The Australian Transport Safety Bureau (ATSB) investigated this occurrence in accordance with the Transport Safety Investigation Act 2003, for the sole purpose of improving transport safety. It is not the object of an ATSB investigation to determine blame, provide a means of determining liability, or to assist in court proceedings between parties.

FACTUAL INFORMATION

History of the flight

On 13 April 2005 at approximately 1130 Eastern Standard Time, the pilot of a Robinson Helicopter Company model R22 Beta, registered VH-HXU, was conducting cattle mustering operations near Mareeba, Qld, when he felt a significant airframe vibration and elected to conduct an immediate precautionary landing. Upon inspection with the engine still running, the pilot reported observing the clutch assembly shaking excessively, followed by the sudden fracture of the clutch shaft at the connection to the main rotor gearbox. The pilot was the only occupant of the helicopter and was not injured. There was no other damage to the helicopter.

Previous occurrence

The helicopter maintenance provider reported the failure to the Civil Aviation Safety Authority (CASA), through the Service Difficulty Reporting system. A representative from CASA subsequently notified the Australian Transport Safety Bureau (ATSB) of the failure because of its similarity to a September 2003 clutch shaft failure sustained by R22 helicopter VH-UXF, which resulted in two fatalities and the destruction of the helicopter[1]. The investigation of that accident lead to the development and promulgation of a CASA airworthiness directive related to inspections and specific assembly procedures for the clutch shaft.

Helicopter information and maintenance history

The helicopter was manufactured in 1997 and at the time of the occurrence had accumulated 2,911.6 hours total time in service (TTIS). In November 2003, at 2,134 hours TTIS, the airframe was completely rebuilt following a heavy landing. As part of that work, a new part number A188-2 clutch assembly (serial number 6337) was installed, including a new part number A166-1 clutch shaft (serial number 6212). Following overhaul and magnetic particle crack inspection, the original part number A907-4 forward yoke (serial number 1232) was re-installed on the clutch shaft.

The helicopter's maintenance documentation indicated that on 11 August 2004, the clutch shaft and yoke (part number A907-4, serial number 1232) were removed and the requirements of airworthiness directive AD/R22/51 Amdt 1[2] carried out. Those requirements included the disassembly of the A907 yoke to A166 clutch shaft joint and the visual inspection of the contact surfaces and bolts for evidence of fretting, cracking or in-service movement. The magnetic particle inspection of the A166 shaft and A907 yoke was also required. The

[1] ATSB occurrence number 200304074

[2] AD/R22/51 Amdt 1 became effective on 5 August 2004. The directive was issued by CASA in response to the accident involving VH-UXF that resulted from the in-flight failure of the A166 clutch shaft.

helicopter maintenance provider indicated that after inspection, the yoke to shaft connection was re-assembled in accordance with the requirements of the directive and had not subsequently been disassembled, worked on or otherwise disturbed before the occurrence flight.

At the time of the occurrence, the clutch shaft and assembly had accumulated 776.6 hours TTIS, with approximately half of that time (384.6 hours) accruing after the performance of the AD/R22/51 inspections. The helicopter maintenance manual prescribed a 4,000 hour life limit for the part number A166 clutch shaft.

AD/R22/51 Amdt 1 specifically required the inspection of the A907 yoke for '…"evidence of paint in the area where the yoke to clutch shaft joint block plates contact the yoke"…'. Also required was the removal of '…"any evidence of paint in the area where the yoke to clutch shaft joint block plates contact the yoke"…'. The purpose of paint removal was to prevent the inadvertent loss of bolt tension and joint loosening as a result of the subsequent compression and extrusion of paint from between the clamping surfaces. Similarly, the March 2004 revision of the helicopter maintenance manual included specific instructions regarding the removal of paint from the yoke exterior at the clamping block attachment areas and from the clamping surfaces of the clamping blocks[3]. Those manual changes had been implemented as a result of the VH-UXF investigation findings.

Examination of the failed clutch shaft

Figures 1 and 2, taken from the R22 helicopter illustrated parts catalog, show the main rotor drive system, including the clutch assembly, shaft and yoke components. The ATSB examined the following components from the assembly:

• Clutch Shaft	PN: A166-1 Rev. U	SN: 6212
• Clutch Assembly	PN: A188-2 Rev. I	SN: 6337
• Yoke	PN: A907-4	SN: 1232
• Flex plate	PN: A947-1 G	SN: Lot 242
• Flex plate bolts	PN: NAS 6605-6	SN: not applicable
• Yoke bolts	PN: NAS 1305-26	SN: not applicable

The clutch shaft had fractured at the connection to the main rotor gearbox yoke and presented a characteristic spiral fracture form, with cracking continuing down the bore of the shaft inside the yoke (refer to figure 4). Although damaged by repeated surface-to-surface contact, the fracture surfaces showed clear evidence of fatigue crack progression markings (beach marks) extending along the fracture path, to a small region of ductile overload fracture that represented the area of final shaft failure (refer to figure 5). In total, fatigue cracking had propagated circumferentially for around 450 degrees (i.e. 1¼ times around the shaft), over an axial length of approximately 25 mm.

