



Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Report – 200604514

Final

**Engine failure
5 km W Archerfield Aerodrome, Qld
8 August 2006
VH-WNR
Cessna Aircraft Company 182P**



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Figure 1 courtesy of Google Earth.

Abstract

On 8 August 2006 at 1115 EST, a Cessna Aircraft Company model 182P aircraft, registered VH-WNR, departed Archerfield Aerodrome, Qld, on a private flight to Goondiwindi, Qld. The pilot was the only person on board. At 1121, the pilot transmitted a distress message to air traffic control that he was attempting an emergency landing and that the aircraft engine had failed. At that time, the aircraft was approximately 5 km west of Archerfield Aerodrome at about 1,000 ft above ground level. The aircraft subsequently collided with powerlines before impacting the roof of a house. It traversed the roof and came to rest inverted a short distance from the rear of the house. A fire began when leaking fuel ignited. The pilot received serious burns to his upper body. The aircraft was destroyed by impact forces and fire. The house sustained major structural damage to its roof and two of the three occupants received minor injuries.

Subsequent engine disassembly and examination revealed catastrophic damage to the engine related to the failure of the number-5 cylinder connecting rod assembly. Reduced connecting rod pre-load, due either to insufficient assembly torque, or excessive torque producing permanent bolt stretch, was considered the most likely reason for the failure of the connecting rod assembly. However, because of the consequential damage caused by continued engine operation, there was inadequate evidence to directly support either failure mode.

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.

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

FACTUAL INFORMATION

History of flight

On 8 August 2006 at 1115 EST¹, a Cessna Aircraft Corporation model 182P aircraft, registered VH-WNR, departed Archerfield Aerodrome, Qld, on a private flight to Goondiwindi, Qld. The pilot was the only person on board. A few minutes after takeoff, an internal mechanical failure caused a substantial loss of engine power. During the subsequent forced landing, the aircraft struck the roof of a house (Figure 1) before coming to rest inverted in the yard at the rear of that dwelling. The aircraft caught fire and the pilot received serious burns as he escaped from the wreckage.

Figure 1: Google Earth image showing intended landing area (shaded) and house location



The pilot reported that the engine had operated normally during the takeoff and departure from Archerfield. After takeoff, he adjusted the engine power to 25 inches manifold pressure and 2,500 RPM. At 1,000 ft, he reduced power to 23 inches and 2,400 RPM and transferred to the Amberley Approach frequency for onwards clearance. The pilot said that he then heard what he described as ‘clunk

¹ The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC)+ 10 hours.

clunk' from the engine and immediately detected the smell of hot oil. He recalled that the engine continued to operate. However, it was apparent from the reducing performance from the aircraft that the engine had sustained a significant power loss.

At that time (1121), the aircraft was approximately 5 km west of Archerfield Aerodrome at 1,000 ft altitude. The pilot transmitted a distress message to air traffic control that he was attempting an emergency landing and that the aircraft engine had failed. He reduced the engine throttle setting and attempted to position the aircraft for a landing in the only area he could see that appeared suitable for an emergency landing (Figure 1).

The pilot intended to land towards the south east. As the aircraft descended, the pilot assessed that the aircraft was too high to land in the selected area. He selected the first stage of flap (5 degrees) and then full flap (40 degrees). However, as the aircraft got closer to the ground, the pilot realised that the aircraft was too low to reach the clear area and he attempted to align the aircraft to land on a road. He recalled seeing a flat-roofed house and believed the aircraft would clear the house. A short time later, he saw power lines ahead and moved the throttle control forward, but there was no response from the engine. He recalled hearing the stall warning sounding intermittently before the aircraft struck the power lines.

The pilot's next recollection was that the aircraft was inverted on the ground and he was suspended in the safety harness. He remembered, as he undid his safety harness, being asked by someone if he was ok. He told the other person that his [right] foot was jammed and was then aware that a fire approximately 1 m in diameter had started under the right wing. He recalled hearing a voice call something like 'it's going to blow, everybody get back'. He was aware that the size and intensity of the fire, was increasing. The pilot said that he was then able to free himself and escape from the wreckage before jumping over a fence to get well clear of the fire and the aircraft.

Ground witnesses reported hearing a normal aircraft piston engine noise as the aircraft approached overhead before their attention was drawn skywards by a loud 'thump'. They saw a thick stream of white smoke emanating from the right side of the engine² (Figure 2). They reported that the engine sounded as though it was 'knocking very badly' but continued to operate at reduced RPM. They observed the aircraft turn left and begin to descend. It completed two left orbits before straightening towards a clear area and disappearing from view.

² The engine exhaust pipe outlet was positioned on the lower right side of the aircraft nose section.

Figure 2: Amateur video snapshot showing aircraft streaming white smoke



The aircraft struck powerlines before impacting the roof of a house (Figure 3). The point of contact with the power lines was approximately 20 m left of the road at the front of the house. After traversing the roof, the aircraft came to rest inverted a short distance from the rear of the house (Figure 4) and caught fire when fuel from the ruptured right wing tank ignited. The pilot received serious burns to his upper body as he escaped from the wreckage. The aircraft was destroyed by impact forces and fire. The house sustained substantial impact damage and some heat damage. Two of the three occupants of the house received minor injuries.

Figure 3: Damage to roof of house (arrow depicts aircraft path)



Figure 4: Aircraft wreckage



The intended landing area

The landing area chosen by the pilot measured approximately 270 m north-south and 350 m east-west. It consisted of two playing fields, the western-most of which was at a lower elevation than the other. That difference, plus some vegetation along the line between the two areas suggested that a landing to the north or south was a more suitable option than to the east or west. The northern boundary of the clear area included power lines, trees, and houses to a maximum height of approximately 15 m.

