



Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Technical Analysis Investigation – 200700054

Final

Crankshaft Failure Analysis - Rotax 912 Engine

30km NW Goulburn, NSW

6 January 2007

Aircraft Registration: 24-3770

TL Ultralight TL-2000 Sting Sport



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Abstract

On 6 January 2007, a TL-2000 Sting Sport ultralight aircraft, registered 24-3770, impacted the ground approximately 30 km north west of Goulburn. The aircraft was fitted with a Rotax 912 ULS Engine. The engine disassembly and inspection was conducted by a Rotax engine specialist at the request of the NSW police, during which, the crankshaft was found to have fractured. Recreational Aviation Australia subsequently requested the assistance of the Australian Transport Safety Bureau in conducting technical analysis of the crankshaft. That analysis found no indications that would have prematurely initiated failure or have been detrimental to the fatigue life of the crankshaft.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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

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.

EXECUTIVE SUMMARY

On 6 January 2007, a TL-2000 Sting Sport ultralight aircraft, registered 24-3770 had not returned after a local flight. The wreckage of the aircraft was subsequently found approximately 30 km to the north west of Goulburn Aerodrome. The pilot and passenger of the aircraft were fatally injured.

During the disassembly of the Rotax 912 ULS engine, carried out by a Rotax engine specialist at the request of the of the NSW police, the crankshaft was found to have fractured. Recreational Aviation Australia (RA-Aus) subsequently requested the assistance of the Australian Transport Safety Bureau (ATSB) for technical analysis of the crankshaft.

The crankshaft in Rotax 912 engines is composite in construction, where the journals are press-fit into web sections. Examination of the crankshaft revealed fatigue cracks in two separate components. Detailed microscopic and metallurgical analysis found that the materials used in the crankshaft construction were appropriate in type and condition. Additionally, no indications were found that would have prematurely initiated failure or have been detrimental to the fatigue life of the crankshaft.

Recreation Aviation Australia will consider any implications of the findings of this report as part of its broader investigation into the safety factors surrounding this fatal accident.

1 FACTUAL INFORMATION

1.1 Introduction

On 6 January 2007 a TL-2000 Sting Sport ultralight aircraft, registered 24-3770 had not returned after a local flight. The wreckage of the aircraft was subsequently found approximately 30 km to the north west of Goulburn Aerodrome. The pilot and passenger of the aircraft were fatally injured.

During the disassembly of the Rotax 912 ULS engine (serial number 4.427.607), carried out by a Rotax engine specialist, the crankshaft was found to have fractured. Recreational Aviation Australia (RA-Aus) requested the assistance of the ATSB for technical analysis of the crankshaft.

1.2 Main crankshaft assembly

The crankshaft from the Rotax 912 ULS engine was received as shown in Figure 1, with the connecting rod journals numbered one through four. The crankshaft used in the Rotax 912 engine was of a composite construction. Each of the forged connecting rod journal sections had been press-fit¹ into two web sections between journals one and two, and also between journals three and four. The crank web between the number one and number two connecting rod journals was found fractured in two locations, shown more clearly in Figure 2.

The liberated section of crank web was also recovered with considerable impact damage consistent with being loose in the rotating engine. The failed crank web and the surrounding connecting rods all exhibited impact damage from the liberated section of web.

There was misalignment evident along the crankshaft due to twisting of the connecting rod journals within the crank web sections (Figure 3). Twisting was evident at all four journals, but particularly noticeable when comparing the positions of the counterweights adjacent to the number one and four journals. The movement was consistent with the direction of engine rotation.

The web section was removed from the number one and two connecting rod journals. The journal was found to have an extensive crack running from the web, approximately 270 degrees around the journal on a 45 degree angle (Figure 4).

¹ Press-fit: A fit which provides an interference between the hole and the shaft when assembled, i.e. the maximum size of the hole is smaller than or, in the extreme case, equal to the minimum size of the shaft. International Organization for Standardisation 286-1: 1988.

Figure 1: Rotax 912 crankshaft, as-received, with cylinders numbered.

