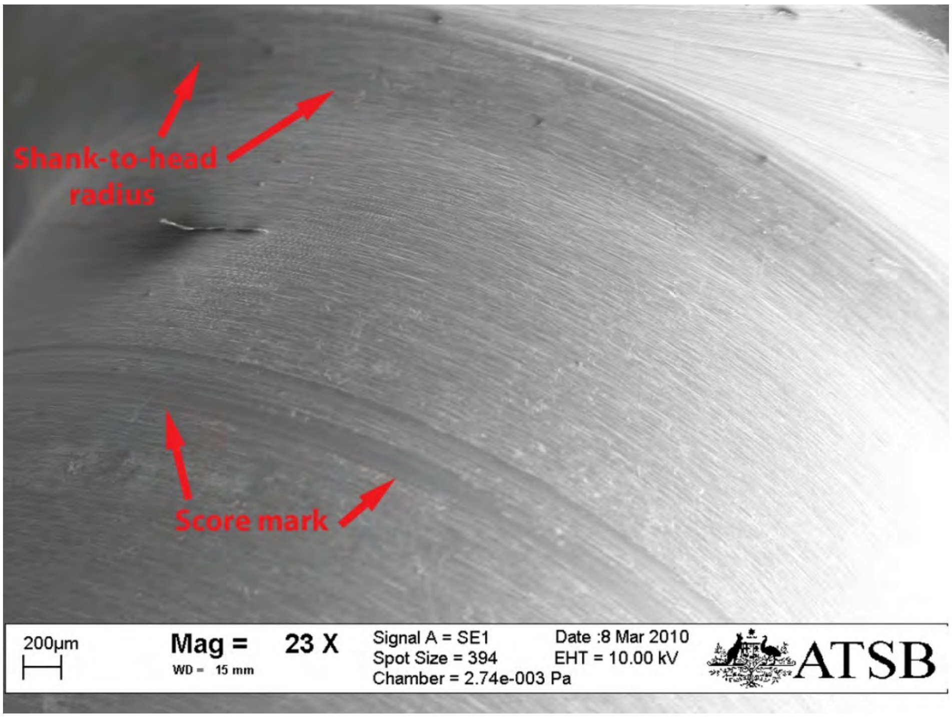
The fracture face (Bolt S) exhibited finely spaced striations at the outer edges, indicative of a low-stress, high-cycle fatigue cracking mechanism (Figure A10). No anomalies that may have contributed to crack initiation were detected at the likely origin points. A faceted fracture surface was observed towards the centre of the bolt, consistent with an overstress failure.

Figure A13: Scanning electron microscope image of the fracture face of Bolt S showing the fatigue striations



The region under the head of Bolt R (Figure A11) was examined for any anomalies that may have led to initiation of a crack at this location. The shank-to-head radius appeared to be relatively smooth, with a continuous change in section. The visually-observed score mark also appeared to be a wide, shallow groove, which was of a consistent depth and thickness around the entire circumference. Evidence of machining was observed on the bearing surface with a small step between it and the head-to-shank fillet radius.

Figure A14: Low magnification scanning electron microscope image showing the shank-to-head radius of Bolt R. Note the smooth appearance of the radius, and the machining marks observed on the radius and the under-head bearing surface