Landing performance

According to the pilot's operating handbook for the aircraft, the ground roll involved in landing on a dry grass surface with a headwind of 10 kts³ and 40 degrees flaps was about 220 m. The distance to land over a 15 m obstacle in the same conditions was about 400 m.

Recorded radar and audio information

Examination of recorded radar and audio information revealed that the aircraft was at 1,200 ft above mean sea level (AMSL)⁴ and about 5 km west of Archerfield when the pilot transmitted the distress message. The last recorded transmission occurred 1 minute 12 seconds later. Engine noise was audible in the background of the recorded audio. It was apparent that the engine was running roughly. The stall

³ The surface wind at Archerfield Aerodrome at 1100 was 180 degrees at 12 kts.

⁴ Ground elevation in the area was 100 to 200 ft.

warning horn, followed by the sound of impact, was audible at the end of the transmission.

Pilot information

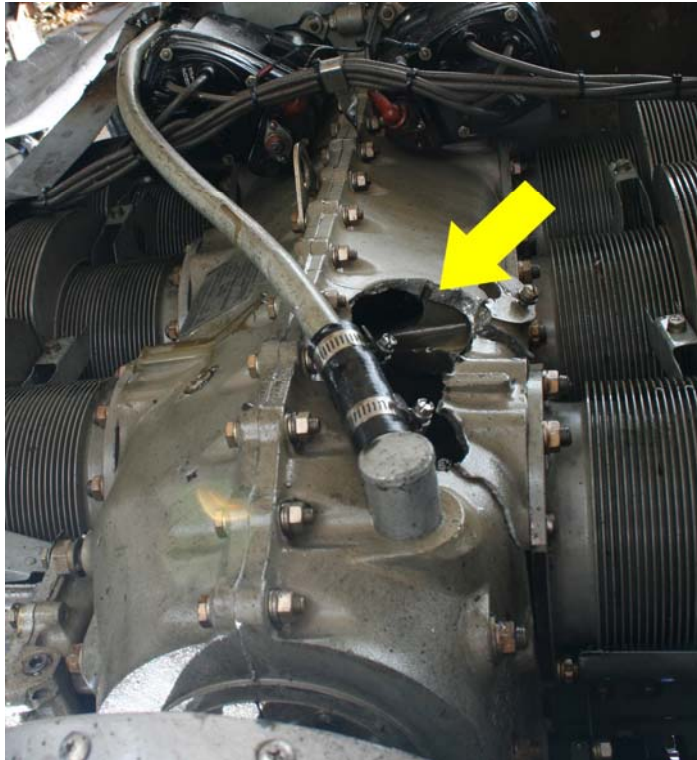
At the time of the accident, the pilot had accrued a total of 55 hours flying experience in Cessna 182 aircraft, including 7 hours as pilot in command on that type. He was issued an unrestricted pilot's licence on 23 August 2006. According to his training records, the pilot had received instruction in aircraft emergency situations, including simulated engine failures and forced landings. The pilot had previously acquired some aeronautical experience flying ultra light aircraft, including greater than 5 hours as pilot in command⁵.

Wreckage examination

The condition of the propeller blades indicated that they were rotating at low RPM at impact. There was evidence of oil residue on the engine firewall. The engine had sustained minor impact damage. However, there was a large hole in the engine crankcase adjacent to the base of the number five cylinder that did not appear to be the result of the impact (Figure 5). The accessory drive-train remained intact. No other fault was found with the aircraft systems that might have contributed to the occurrence. The wing flaps were found in the 10 degrees position. However, airframe disruption during the impact sequence meant that the flap setting at impact could not be confirmed.

⁵ Under Civil Aviation Regulation 2.1, a pilot's ultra light flying experience can be credited towards the 10 hours minimum command time required for a private pilot's licence.

Figure 5: Engine as removed from wreckage showing hole in crankcase



Engine examination

The Teledyne Continental Motors model O-470-S1B, serial number 269406R engine was progressively disassembled and examined under Australian Transport Safety Bureau (ASTB) supervision. Further detailed metallurgical examination of the failed components was then undertaken. The complete report on that examination is included at Attachment A to this report (ATSB Technical Analysis Report BE200600020). The report is summarised below.

A large section of the upper left-side crankcase had been punctured and broken away during the failure event, exposing the crankshaft and reciprocating assembly for the number-5 and 6 cylinders. Also, the number-5 connecting rod had completely separated from its respective crankshaft journal. Multiple pieces of the number-5 connecting rod were recovered from within the crankcase and sump pan, along with many piston and crankcase wall fragments.

Metallurgical examination of the recovered number-5 connecting rod segments revealed that all fractures were the result of overload. Figure 6 presents the fragments collectively and illustrates the level of mechanical damage sustained.

Figure 6: Number-5 cylinder connecting rod bolt and nut assembly



The outer surfaces of the fracture between the rod arm and one side of the journal boss showed some evidence of progressive, cyclic crack growth, with areas presenting features consistent with high-stress, low-cycle fatigue crack initiation and development. The remaining fractures in the connecting rod that were not obscured by damage, were consistent with ductile tensile or bending overload failures, with no pre-existing cracking or other latent defects.

Both bolts from the number-5 connecting rod assembly had fractured and separated from the rod boss. A single point, unidirectional bending overload failure through the central shank was evident on one bolt. The other bolt was recovered in three sections that had sustained significant impact damage. The nut from the bolt was found in four pieces (Figure 7) amongst the engine crankcase debris.

Figure 7: Fragments of nut from number-5 connecting rod bolt 'B'



The nut had fractured radially. Internally, the nut thread form was intact and had not stripped onto the threads of the bolt and there were no indication that the bolt

threads had stripped within the nut. The nut fragments showed some evidence of thread-form deformation consistent with shear forces transferred through the lower nut threads.