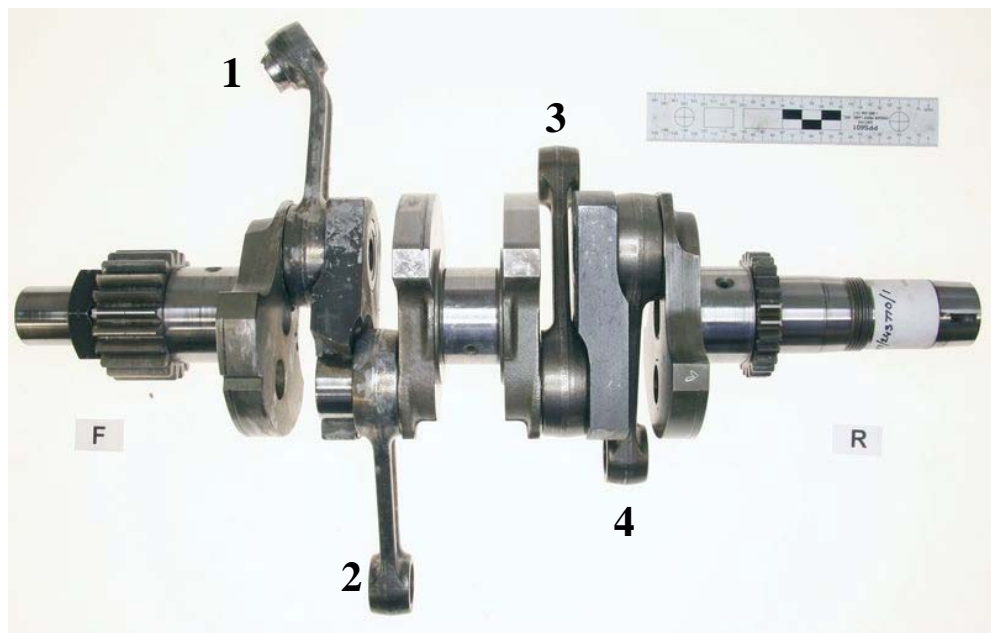


Figure 2: Section of crank web failed in two locations (labelled 'A' and 'B') at the number two journal.

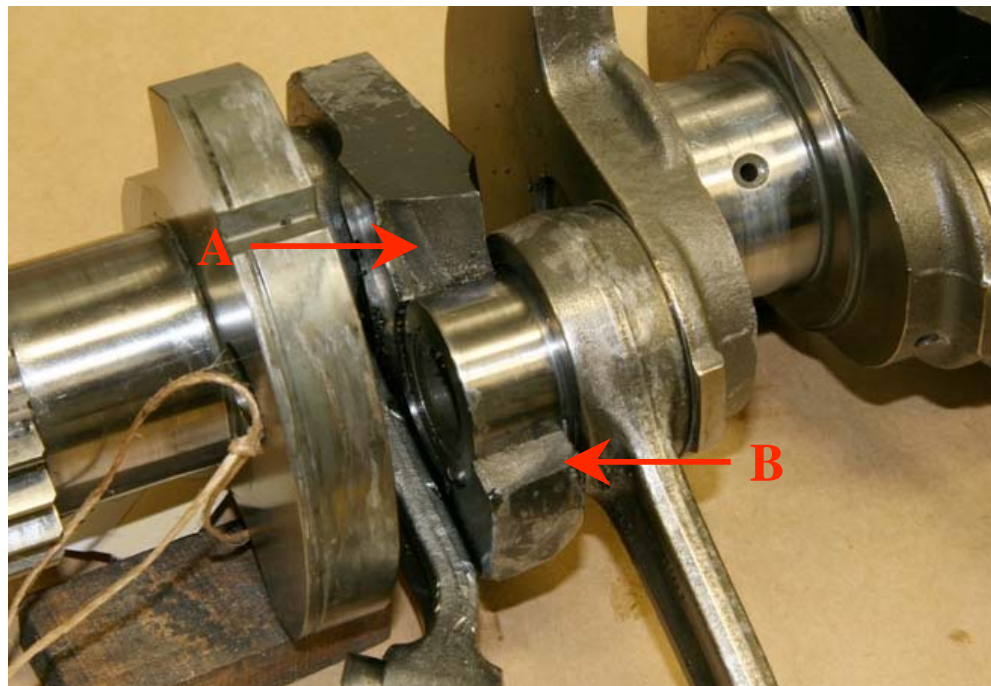


Figure 3: Twist evident in the crankshaft.