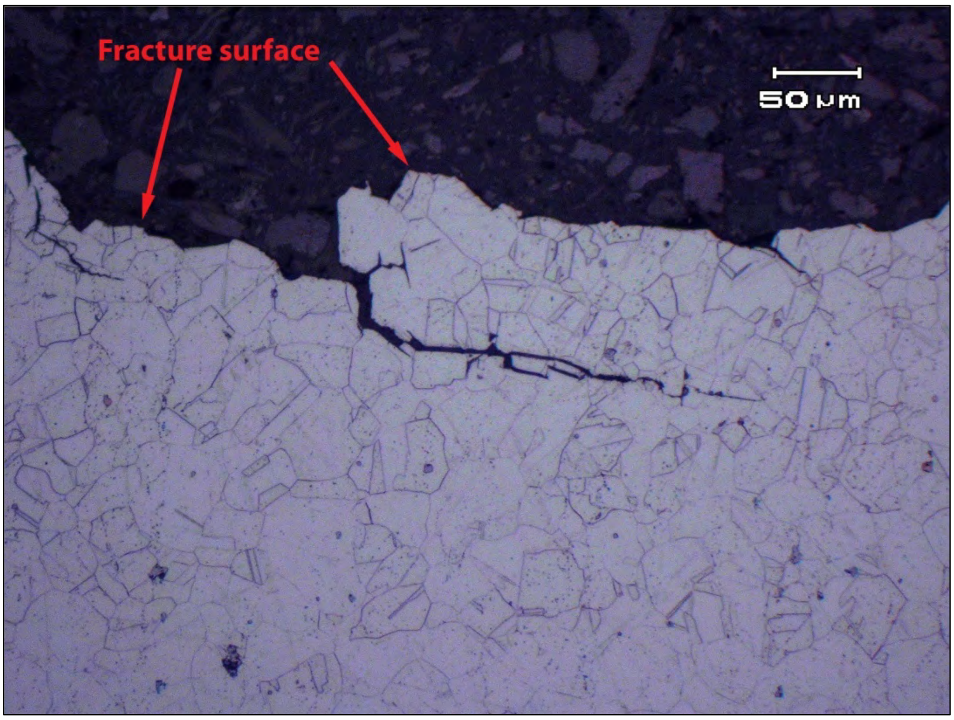


Microstructural examination

Sections were removed from the fracture face of Bolt S and the head-to-shank fillet radius of Bolt R for microstructural examination. The samples were mounted, polished and etched using Marble's reagent to reveal the structure.

Both bolt samples exhibited an austenitic grain structure with an intragranular dispersal of a fine precipitate - consistent with the specified material type and condition.

Figure A15: Bolt S fracture surface



The fracture path morphology was essentially transgranular in nature, but areas of intergranular crack propagation were also observed. A number of secondary cracks extending from the primary fracture face were observed. The secondary cracks were straight and had propagated in a transgranular manner (Figure A12).

An examination of the threads of Bolt S revealed them to have been rolled rather than cut (Figure A13) - consistent with the process specified in SAE AS7477. The head-to-shank fillet radius showed an equiaxed grain microstructure, which indicated that the bolt had not undergone any form of post machining cold rolling or other localised compressive process such as shot-peening (Figure A14).

No evidence of any detrimental phases or other microstructural anomalies were identified in the sections examined.

Figure A16: Bolt S threads showing manufacture by rolling. The thread profile looked smooth with no flaws observed in the sections examined

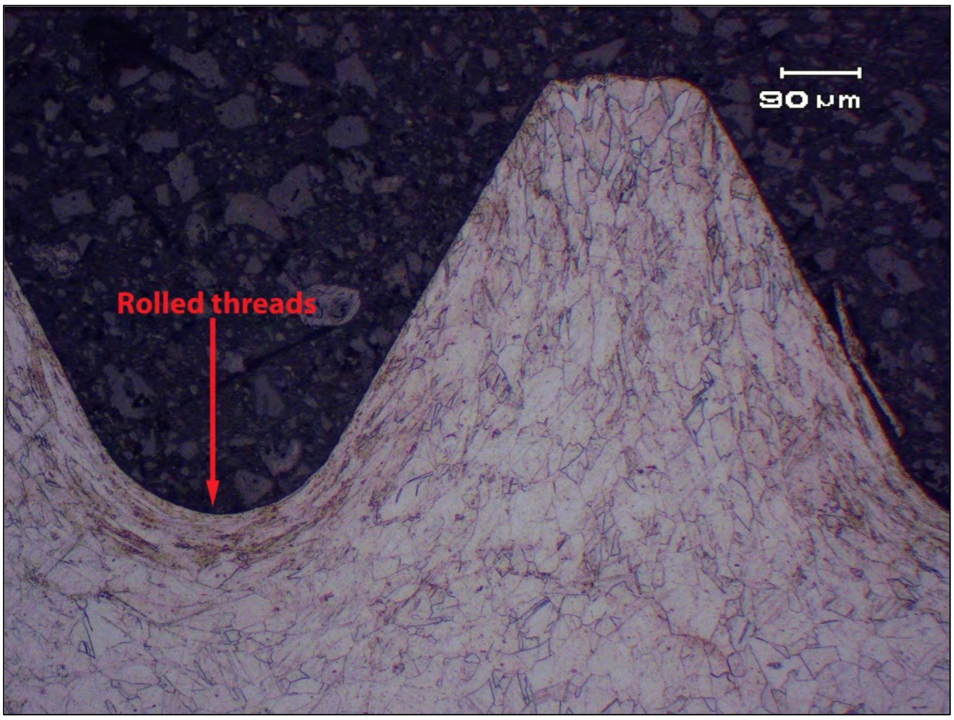
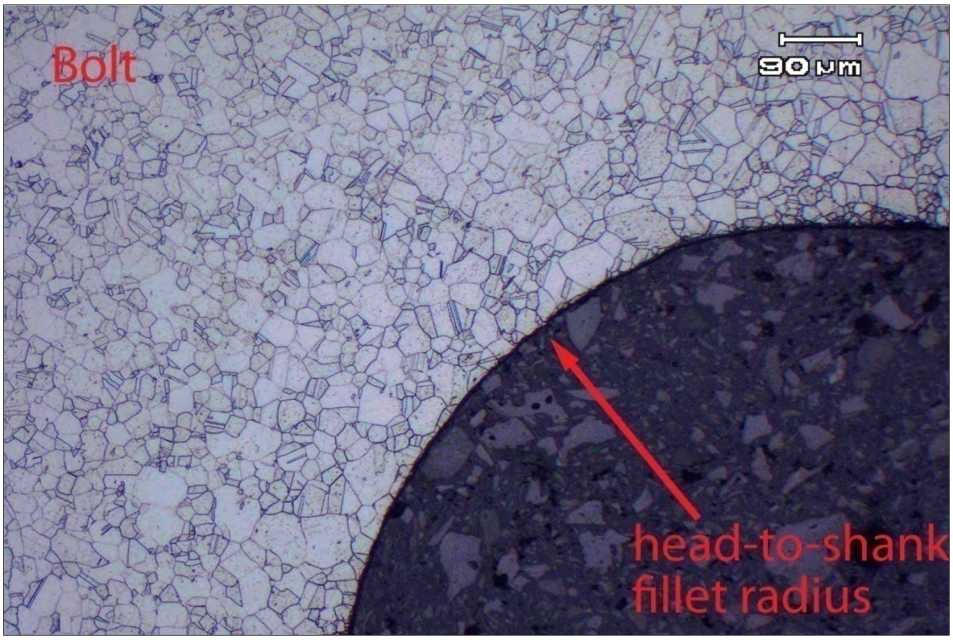