The pre-existing preload within the bolts from cylinders number-5 and 6 could not be established because of the extent of damage to the nut fragments.

The crankshaft journal bearings from the number-5 connecting rod were crushed and deformed, but showed no indication of damage that was not attributable to the mechanical breakdown of the connecting rod assembly.

Both number-5 and 6 pistons from the engine had broken up within their respective cylinders. The fragments showed no evidence of any pre-existing cracking, damage or defects.

The nature and extent of the engine damage would have rendered cylinders number-5 and 6 inoperative, significantly reducing the available power output of the engine and its response to throttle commands. The engine was likely to have continued operating during and following the failure event for a limited period because the accessory drive-train was maintained and cylinders 1 to 4 were not compromised.

Checks of the torque settings on the eight retention nuts on the four intact cylinder connecting rod assemblies⁶ (numbers 1, 2, 3 and 4) confirmed that they had been torqued to the engine manufacturer's recommended settings.

Connecting rod bolt tension/preload

Connecting rod bolt tension/preload was established by design, through the tightening torque applied to each fastener during assembly. Where a reduced bolt preload exists in a connecting rod assembly, it may either be a result of low initial torque or excessive thread friction, or be lost after assembly from:

- bolt stretch (under-strength bolts or over-torquing)
- embedment relaxation (compression of roughness or unevenness on the mating faces)
- surface fretting (elevated loads causing movement and mating-surface wear)
- film removal (interfacial material worn or squeezed out).

Reduced tension/ preload within the associated connecting rod bolt will reduce the rigidity and stiffness of the connection under the reciprocating action of the assembly. Reduced joint stiffness allows the exposure of the assembly to operationally-induced cyclic bending stresses that are conducive to the initiation of fatigue cracking.

⁶ The engine crankshaft assembly with the connecting rods attached had been removed from the engine with the four remaining connecting rods still torqued as assembled during overhaul.

Engine maintenance history

The engine time between overhaul was 1,500 hours. The engine had undergone a complete overhaul on 17 January 2006.

At the time of the overhaul, the engine had accumulated 1,790.9 hours time since new. The engine maintenance records indicated that the 12 connecting rod bolts (part number 655961) and 12 retaining nuts (part number 654490) were replaced, as required by the engine manufacturer, during the overhaul.

Examination of the worksheets associated with the overhaul did not reveal any abnormalities. The worksheets included signatures, which confirmed that an independent inspection⁷ had been completed on critical components, including connecting rod retention hardware torque values, during the reassembly of the engine. Interviews with maintenance personnel who completed this work did not indicate any interruptions of work had occurred during completion of the task and that all required work was completed.

On 28 February 2006, the engine was re-installed into the aircraft. On 9 June 2006, following extensive unrelated maintenance to the aircraft, a maintenance release for the aircraft was issued and a piston engine condition report was completed⁸. The maintenance release for the aircraft was destroyed in the accident. Based on the pilot's log book, the investigation estimated that approximately 35.7 hours were flown on the aircraft and engine since overhaul.

Service bulletins

On 11 June 1996, the engine manufacturer issued Service Bulletin SB96-7C which addressed torque limits on the fasteners (bolt and nut combinations) utilised on all of their engines. The bulletin included a warning which stated:

Proper torqueing practices cannot be overemphasized. Torque values are provided as a convenient method of achieving correct pre-loading of highly stressed fasteners. If the fasteners are not properly plated, the fastener threads are not clean and free of deformation or are not properly lubricated, the correct fastener pre-load will not be achieved even though the given torque values is reached. For this reason, it is critical that all fasteners be inspected for proper plating, thread form and correctly lubricated prior to torqueing. Failure to verify a fastener's serviceability or correctly lubricate the fastener prior to assembly and torqueing will result in the fastener not being properly pre-loaded and subsequent failure of the fastener may occur.

The bulletin also noted a requirement to use a clean 50 weight aviation engine oil applied to the threads of the fasteners when torqueing unless otherwise specified. It also included another warning advising that the use of sealants or lubricants other than those specified could result in incorrect torque application and subsequent engine damage or failure.

⁷ An independent technician certified that the torque applied to the nuts had been completed correctly.

⁸ Part of the requirements for a Piston Condition Report was running the engine and checking for serviceability.

Surveillance of the engine overhaul facility

The engine overhaul organisation operated at five locations in Australia. The main operating base was last audited by the Civil Aviation Safety Authority (CASA) in September 2005. Only minor discrepancies were noted during the audit, none of which were relevant to engine overhaul practices or standards.

Aircraft information

A maintenance release had been issued for the aircraft on 9 June 2006 at 4,926.3 hours total time in service (TTIS), and was valid until 9 June 2007 or 5,026.3 hours TTIS. It was calculated that at the time of the occurrence, the aircraft had accumulated approximately 4,962.0 hours TTIS. An entry on the maintenance release stated that the aircraft engine oil and filter was due for replacement at 4,976.3 hours TTIS and that 'break in' oil was in use in the engine.

ANALYSIS

Engine failure

The investigation attributed the engine malfunction to the mechanical disruption and subsequent destruction of the number-5 and 6 cylinder reciprocating components. The separation of the number-5 connecting rod and the fragmentation of the number-5 and 6 pistons rendered those cylinders inoperative, substantially reducing the available power output of the engine and its response to throttle commands. The engine continued operating following the failure event because the accessory drive-train was maintained and cylinders 1 to 4 were not compromised.

The identification of fatigue cracking within one side of the connecting rod boss signified the presence of abnormally high flexure and bending stresses within the upper boss walls. Due to the level of post-failure damage sustained by the connecting rod fragments, it was not possible to establish with any certainty the sequence of connecting rod failure. It was probable however, that reduced joint rigidity and the associated elevated stresses resulting from a reduced connecting rod bolt preload, led either to the fracture of the upper boss section from the area of fatigue cracking, or the destruction and separation of the connecting rod nut.