3 Robinson Maintenance Manual, Model R22, page 7.26, Change 22, March 2004.

Figure 1 Illustration of the R22 clutch and main rotor drive assembly

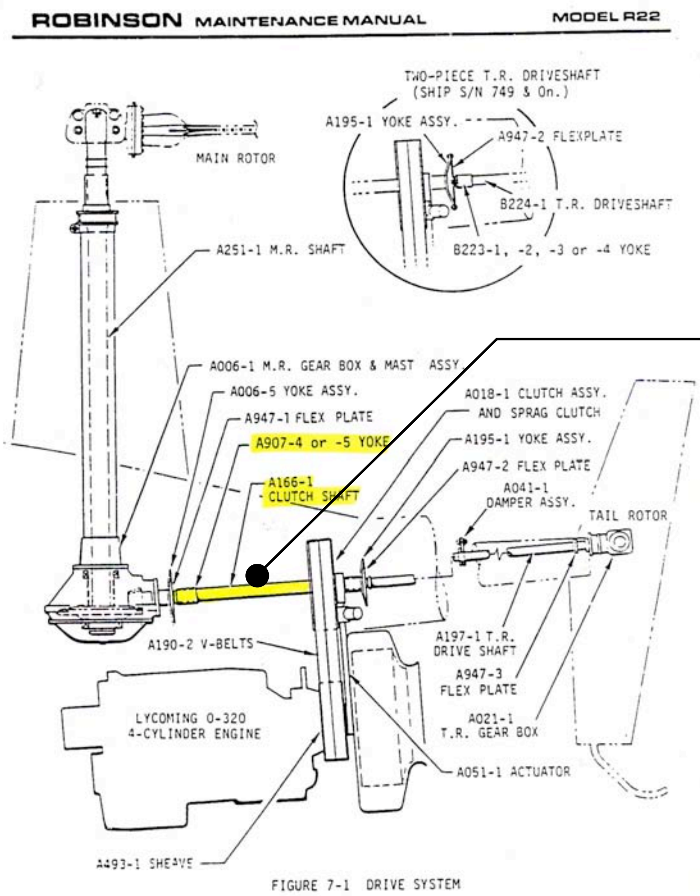


Figure 2 Clutch shaft, yoke and bolting arrangement (highlighted)

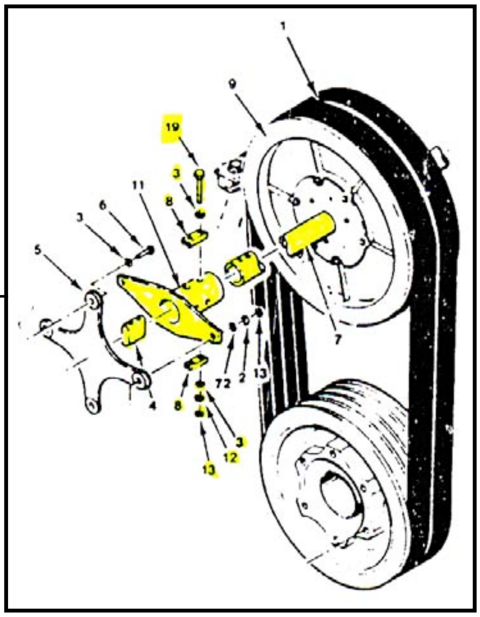


Fig. 3 Fracture coincident with the end of the forward yoke.

Fig. 4 Progression of cracking from within the shaft bore.