Figure A17: Bolt R head-to-shank fillet radius showed no evidence of cold rolling



Material properties

Chemical analysis

A section of Bolt S was removed and submitted for chemical analysis (Table A1). The chemistry of Bolt S was within AMS5731 specification limits.

Table A1: Chemical analysis results

Fe	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	V	Nb	Ti	Al
Sample: Bolt S													
55.2	0.05	1.73	0.17	0.01	0.02	24.0	14.8	1.24	0.33	0.27	0.06	1.94	0.18
AMS5731 Specification Limits													
Rem*	0.08 max	2.00 max	1.00 max	0.025 max	0.025 max	24.0-27.0	13.5-16.0	1.0-1.5	0.50 max	0.10-0.50	-	1.90-2.35	0.35 max

* Rem = Remainder

Hardness testing

Sections removed from Bolt S and Bolt R were hardness tested using the Vickers method with a 5kg indenter load (HV5), with the average converted to the Rockwell C (HRC) using *ATSM, E140-02*[15],. The hardness values of the two bolts examined were consistent with the limits specified in AS7477.

Table A2: Hardness test results

Sample	Hardness values (HV5)	Average hardness (HV5)	Average hardness (HRC)
Bolt S	299 293 293	295	29
Bolt R	321 313 313	316	30
AS7477 Section 3.6.2 (requirement)			24 – 31

15 *ATSM, E140-02 Standard Hardness Conversion Tables for metals, Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*

Examination of splined adapter

Visual examination

The splined adapter was fastened to the carrier plate by the six carrier bolts. The adapter was triangular in shape, with a central circular internal gear. The engine manufacturer indicated that the splined adapter was manufactured from SAE AMS 6265, a 1.2% Cr, 3.25% Ni, 0.12% Mo case-hardening steel.

The splined adapter was sectioned through the internally threaded sections for characterisation of the thread form and condition (Figure A15). A section was removed through bolt holes S and T (both fractured under the bolt head), and another through bolt holes R (intact) and N (failure through threads). The thread form exhibited a squared-crest profile and a flattened root contour; consistent with an internal UNJF thread-form (Figure A16).

Figure A18: Corner of splined adapter with the location of the section removed shown in red