The possibility of an insufficient initial assembly torque, or an excessive torque producing permanent bolt stretch, remain as the most probable reasons for a reduced connecting rod bolt preload. However, there was no specific evidence to directly support either scenario. In any event, the separation of one side of the assembly would have produced the observed opening, breakup and separation of the boss from the crankshaft journal under very few subsequent engine revolutions.

In view of the absence of any identifiable deficiencies within the engine pistons and considering their production from a comparatively low-ductility alloy, it was concluded that the damage and fragmentation sustained by the number-5 and 6 pistons was the result of abnormal stresses and impacts sustained as a result of the connecting rod failure.

Pilot's actions

Although the engine continued to operate after the malfunction became evident, the limited power available meant that the pilot had no option but to attempt a landing in the immediate area. The area he chose appeared, from aerial images, to be the most suitable in the vicinity. However, its limited size meant that a high degree of experience and skill would have been required to achieve a successful outcome. From the description of events provided by the pilot, he experienced difficulties in judging the landing approach and did not assess that the aircraft was too low to reach the clear area until late in the approach. In that regard, a number of issues could have influenced his performance after the engine lost power. They included:

- the pilot's low level of flying experience limited the background knowledge against which he could assess the situation and make critical decisions
- the malfunction occurred over unfamiliar terrain, making distance and height assessment by the pilot difficult

- the altitude of the aircraft when the malfunction occurred (1,200 ft) provided the pilot with little time to evaluate options and make critical decisions
- the performance characteristics of the aircraft (altitude lost per distance flown) with the engine operating in its damaged state would likely have been different to those experienced by the pilot during forced landing training
- elevated stress levels associated with the reality of an actual engine malfunction at low altitude over a built-up area were likely to have been present
- possible fluctuations in the wind speed and direction.

The sound of the stall warning in the final transmissions from the pilot indicated that the aircraft's speed was close to the stalling speed at that time. It is possible that the aircraft lost airspeed when the pilot attempted to align it with a road after he assessed that the aircraft was too low to reach the clear area. The impact with the power lines may have slewed the aircraft's direction of travel towards the house.

FINDINGS

Contributing safety factors

- A low preload condition either developed, or was pre-existing, in one of the two bolts from the engine's number-5 connecting rod assembly.
- The low bolt preload reduced the rigidity and stiffness on one side of the connecting rod boss connection, allowing exposure of the assembly to reciprocating service loads and the development of fatigue cracking within the upper boss section.
- Growth of fatigue cracking and the cyclic loading of the fastener assembly probably contributed to the separation of the connecting rod boss from the crankshaft journal while the engine was operating in-flight.
- Flailing of the released connecting rod and multiple subsequent impacts with the still-rotating crankshaft produced the internal fragmentation, crankcase perforation and destruction of the number-5 and 6 pistons.
- The available engine power following the failure was insufficient to maintain level flight.
- There was no area suitable for a forced landing in the vicinity of the where the engine malfunction occurred.

Other safety factors

- The outcome of the forced landing was likely to have been influenced by the pilot's low experience level and the unfamiliar circumstances of the situation.

APPENDIX A: TECHNICAL ANALYSIS REPORT

**ATSB TECHNICAL ANALYSIS
BE200600020**

**Examination and Analysis of a Failed
Teledyne Continental Motors Model O-470
Aircraft Engine
Cessna Aircraft Company Model 182P
VH-WNR, 8 August 2006**

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

SUMMARY

Shortly after takeoff from Archerfield Aerodrome Qld, on 8 August 2006, the engine of a Cessna Aircraft Co model 182P, registered VH-WNR, sustained an internal mechanical failure that caused a significant power loss; requiring the pilot to conduct a forced landing into a suburban residential area. The aircraft was destroyed by impact forces and a post-impact fire.

Although limited by the extent of post-failure impact and mechanical damage sustained by the engine components, workshop and laboratory examination determined that the failure and separation of the number-5 connecting rod from the crankshaft journal, was the principal factor contributing to the engine breakdown event. Subsequent rod flailing and repeated impacts against the adjacent reciprocating components continued to produce damage after the rod separation.

Evidence of fatigue cracking on one side of the separated connecting rod boss, implied the existence of a low preload condition within the connecting rod bolt on that side. This had exposed the assembly to operational cyclic loads, brought about through the lack of sufficient clamping or 'hold-down' forces normally provided by the appropriately tightened connecting rod bolt. Insufficient evidence was available for the investigation to determine whether the preload had been lost from the correctly tightened connecting rod bolt during the period of service between overhaul and failure, or if the bolt had been inadequately tightened during the overhaul assembly process. The investigation found no evidence of inadequate tightening within any of the adjacent connecting rod bolts, nor was there any indication of deficiencies with the properties or manufacturing quality of the components themselves.

FACTUAL INFORMATION

Introduction

On 8 August 2006, shortly after departure from Archerfield Aerodrome, Queensland, a Cessna Aircraft Co model 182P (registered VH-WNR) sustained a partial engine failure, requiring the pilot to conduct a forced landing within a suburban residential area. The aircraft was destroyed as a result of damage sustained during the forced landing and post-impact fire.

From an initial examination of the engine at the accident site and subsequent studies during a workshop disassembly supervised by the (ATSB) Australian Transport Safety Bureau, it was evident that the engine had sustained the damage and mechanical failure of several key reciprocating assembly components from the number-5 and 6 cylinder units. The damaged and failed items were subsequently retained for detailed examination in the ATSB's Canberra laboratories.