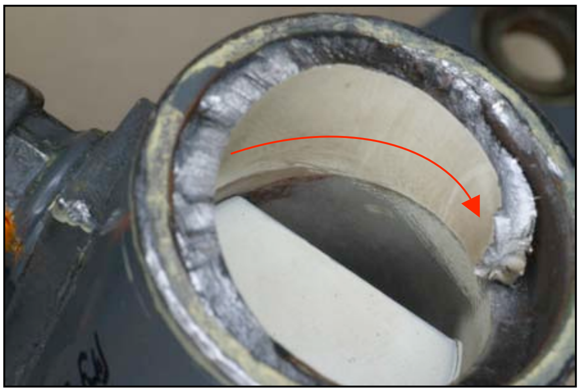
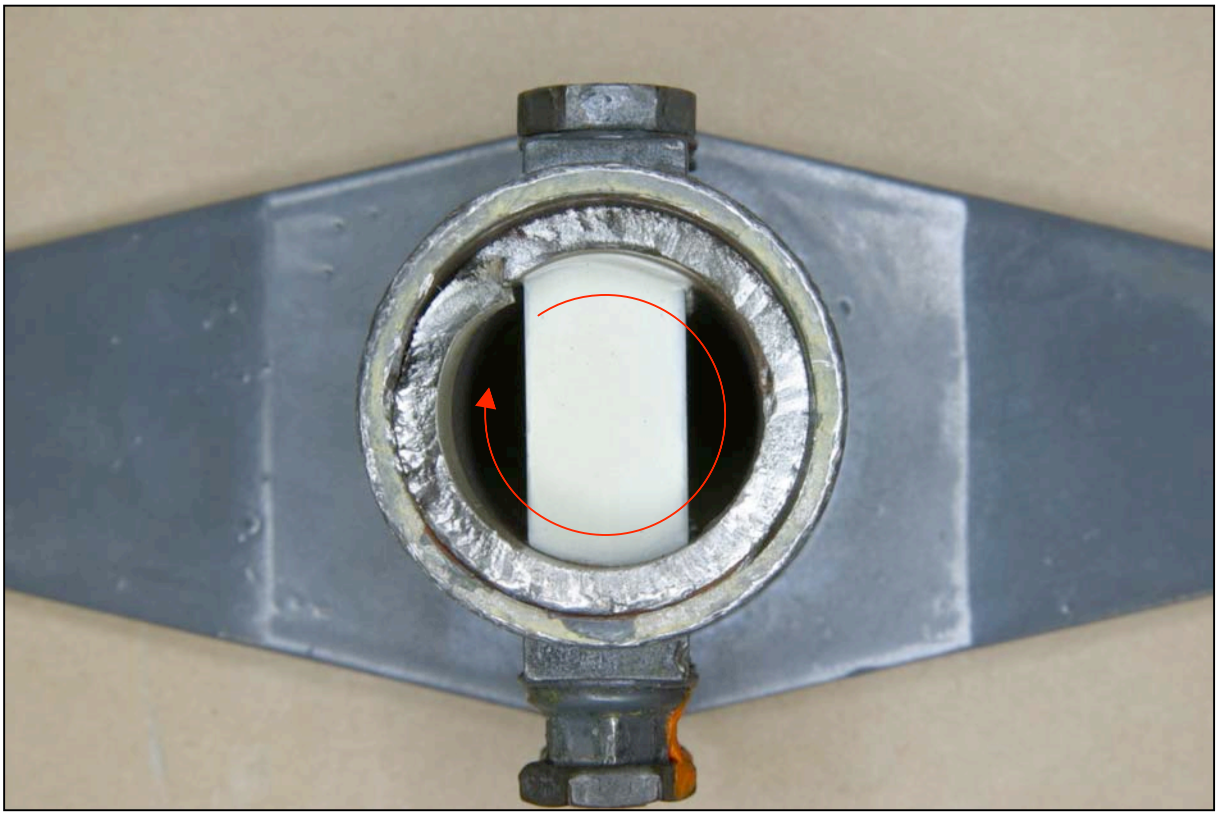


Fig. 5 Spiral nature of cracking, with direction of crack propagation indicated.



Progressive disassembly of the shaft/yoke connection revealed grey enamel external paint beneath the clamping plates (refer to figures 6, 7), with no evidence of any attempt having been made to remove the paint before the last assembly. Ridging and extrusion of the paint was evident along the edges of the block seating positions (refer to figure 8).

Figs. 6 & 7 External surfaces of the A907 (forward) yoke, showing paint beneath the clamping block seating locations on both sides.