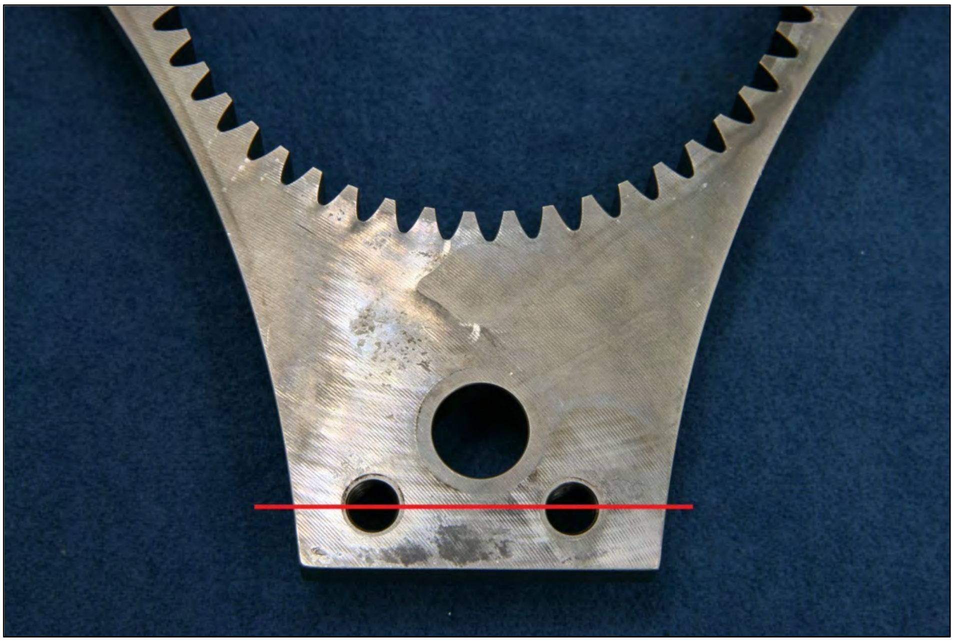
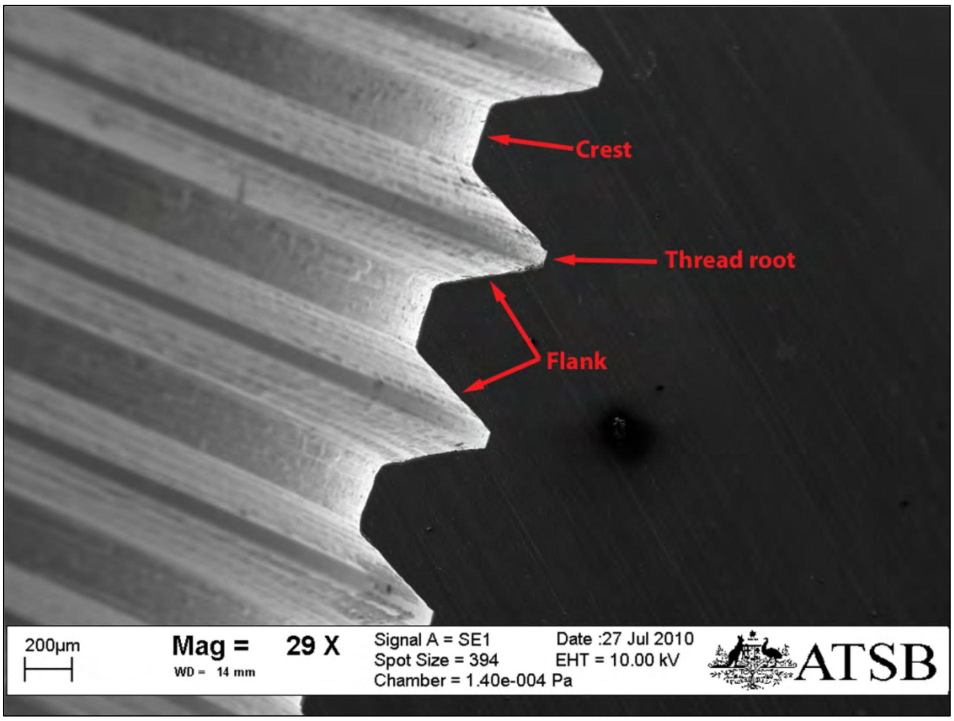
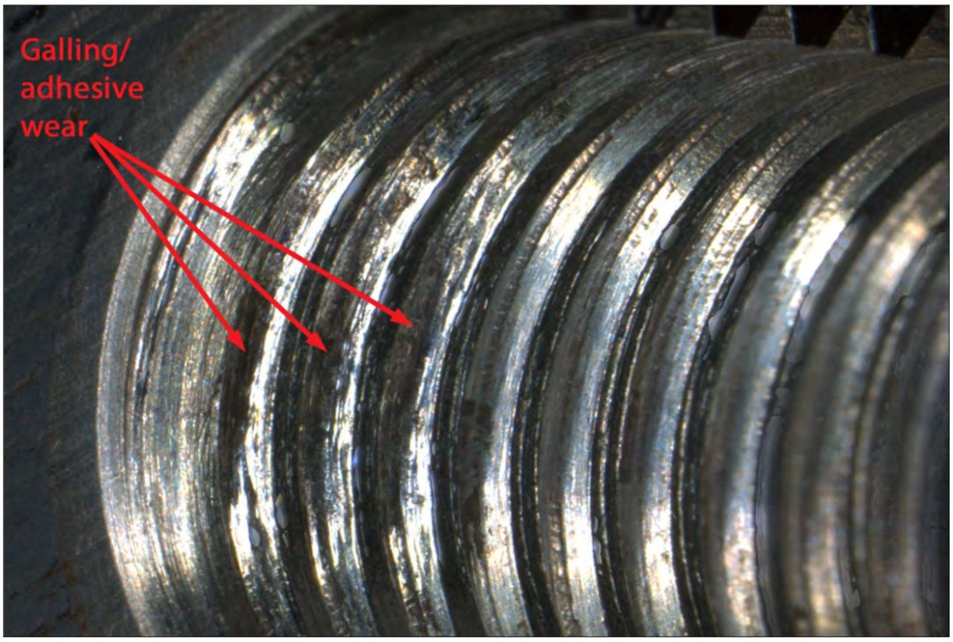