Scope of the examination

The intent of the ATSB laboratory examination was to identify the nature and characteristics of the damage sustained by the engine, with a view to ascertaining the factors that contributed to the in-flight breakdown and power loss.

Operational characteristics of the failure

The aircraft was fitted with a Teledyne Continental Motors model O-470-S1B, six-cylinder conventionally-aspirated reciprocating piston engine. The engine had been installed into VH-WNR during October 2005, as a fully-overhauled unit. Statements from the pilot of the aircraft indicated that the engine had functioned normally in the ensuing hours of operation between the overhaul and the failure event. Engine throttle response, power output and instrument indications had been as-expected by the pilot, with no suggestion of a pre-existing mechanical problem.

The pilot reported that the engine failure event presented as a loud 'clunk-clunk' sound, followed by the smell of heated engine oil and the appearance of small spots of oil on the aircraft windshield. At that time, the aircraft was climbing, with 23 inches Hg manifold pressure and 2,400 RPM set. Following the loud engine noises, the pilot reduced the manifold pressure and RPM and commenced preparation for a forced landing. Late in the descent, in an attempt to clear an obstacle, the pilot reopened the throttle fully, but the engine did not respond.

Engine disassembly observations

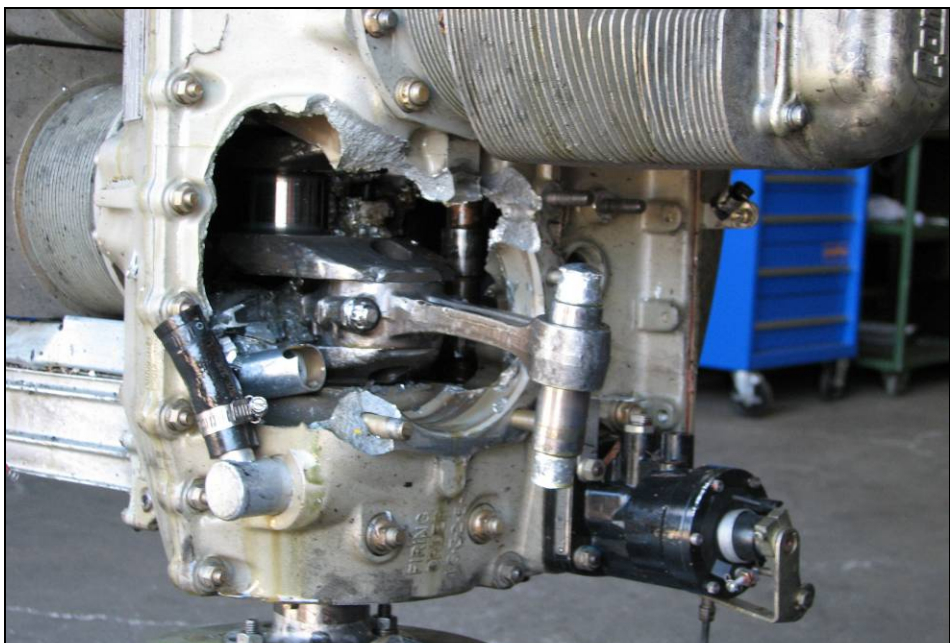
Following removal from the airframe, the engine was progressively disassembled and examined under the supervision of ATSB investigators. It was readily evident that a large section of the upper left-side crankcase had been punctured and broken away during the failure event, exposing the crankshaft and reciprocating assembly for the number-5 and 6 cylinders, as shown in Figure 1. Extensive cracking was also evident through and around the number-5 and 6 cylinder mounts. Removal of

the number-6 cylinder barrel and the associated fractured crankcase section (as shown in Figure 2) exposed the number-6 connecting rod and gudgeon pin; the piston having broken up completely within the cylinder bore. Also evident through the exposed crankcase was the complete separation of the number-5 connecting rod from its respective crankshaft journal. The connecting rod and pin had also broken away from the piston body, leaving the piston upper section within the cylinder. Multiple pieces of the number-5 connecting rod were recovered from within the crankcase and sump pan, along with many piston and crankcase wall fragments.

Figure 1: Crankcase perforation sustained during the engine failure



Figure 2: Damage exposed following removal of the number-6 cylinder



The engine disassembly was completed upon removal of the crankshaft and remaining connecting rods from the crankcase halves. The connecting rods were

left in-place on the crankshaft for later laboratory assessment of the connecting rod bolt tension levels.

Connecting rod bolt tension

By convention, the security and stability of the connecting rod to crankshaft boss connection was provided by the uniform clamping action of the two connecting rod bolts. Clamping force (in the Teledyne-Continental system) was achieved by the application of a specified tightening torque to each of the connecting rod bolts, which established a pre-determined bolt tension, or preload. Inadequate bolt preload can result in the exposure of the assembly to operational cyclic stresses and consequent fatigue damage.

To establish the approximate torque to which each of the remaining connecting rod bolts had been assembled during the engine overhaul, the as-tensioned length of each bolt was measured in-situ (to a precision of 0.0005”). Break-out (loosening) torque was then recorded for each bolt, followed by re-torquing of the bolts (where possible) to the level specified for the engine assembly (57.5 – 59.2 ft/lb, Teledyne Continental Motors Service Bulletin SB 96-76 Rev. C). Comparative length measurements after re-torquing showed no difference against the originally tensioned bolt lengths – indicating the likely original assembly torque to have been within the specified range.