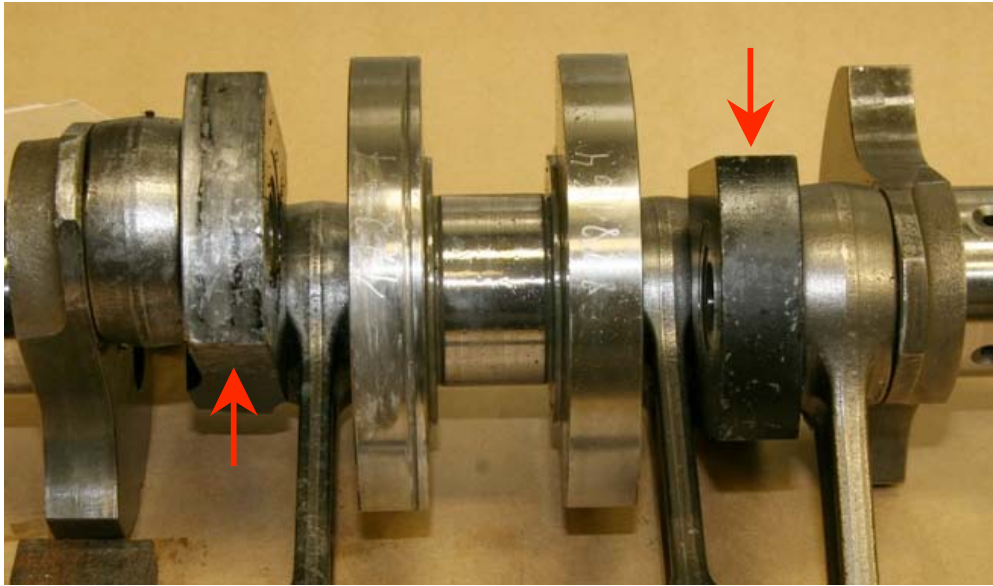


Figure 4: Crack in the number one connecting rod journal.



1.3 Crankshaft web

1.3.1 Visual examination

The crank web failed in two locations, marked 'A' and 'B' as shown in Figure 2.

Visible on fracture surface at 'A' was a series of beach marks originating at one corner on the outside of the crank web and progressing through the section to a final overload region, where the part failed catastrophically. Beach marks are associated with fatigue failures and indicate the location of the advancing crack front. Beach marks radiated outward from the crack origin which was one of the outside corners of the web as indicated in Figure 5.

The fracture at 'A' occurred at a reduction in the crank web cross-sectional thickness and originated at the end of the edge chamfer, at a point equivalent to that indicated in Figure 6. The surface of the web section exhibited a textured, dimpled appearance consistent with shot-peening. Peening is surface treatment mechanically applied to fatigue-critical parts to improve the fatigue life.

Fracture 'B' occurred through the crank web where the cross sectional area was at a minimum. Visual examination showed galling wear adjacent to the fracture, on the surface in contact with the number two journal (Figure 7) and also on the number two journal (Figure 8). Galling is the result of microscopic welding caused by high-friction sliding contact between mating parts.

Growth of the web cracks would have reduced the interference loads on the journal-web joint, allowing for some high-friction movement, as evidenced by the adhesive wear between the web and journal prior to the liberation of the web section.

Beach marks were also readily visible on the fracture surface at 'B'. The marks appeared to originate from one of the areas of galling.

Figure 5: Failure 'A' in crank web.