Figure A19: Scanning electron microscope image, showing the squared-crest profile of the internal threads of the splined adapter



An examination of the thread crests and flanks revealed evidence of minor plastic deformation of the surface (Figure A17 and A18); likely to be consistent with the general surface features associated with the thread forming process. Some evidence of galling/adhesive wear was observed on the thread flanks towards the surface in contact with the bolt head.

Figure A20: Bolt hole T showing the galling/adhesive wear observed on the thread flanks



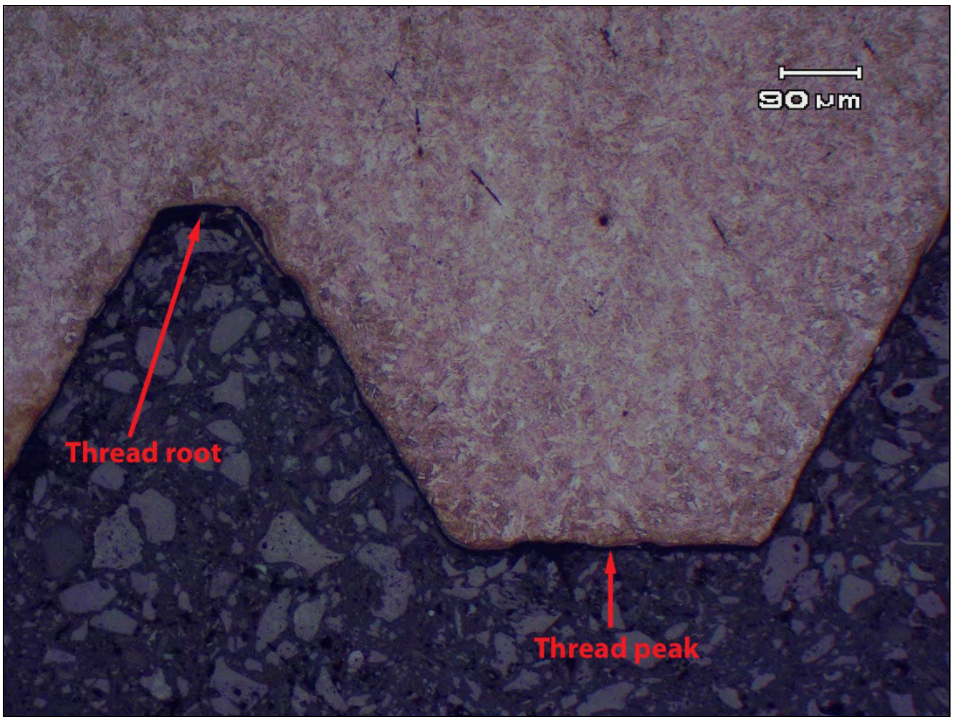
Material properties

Microstructural examination

The bulk microstructure of the splined adapter consisted of tempered transformation products such as martensite.

The surface irregularities observed previously on the thread crests and flanks was also evident on the adapter cross section (Figure A18).

Figure A21: Photomicrograph showing the thread profile, including square profile and flattened root contour. Also note the irregularity of the surface, particularly on the thread flanks



Hardness testing

Hardness testing was performed at various locations across the mounted sample and was found to be within the limits set by the manufacture of 35-41 HRC (Table A3).