Table 1: Connecting rod bolt torque/tension evaluation results

Bolt ^[1] ID	Installed length (in)	Break-out torque (ft.lb)	Re-tensioned length (in)	Difference Initial vs. re-tensioned lengths	Free length (in)	Extension under applied tension (in) ^[2]
1 A	2.5640	55	2.5640	0.0000	2.5595	0.0045
1 B	2.5640	56	2.5640	0.0000	2.5595	0.0045
2 A	2.5635	57	2.5635	0.0000	2.5600	0.0035
2 B	2.5630	57	2.5630	0.0000	2.5595	0.0035
3 A	2.5645	57	2.5645	0.0000	2.5600	0.0045
3 B	2.5640	57	2.5640	0.0000	2.5595	0.0045
4 A	2.5640	57	2.5640	0.0000	2.5600	0.0040
4 B	2.5635	56	2.5635	0.0000	2.5600	0.0035
5 A	Fractured	n/a	n/a	n/a	n/a	n/a
5 B	Fractured	n/a	n/a	n/a	n/a	n/a
6 A ^[3]	2.5650	20	Damaged	n/a	Damaged	n/a
6 B ^[3]	2.5870	40	Damaged	n/a	Damaged	n/a

Notes:

- [1] Bolts identified with respect to cylinder number, the side of the connecting rod carrying the cylinder number (A), and the opposite side (B).
- [2] Determined as tensioned length minus free length.

- [3] Both bolts from the number-6 connecting rod had distorted and sustained impact damage, preventing re-tensioning and contributing to the low break-out torques measured.

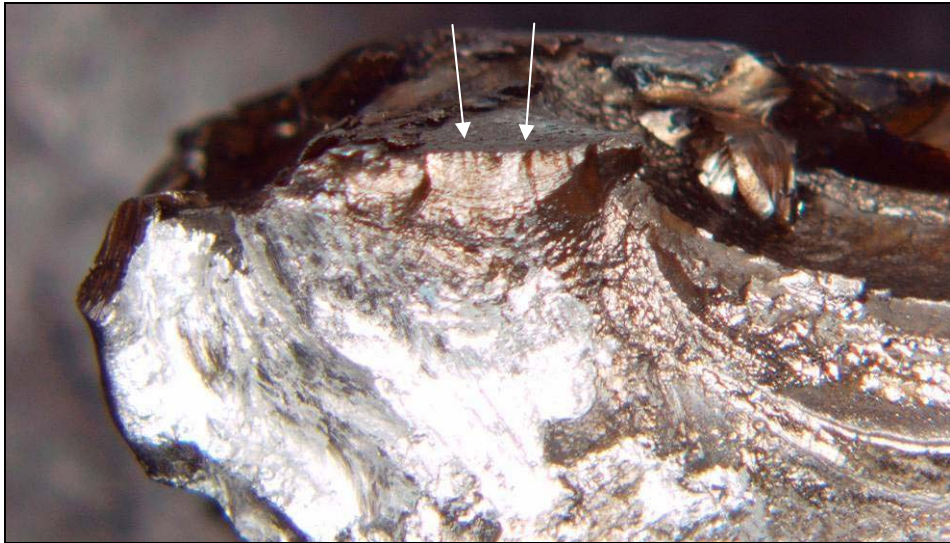
Connecting rod failure

All major fragments of the number-5 connecting rod assembly were recovered and examined to ascertain the mechanisms contributing to the failure. Attachment A presents the fragments collectively and illustrates the level of mechanical damage sustained. The crankshaft journal boss (big-end boss) had separated into five segments, with fractures to either side of the rod-arm transition and through the centre of the bearing cap. All fractures showed significant levels of ductility and associated plastic deformation of the surrounding material, with all having sustained significant levels of post-failure mechanical impact damage. The outer surfaces of the fracture between the rod arm and one side of the journal boss (between segments 1 and 2, Attachment A) also showed some evidence of progressive, cyclic crack growth, with areas presenting features consistent with high-stress, low-cycle fatigue crack initiation and development, see Figures 3 and 4. The remaining fractures, where not obscured by damage, were all consistent with ductile tensile or bending overload failures, with no pre-existing cracking or other latent defects. Similarly, the centrally located fracture through the rod arm was also entirely consistent with mechanical overload.

Figure 3: Fragment of the number-5 connecting rod boss, showing evidence of fatigue crack initiation and growth (arrowed areas)



Figure 4: Closer view of a region of fatigue cracking shown in Figure 3. Surface origins as indicated



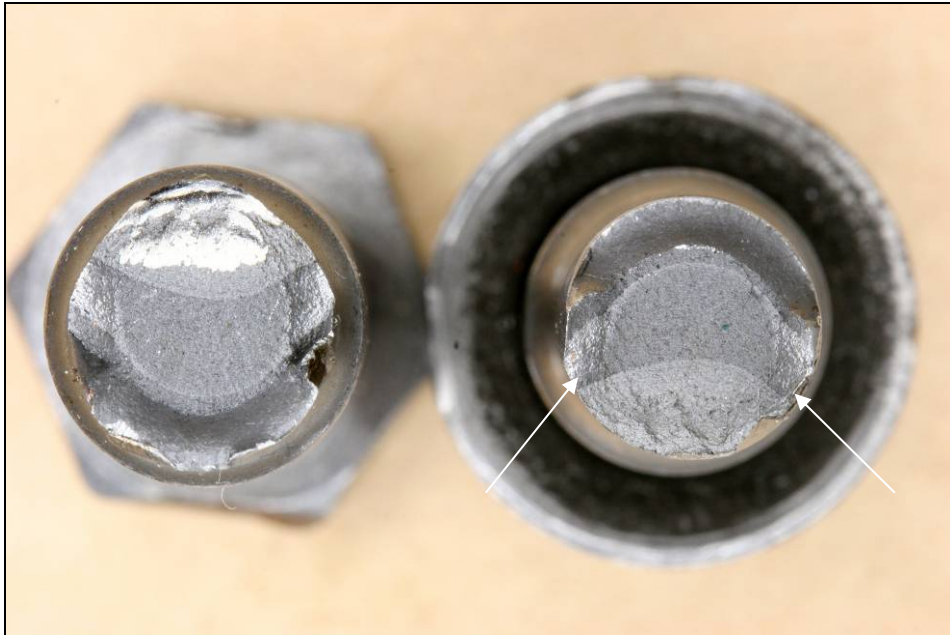
Connecting rod bolt failure

Both bolts from the number-5 connecting rod assembly had fractured and separated from the rod boss. Bolt 'A' (see Attachment A and Figure 5) presented a single point, unidirectional bending overload failure through the central shank. The typically ductile fracture showed a single crack arrest mark (see Figure 6), suggesting failure to have occurred over two loading cycles.