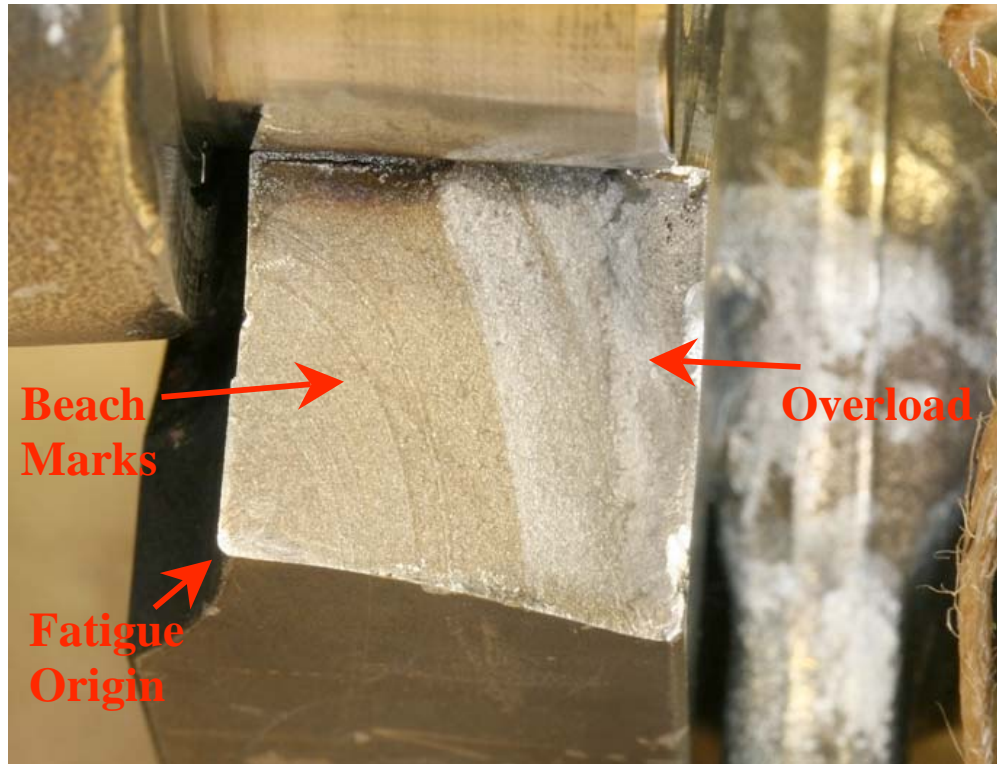


Figure 6: Web section opposite failure site showing change in section thickness and similar location of crack initiation.

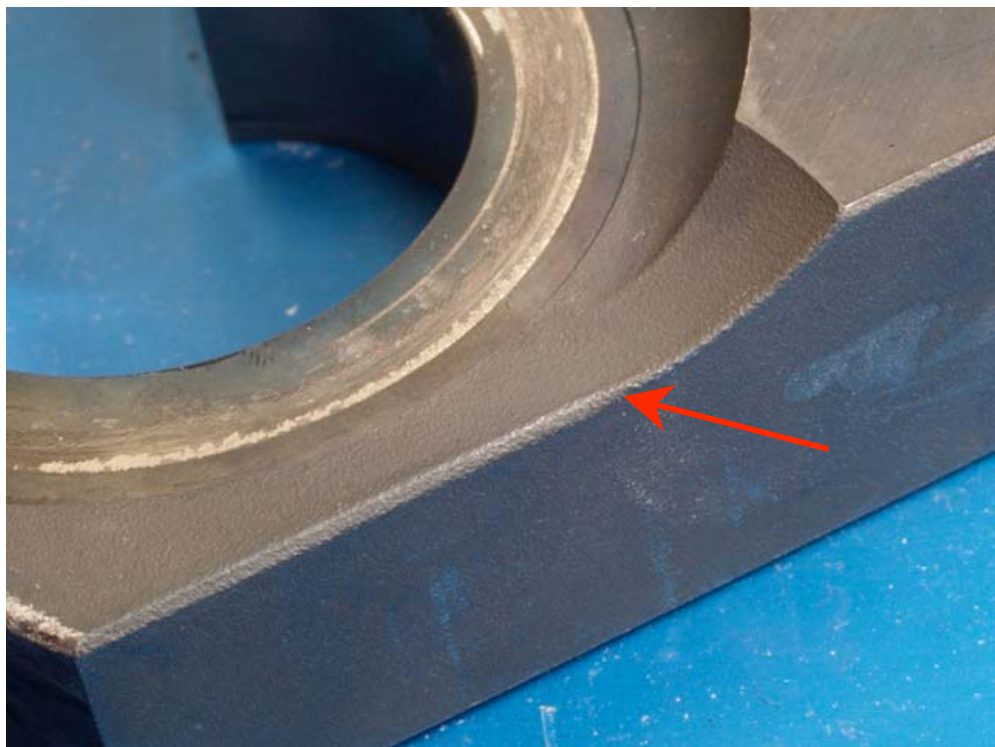


Figure 7: Failure 'B' in crank web with adhesive wear on journal contact surface.