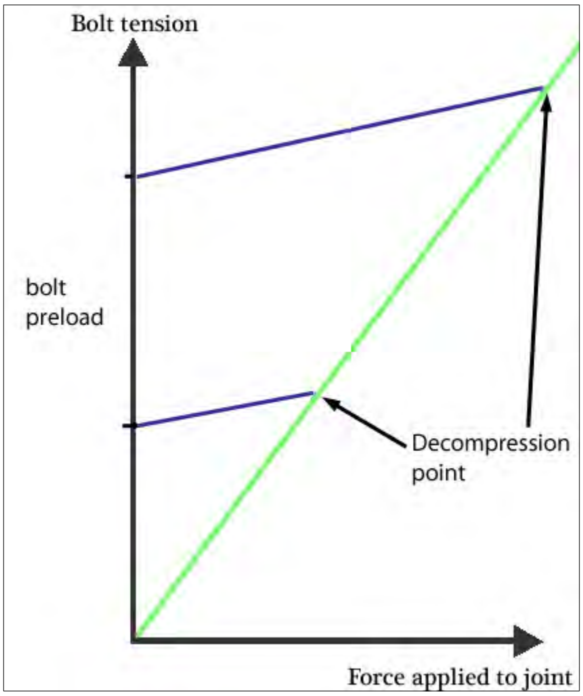
Table A3: Hardness test results

Sample	Hardness values (HV10)	Average hardness (HV10)
Splined adapter	387 383 383 383 383	384
Manufacturer specification: AMS 6265, alloy steel		35-41 HRC (345-402 HV)

Torque and tension in fasteners[16]

Bolts are usually tightened by applying rotational torque to the head or nut, with the spiral thread form causing the bolt to stretch. This stretching results in bolt tension or preload, which is the clamping force that holds a joint together. High preload tension helps keep bolts tight, increases joint strength, creates friction between parts to resist shear and improves the fatigue resistance of bolted connections (Figure A19). Further, the joint will not be vulnerable to fatigue cracking until the cyclic operational stresses increase above the original applied preload, i.e., above the decompression point in Figure A19. That is, the higher the bolt preload, the more force can be applied to the joint before the decompression point is reached.

Figure A19: Graphical representation of affect of pre-load on strength of bolted joint



Torque is relatively easy to measure with a torque wrench, so it is the most frequently used indicator of bolt tension. Unfortunately, a torque wrench does not always represent bolt tension accurately, mainly because it does not take friction into account. Joint friction is affected by a number variables including (but not limited to) bolt, nut and washer materials, surface smoothness, machining accuracy, degree of lubrication and the number of times that a bolt has been installed. The use of specific lubrication and multiple torque procedures have been used to reduce the scatter associated with the friction of the bolted joint by conformal wear of the mating thread surfaces.

Joints with insufficient bolt torque (and thus tension) can result in a loss of compression during service. This may result in loosening of fasteners under conditions of cyclic loading and reduction of fastener fatigue life. A common location for bolt failure in this situation is directly under the bolt head.

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16 Information contained in this section came predominantly from the training papers/references found at www.boltscience.com

In most applications, a tolerance will be stated for any given torque value; the lower value would be the minimum required to provide sufficient clamping force, while the upper value is typically a limiting value, beyond which, permanent plastic deformation (yielding) of the bolt may result.

Torque relaxation

Local surface compressive yielding due to higher than average bearing stress on the mating faces of nuts and bolts (caused by high local spots, rough surface finish and the lack of perfect squareness of bolt and nut bearing surfaces), may result in preload relaxation after preloads are first applied to a bolt. Bolt tension also may be unevenly distributed over the threads in a joint; hence thread deformation may occur, causing the load to be redistributed more evenly over the threaded length. Preload relaxation under these conditions can occur over a period of minutes to hours (or longer) after the application of the preload.

Carrier bolt failure

Seizure of the propeller reduction gearbox was attributed to failure of the first stage reduction carrier bolts. Bolts S, T, U and W failed under the bolt head due to low-stress, high-cycle, reverse-bending fatigue, as a result of service stresses that led to flexure of the carrier assembly during changes of power. Bolt N failed due to bending overstress, most likely as a result of the other four bolt failures.

The material properties of Bolt S and the splined adapter were consistent with their designation as per the relevant standards. However, the bolts did not exhibit grain deformation consistent with a cold rolling process at the head-to-shank fillet radius. Cold rolling would have induced a compressive residual stress into this area, reduced the potential for stress raisers induced through the previous manufacturing steps and increased the strength through work hardening of the surface. The lack of cold rolling of the head-to-shank fillet radius reduced the local fatigue endurance properties of the bolt, and thus increased the propensity for failure at this location.

No evidence of impact damage was observed at any location on any of the bolts examined or the splined adapter.

Evidence of movement between the carrier plate and splined adapter was observed, which indicated that the assembly did not have sufficient clamping force to maintain the integrity of the assembly.