Figure 5: Number-5 connecting rod bolt 'A'



Figure 6: Characteristic bending overload fracture with single crack arrest mark



The opposing bolt (bolt 'B', attachment A and Figure 7) was recovered in three sections; all having sustained forceful sliding and impact damage. All shank fractures were typical of ductile overload under bending or shear conditions.

Figure 7: Number-5 connecting rod bolt 'B'



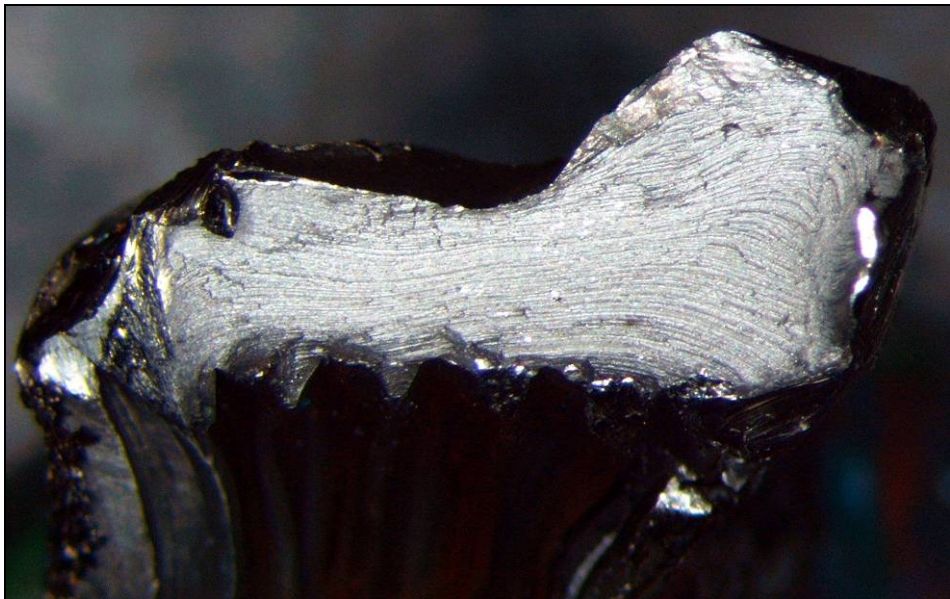
As shown in Figure 8, the nut associated with bolt 'B' was recovered in four fragments from amongst the finer debris removed from the engine crankcase during the disassembly.

Figure 8: Fragments of nut from number-5 connecting rod bolt 'B'



The nut had fractured radially, with all fractures presenting a coarse, woody morphology (see Figure 9), reflecting the underlying wrought material microstructure and being typical of gross overloading conditions. Internally, the nut thread form was intact and had not stripped onto the threads of the bolt, nor was there any indication that the bolt threads had stripped within the nut. Low-power stereomicroscopic study of the nut fragments did show some evidence of thread-form deformation consistent with shear forces transferred through the lower nut threads, while the threads of a similar undamaged nut showed only markings consistent with uniform thread engagement.

Figure 9: Typical 'woody' fracture surface of the failed nut



Hardness measurements taken from centrally-located sections through both bolts returned comparable values, with all measurements falling within the range of 415 – 422 HV₃₀. Expressed as an approximate tensile strength, both bolts were at an

ultimate strength level of around 1,335 MPa, and as such, typical of high strength connecting rod bolts of property class 14.9⁹.

Journal bearings

Both crankshaft journal bearings from the number-5 connecting rod were recovered amongst the debris. Although crushed and deformed, both showed no indication of overheating or abnormal operation. The bearing surfaces showed no scoring, loss of material or other damage that was not attributable to the mechanical breakdown of the connecting rod assembly.

Piston failure

Both number-5 and 6 pistons from the engine had broken up within their respective cylinders. The number-6 piston had completely fragmented and broken away from the gudgeon pin – most remnants being recovered from within the sump and crankcase. A study of the identifiable fragments of the piston body and crown found no evidence of any pre-existing cracking, damage or defects. All fractures were typically uniform and presented the typically brittle appearance associated with the overload failure of high-strength aluminium alloys. The partially reconstructed surface of the piston showed no evidence of abnormal combustion behaviours or deposits.

The number-5 piston had broken up around the lower skirt and gudgeon boss region, releasing the crown and upper section (see Figure 10) which remained in the cylinder until engine disassembly. All examinable fractures were similar to the number-6 piston, in that they were brittle-impact type failures, with no evidence of pre-existing defects.

A sample of the number-6 piston material was spectrographically analysed to determine its nominal chemical composition¹⁰. The material was identified as an Al-Si-Cu-Mg-Ni alloy, similar in chemistry to a UNS¹¹ A03390 or AA¹² 339.0 alloy. Materials literature¹³ indicates that the AA 336/339 alloys are commonly used for the permanent mould casting of automotive and aeronautical pistons. Hardness tests returned results within the 101-105 HB_{40/2}, which was consistent with the alloy being in the T551 temper condition and typical of reciprocating engine pistons produced from the 339 alloy.