Figure 8: Adhesive wear on number two connecting rod journal.



1.3.2 Microscopy

The web fracture surfaces were examined by optical and scanning electron microscopy, however no additional information on the initiation of the fatigue crack could be identified.

A metallographic section was prepared through the fracture at 'A' (Figure 9). The section was taken perpendicular to the fracture surface, diagonally through the crack origin and the opposite corner. There were no indications of inclusions or defects. When examined in the etched condition (Figure 10), the section appeared to have a predominantly martensitic structure. There was a change in microstructure approximately 200-300 microns below the surface of the web and an unetched, white layer on the surface. Neither of these features were considered to be related to the fracture, but were consistent with the part being case-hardened by nitriding.

Figure 9: Orientation of metallographic section taken perpendicular to fracture surface 'A'.

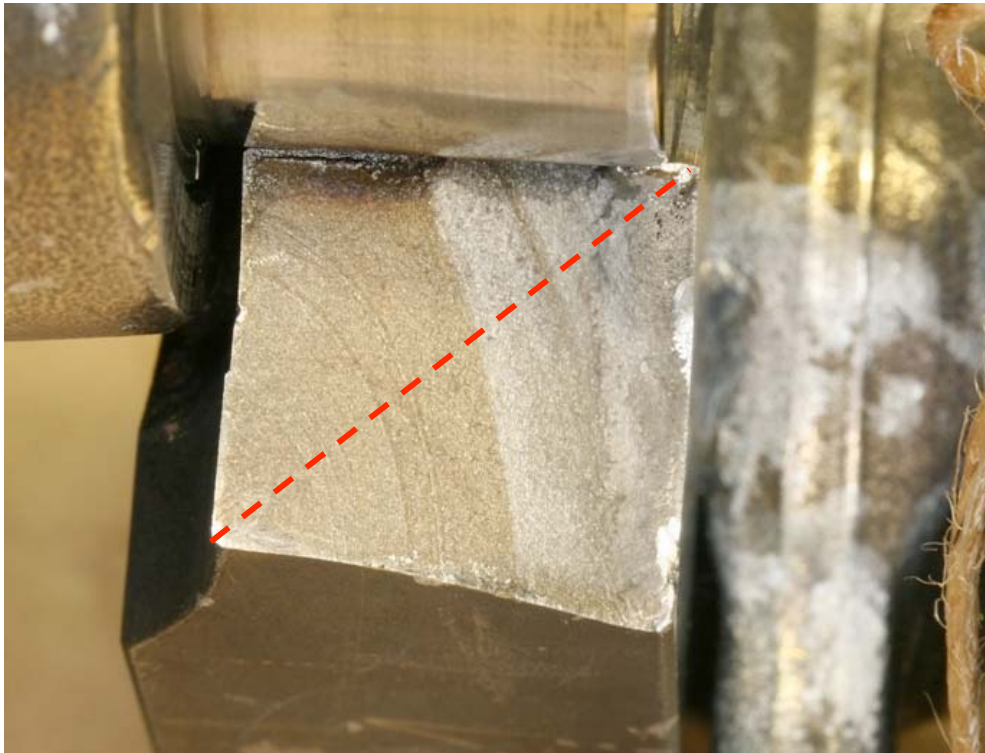
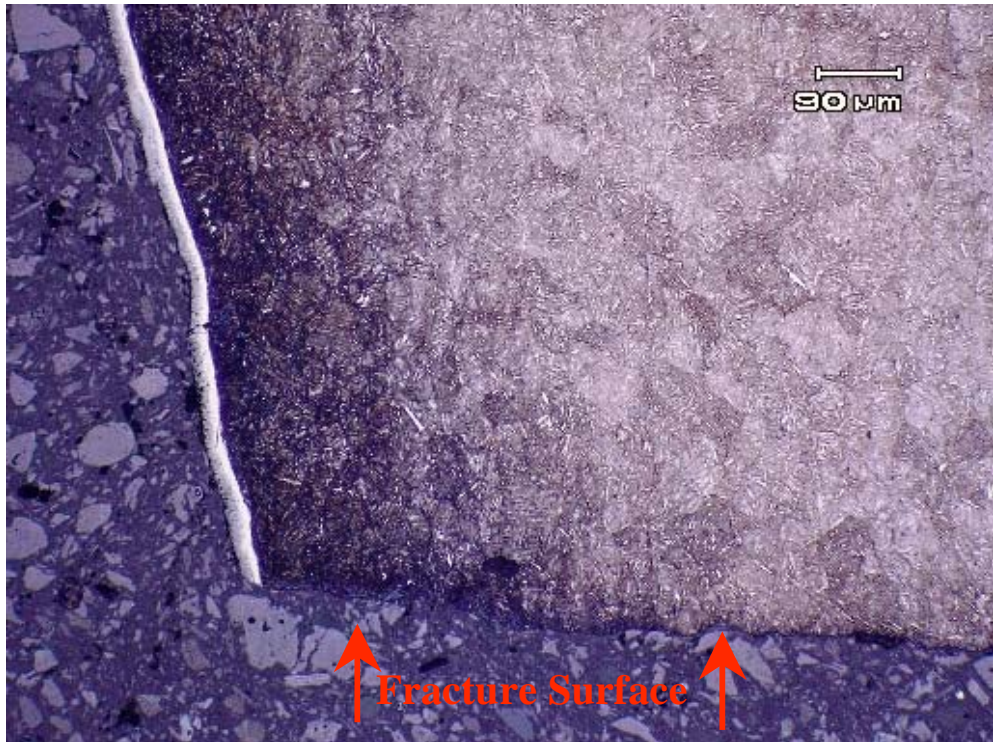