FINDINGS

The following statements are a summary of the findings made during examination of the reduction gearbox components from PT6A-67B engine (S/N PR0092) from VH-NWO.

- The seizure of the first stage reduction assembly was the result of failure of the carrier bolts. Four of the six bolts had failed by high-cycle, low-stress, fatigue cracking at the head-to-shank fillet radius.
- The carrier bolts did not have the specified cold rolling-at the head-to-shank fillet radius, leading to increased propensity for failure at this location.
- During the course of the investigation, a review of the assembly procedures for the reduction gear box led to the following procedures being implemented by the engine manufacturer:
    1. Using new bolts at overhaul
    2. Specific lubrication requirements
    3. Introduction of a triple-torquing procedure – to reduce the scatter in the friction of the bolted joint and eliminate the low-range preload values.
    4. Increase in the torque value from 65-85 lb.in to 85-105 lb.in

APPENDIX B: AAC-1-116 APPROVED SINGLE-ENGINE TURBINE POWERED AEROPLANE

Part 1 - Airworthiness Articles

AAC 1-116 Approved Single Engine Turbine Powered Aeroplane (ASETPA) 8/2000

Introduction:

Civil Aviation Regulations (CAR) 174B and 175A permit passengers to be carried for hire or reward in a single turbine engine aeroplane under IFR and at night under VFR subject to CASA approving the operator in writing and approving the aeroplane type in writing. The carriage of passengers for hire or reward operations under CARs 174B and 175A is termed; an Approved Single Engine Turbine Powered Aeroplane (ASETPA) operation.

The CASA requirements for an ASETPA operation, including approval of an aeroplane type, flow from CASA Aviation Regulatory Proposal (ARP) 1/95 and subsequent CASA decisions published in a Disposition of Comments and Decisions paper dated December 1996. Those requirements are based on a similar philosophy to that required for extended range operations for twin engine aeroplane (EROPS). That is; for ASETPA operations:

1: The aeroplane shall meet a certain design standard, and

2: the engine shall meet a documented level of reliability, and

3: the aeroplane shall have an enhanced level of essential operating equipment redundancy, and

4: an enhanced level of engine condition monitoring, and

5: an enhanced level of crashworthiness, and

6: the aeroplane shall comply with Australian regulatory requirements detailing operational equipment requirements for commercial passenger carrying IFR operations, and

7: the operator shall have an enhanced level of pilot qualifications, operation control and maintenance control.

ASETPA aeroplane type approval application:

The issue of an ASETPA aeroplane type approval will be subject to the aeroplane manufacturer, or its representative, submitting an application to the Head of Certification Standards, Standards Division, Canberra. The application will be assessed in consideration of the following requirements:

The aeroplane: Aeroplanes eligible are aeroplanes originally certificated as turbine powered aeroplanes under an equivalent to FAR 23 amendment 28 or a subsequent amendment. That is; turbine conversions of originally piston powered aeroplanes are not eligible.

The engine: The engine type shall have documented evidence of an acceptable world fleet reliability rate. An engine type reliability rate acceptable for ASETPA operations shall be; a 6 month rolling average, in-flight shut down (IFSD) rate of not greater than 0.01 per 1,000 hours based on a minimum experience history of 100,000 hours time in service. Where the accumulated history is less than the requirement, account may be made of the history of individual components which have demonstrated time in service in similar engine types.

The engine reliability rate of an approved aeroplane type will be monitored by the CASA Certification Standards Branch, Standards Division, Canberra. A deterioration of the engine IFSD rate to 0.0125 per 1,000 hours would be cause for a review of the aeroplane's type approval.

Aeroplane Equipment: The following essential aeroplane equipment shall be incorporated:

Ignition System The aeroplane type shall be equipped with an engine ignition system which shall be either an:

1: An automatic ignition system which activates in the event of a loss of an engine parameter such as engine speed, turbine temperature or engine torque, or

2: An ignition system which can be selected 'ON" and has a duty cycle greater than one hour.

Redundant Engine Control In addition to the engine power lever, the aeroplane type shall be equipped with a manual throttle system that bypasses the governing section of the engine fuel control unit.

Chip Detector The aeroplane shall be equipped with an electronic magnetic particle detection system which provides the pilot with an in-flight, visual, caution/warning indication of possible contamination of the engine, including, as applicable, the reduction gearbox and accessory gearbox, oil system(s).

Engine Fire Warning System The aeroplane shall be equipped with an engine compartment fire detection and in-flight warning system acceptable to CASA.

Engine Monitoring The aeroplane shall be equipped with an automatically activated electronic engine trend monitoring recording (ECTM) system. The system shall record engine parameters referenced in the engine manufacturer's published engine trend monitoring procedures.