9 As defined by engineering standard ISO 898-1.

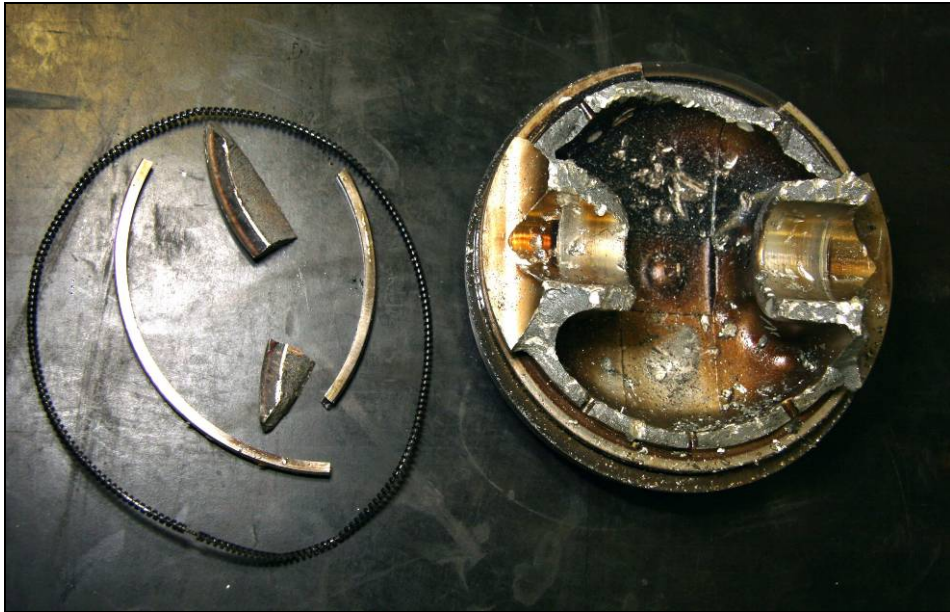
10 Analysis by Spectrometer Services Pty Ltd, Coburg Vic. Report number 27555.

11 Unified Numbering System for metal alloys.

12 US Aluminium Association designation system.

13 ASM Handbook Vol.2, pages 161, 162.

Figure 10: Upper section of the number-5 piston that remained in the cylinder bore after the failure



All examinable piston crown surfaces carried the metal-stamped identification:

AEC 646263 G 10/04 1

That marking identified the pistons as the product of Airmotive Engineering Corp, San Antonio, Texas USA and produced under Federal Aviation Administration (FAA) parts manufacturing approval (PMA) number PQ0003SW. The part number (AEC646263) was confirmed as an authorised replacement for the original equipment manufacturers (OEM), part number 646263, and suitable for use in the Teledyne Continental O-470-S model engine.

ANALYSIS

Engine failure

The investigation attributed the in-flight failure of the Teledyne-Continental O-470 engine, to the mechanical disruption and destruction of the number-5 and 6 cylinder reciprocating componentry. The separation of the number-5 connecting rod and the fragmentation of the number-5 and 6 pistons, as sustained, would have rendered those cylinders inoperative, significantly reducing the available power output of the engine and its response to throttle commands. It is likely, however, that the engine would have continued operating during and following the failure event, given that the accessory drive-train was maintained and cylinders 1-4 were not compromised.

Failure mechanism

The identification of fatigue cracking within one side of the connecting rod boss indicated the presence of abnormally elevated flexure and bending stresses within the upper boss walls. With regard to the design of the boss, it can be shown that a reduced preload (tension) within the associated connecting rod bolt, will reduce the rigidity and stiffness of the connection under the reciprocating action of the assembly. Reduced joint stiffness allows the exposure of the assembly to operationally-induced cyclic bending stresses that are conducive to the initiation of fatigue cracking. Due to the level of post-failure consequential damage sustained by the connecting rod fragments, it was not possible to establish with any certainty, the sequence of connecting rod failure. It is probable however, that the influence of reduced joint rigidity and the associated elevated stresses resulting from a reduced a connecting rod bolt preload, led either to the fracture of the upper boss section from the area of fatigue cracking, or the destruction and separation of the connecting rod nut. In any event, the separation of one side of the assembly would have produced the observed opening, break-up and separation of the boss from the crankshaft journal under very few subsequent engine revolutions.

In view of the absence of any identifiable deficiencies within the engine pistons and considering their production from a comparatively low-ductility alloy, it was concluded that the damage and fragmentation sustained by the number-5 and 6 pistons, was a result of abnormal stresses and impacts sustained as a result of the connecting rod failure.

Bolt tension/preload

Connecting rod bolt preload is established by design, through the tightening torque applied to each fastener during assembly. Where a reduced bolt preload exists in a rod assembly, it may either be a result of low initial torque or excessive thread friction, or be lost after assembly, from:

- bolt stretch (under-strength bolts or over-torquing)
- embedment relaxation (compression of roughness or unevenness on the mating faces)

- surface fretting (elevated loads causing movement & mating-surface wear)
- film removal (interfacial material worn or squeezed out).

The investigation found all bolts from engine cylinders 1-4 were carrying a preload consistent with having been correctly torqued, i.e. to the torque levels specified by the engine manufacturer. The investigation was unable to determine the pre-existing preload within the bolts from cylinders 5 and 6, due to the damage sustained by the failure event. No evidence of significant embedment relaxation, surface fretting or film removal effects, was found associated with the separated joint surfaces, nor would those effects generally be considered as possible factors, given the bolted joint design and configuration. The possibility of an insufficient initial assembly torque, or an excessive torque producing permanent bolt stretch thus remain as the most probable factors in this instance, however there was no specific evidence to directly support the contribution of either scenario. The nominal strength of both bolts from the number-5 connecting rod was satisfactory and consistent with the application.

ATTACHMENT A

Connecting rod number-5