Figure 10: Metallographic section through fatigue origin at 'A'.



Etched using 1% Nital.

1.4 Crankshaft journal

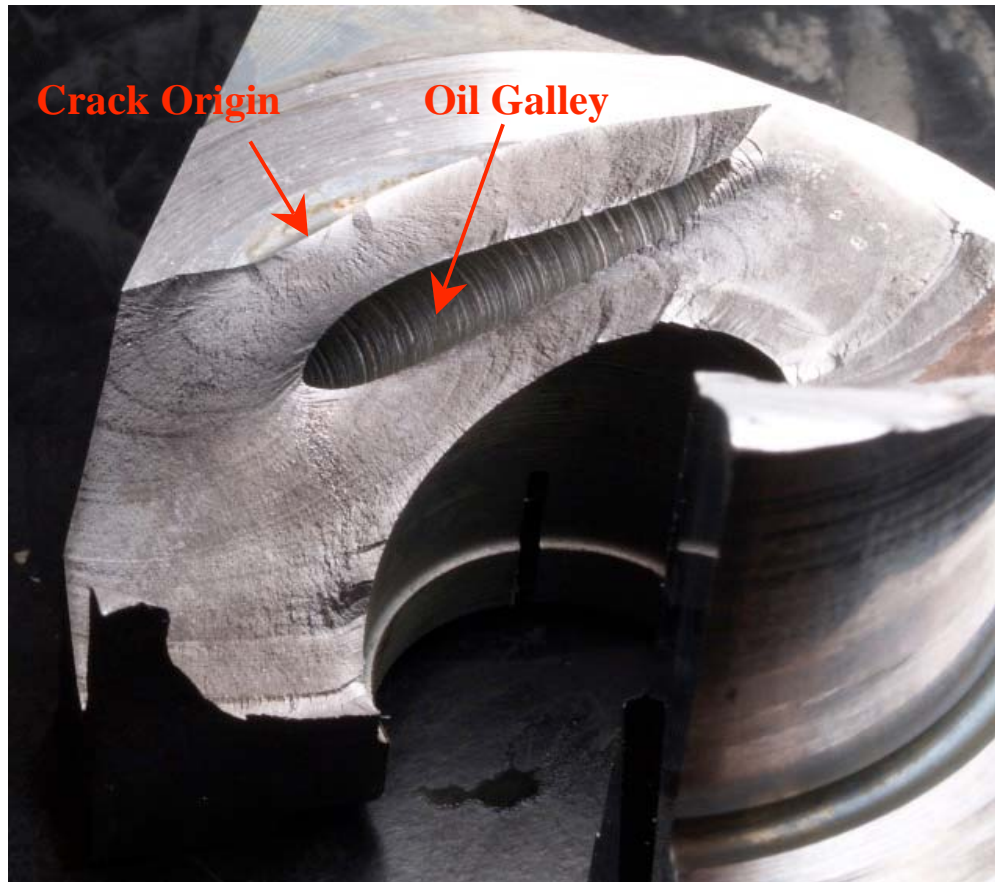
1.4.1 Visual examination

The number one journal fatigue crack, as shown in Figure 4, had progressed approximately 270 degrees around the journal, but had not completely separated the journal at the time of disassembly. The journal was sectioned so that the fracture surface could be examined. Both halves of the journal are shown in Figure 11. Visual examination of the fracture surface showed beach marks radiating out from