Electrical Power Sources In addition to the aeroplane's primary electrical generator and the primary electrical storage battery(s), the aeroplane type shall be equipped with an alternative source of electrical power. The alternative source shall be capable of supplying power to all essential flight instruments, navigation systems and aeroplane systems required for the endurance of the aeroplane for flight under IFR at night.

Battery Storage Capacity The electrical storage capacity of the aeroplane's prime battery(s) must be sufficient to maintain operation of essential flight and navigation instruments and associated icing protection systems. The required period shall be; following an engine failure in flight, the period required to glide to sea level from the maximum operating altitude, or an elected limiting altitude, at the aeroplane's best range gliding speed.

Additionally, the battery(s) shall then have sufficient capacity remaining to conduct two engine start attempts and to lower the flaps and undercarriage.

The requirement for two engine starts may be reduced to one engine start, provided:

1: The aeroplane's fuel system has no cockpit controls affecting fuel distribution up to the firewall shut-off, and

2: the engine compressor air intake incorporates continuous anti-icing whilst the engine is operating, and

3: the aeroplane incorporates an automatic engine ignition system which activates in the event of a loss of an engine parameter such as engine speed, turbine temperature or engine torque.

Electrical Load Shedding The electrical load shedding system or procedure requirements for an engine failure in flight, maximum range glide descent, shall be detailed in the Airplane Flight Manual or approved equivalent.

Engine inoperative descent in icing conditions For aircraft approved for flight in icing conditions, the procedures for an engine failure in flight, maximum range glide descent through icing conditions, shall be detailed in the Airplane Flight Manual or approved equivalent.

Secondary Flight Instruments Aeroplanes incorporating an electronic display flight instrument system for the pilot which, during an engine inoperative glide, may be affected by a high electrical load situation, shall incorporate secondary non-EFIS attitude and gyroscopic heading instruments located on the pilot's flight instrument panel.

Flight Instruments and Power Sources The aeroplane type must be equipped with flight and navigation instruments and instrument power sources complying with Australian regulatory requirements for commercial passenger carrying IFR operations.

Global Navigation System The aeroplane type must be equipped with an IFR approved Global Positioning System (GPS) .

Auto Pilot For single pilot operations, the aeroplane type must be equipped with an automatic pilot complying with Australian regulatory requirements for commercial passenger carrying IFR operations.

Radar/Radio Altimeter The aeroplane must be equipped with a radar/radio altimeter acceptable to CASA.

Supplementary Oxygen Requirements for Pressurised Aeroplanes All occupants shall be provided with sufficient supplemental oxygen to permit, following an engine failure, a descent to 14,000 feet AMSL from the maximum operating altitude, or an elected limiting altitude, at the aeroplane's best range gliding speed.

Weather Radar The aeroplane type shall be equipped with a weather radar system acceptable to CASA.

Passenger Seating The aeroplane type shall be equipped with passenger seats, identified by part number and /or model number, meeting the requirements of:

Amendment 36 of FAR 23, parts 23.562 and 23.785, or

the General Aviation Safety Panel (GASP) proposal for passenger seats.

Shoulder harnesses Each passenger seat must be equipped with a shoulder harness acceptable to CASA.

Approval:

CASA will consider applications and on approval, provide the applicant with an ASETPA Aeroplane Type Approval Certificate. The certificate will include reference to a schedule of equipment and any conditions required for the issue of that certificate.

Pursuant to CAR 174B and 175A, aeroplane types and models currently approved by CASA for ASETPA operations are:

- Cessna Model 208 and 208B Caravan 1.
- Pilatus PC-12 and PC-12/45.

Further information:

For further information on detailed aeroplane equipment requirements for aeroplane approved for ASETPA operations, contact the office of:

Head of Certification Standards
Standards Division
Canberra
Phone number 131757 (Australia only)
61 2 6217 1551 (International)
Facsimile number 61 2 6217 1914

APPENDIX C: SOURCES AND SUBMISSIONS

Sources of Information

The sources of information during the investigation included:

- the pilot of the aircraft
- the aircraft operator
- the engine manufacturer
- the Bureau of Meteorology
- Transport Canada.

Submissions

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

A draft of this report was provided to the pilot and aircraft operator, the aircraft manufacturer, the Transportation Safety Board of Canada, the engine manufacturer, the Society of Automotive Engineers International, the bolt manufacturer and the Civil Aviation Safety Authority (CASA).

Submissions were received from the pilot of the aircraft and CASA. The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Total power loss - 11 km NE of Derby Airport, WA, 29 January 2010
VH-NWO, Pilatus PC-12/45