a point in the relief radius between the web and journal, in close proximity to the oil galley (Figure 12).

Figure 11: Failed number one connecting rod journal.



Figure 12: Number one connecting rod journal fatigue surface. Arrow indicates fatigue initiation site.

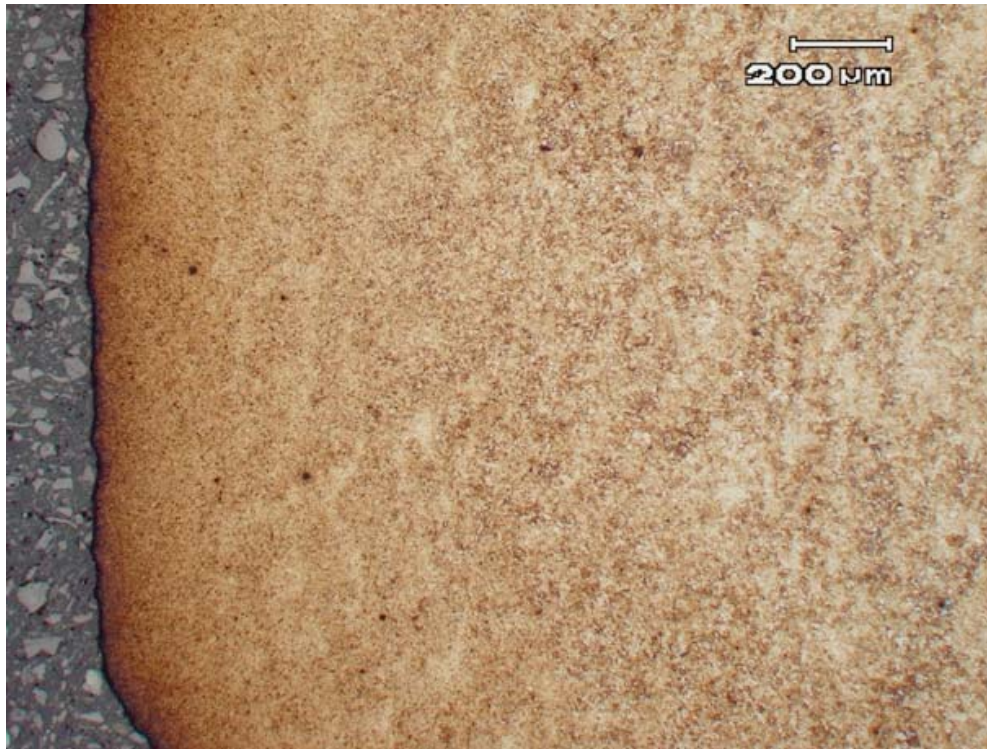


1.4.2 Microscopy

Optical and scanning electron microscopy of the fracture surface site did not reveal any anomalies. As with the web failure, a metallographic section was taken through the crack origin indicated in Figure 12, perpendicular to the fracture surface.

Figure 13 shows a micrograph through the journal surface. There was a visible difference in the microstructure between the journal surface and the core of the material. The microstructure was also visibly different from that observed in the web section and was consistent with a surface hardening treatment.

Figure 13: Microstructure of the number one journal cross section.



Etched using 1% Nital.

1.5 Hardness testing

Microhardness testing was carried out on both metallographic sections through the web and journal failures. The hardness was profiled from the surface of the part through to the core of the material.

The average hardness near the surface of the web section was found to be approximately 730 Vickers. The bulk of the material had a hardness of approximately 380 Vickers.

The average hardness at the journal surface was approximately 710 Vickers, compared with the bulk of the sample at approximately 430 Vickers. The case depth was observed to be greater in the journal section.

These results confirmed that both parts had been subjected to a surface hardening treatment. The presence of the white layer on the surface of the web section (Figure 10) was consistent with that which is typically formed during the nitriding process. The absence of the white layer and the greater case depth observed in the journal section was more consistent with a carburising process.

1.6 Chemical analysis

Samples were taken from the web and journal sections of the crankshaft and chemically analysed by optical emissive spectroscopy³. The spectroscopy results were consistent with the alloys specified by Rotax for the web and journal sections which were DIN 42CrMo4 and DIN 15CrNi6 respectively. The results from the chemical analysis and standard chemical compositions of the specified alloys are shown in Table 1.

Table 1: Chemical analysis results and specified alloy compositions⁴ (Weight %).

	Web	42CrMo4		Journal	15CrNi6
Fe	Balance	Balance		Balance	Balance
C	0.39	0.38 - 0.45		0.18	0.14 - 0.19
Mn	0.072	0.60 - 0.90		0.57	0.40 - 0.60
Si	0.21	0.40 max.		0.23	0.40 max.
S	0.02	0.035 max.		0.01	0.035 max.
P	0.01	0.035 max.		0.01	0.035 max.
Ni	0.15	-		1.47	1.40 - 1.70
Cr	1.11	0.90 - 1.20		1.67	1.40 - 1.70
Mo	0.23	0.15 - 0.30		0.05	-
Cu	0.21	-		0.24	-
V	0.01	-		0.01	-
Nb	< 0.01	-		< 0.01	-
Ti	< 0.01	-		< 0.01	-
Al	< 0.005	-		0.03	-
B	< 0.0005	-		< 0.0005	-

³ Chemical analysis conducted by Spectrometer Services Pty Ltd, Coburg North, Victoria.

⁴ The 42CrMo4 and 15CrNi6 alloy chemistry was taken from the website <http://www.metallograf.de/>, January 2008.

2

ANALYSIS

2.1 Material analysis

The metallographic, chemical and hardness testing of the crankshaft showed that the alloys were correct per Rotax specification and in an appropriate heat-treated condition to be used in the crankshaft.

2.2 Failure analysis

The failures in the crank web and connecting rod journal occurred in areas of reduced section thickness that would have acted as stress concentrators or weak-points in the structure. There were no metallurgical indications observed that suggested there were any material or manufacturing defects.

The loss of the interference fit in the number two journal to crank web section, may have contributed to a higher loading condition which resulted in the fatigue crack observed in the number one journal. The appearance and 45 degree angled progression of the crack in the number one connecting rod journal was consistent with fatigue through cyclic torsional loading.

While there was misalignment evident in the crankshaft, the investigation could not establish if it had been pre-existing or if it developed as a result of forces sustained during the final mechanical breakdown of the engine.

Recreation Aviation Australia will consider any implications of the findings of this report as part of its broader investigation into the safety factors surrounding this fatal accident.

3

FINDINGS

3.1 Contributing safety factors

- The crankshaft from the Rotax 912 ULS engine (serial number 4.427.607) failed as a result of the initiation and propagation of fatigue cracking in the web section that spanned the number one and number two connecting rod journals.

3.2 Other key findings

- A secondary fatigue crack had initiated and propagated through the number one connecting rod journal. The number one journal had not completely failed at the time of the accident.
- Metallurgical analysis of the crankshaft found that the materials used were the correct alloy and condition. No obvious metallurgical or manufacturing defects were observed that may have contributed to the crank failure.