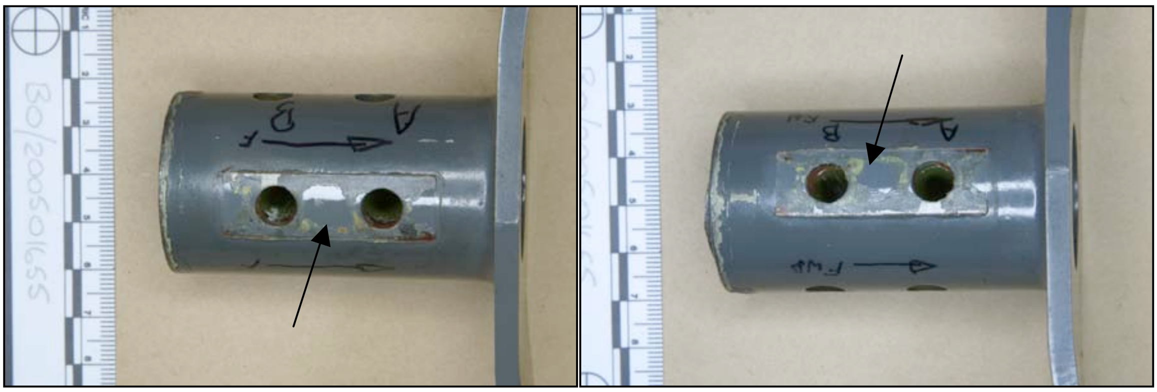


Fig. 8 Ridging and extrusion of paint (arrowed) from beneath the clamping blocks.

Fig. 9 Fretting and rubbing contact within the shaft yoke bolting holes.

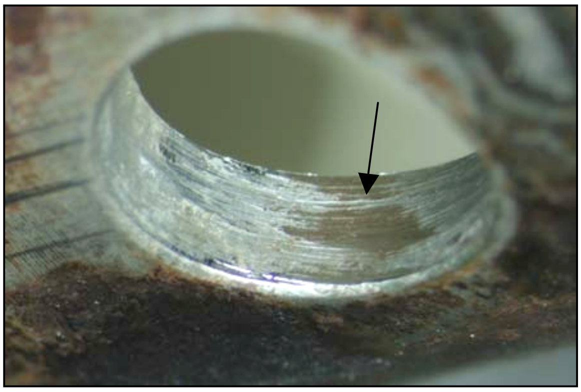


Fig. 10 Yoke through-bolts, showing comparable shank fretting damage.

Both the inside bore of the clutch shaft bolt holes (refer to figure 9) and the bolt shank surfaces passing through the shaft (refer to figure 10) showed fretting damage associated with the repeated movement of the surfaces against each other under load. The separated clutch shaft and yoke surfaces both showed extensive fretting damage, characterised by distinct surface corrosion and production of a fine brown powder-like product (refer to figures 11 and 12).

Fig. 11 Heavily fretted clutch shaft stub after removal from the yoke.

Fig. 12 Fretting damage inside yoke bore.

The separated surfaces also showed evidence of having been assembled using the wet primer method[4] recommended by the manufacturer. There was no indication or evidence of the use of a non-hardening jointing compound or any other non-approved material to assemble the joint.

The spiral fatigue crack propagating around the clutch shaft had originated from the bore of a second row bolt hole. Prominent bore surface rubbing and fretting damage surrounded the crack origins (refer to figure 13).

Sectioning of the shaft to intersect the cracked bolt hole allowed the separation and examination of the crack surfaces (refer to figure 14). Clear progression markings characterised the crack length and confirmed the bolt hole origin. Closer light and electron microscopy provided evidence that the cracking had initiated at the outer bolt hole corner and subsequently propagated inward and around the clutch shaft as flight cycles accumulated.

The examination found no evidence of material or manufacturing deficiencies within the clutch shaft or assembly components. Similarly, there was no evidence that the shaft had sustained any damage that may have predisposed the item to premature failure.

Fig. 13 Origin of fatigue cracking within a clutch shaft bolt hole. Note associated fretting.

Fig. 14 Torsional fatigue crack propagation path.

[4] Robinson Maintenance Manual, Model R22, page 7.26, 'To Install' steps 3, 4.

Previous similar failures

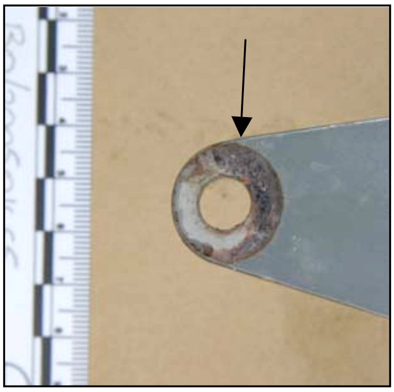
The ATSB was aware of two previous instances of clutch shaft failure stemming from torsional fatigue cracking at the forward yoke connection. Both events (ATSB occurrences 199201139, VH-HFP and 200304074, VH-UXF) were attributed to the loosening of the shaft/yoke connection. Attributed to maintenance factors, the loosening allowed shear forces to develop and act through the bolt and bolt hole surfaces. The resultant point loading and surface fretting damage produced conditions suitable for the initiation and growth of fatigue cracking under normal operational loads.

Yoke and forward flex plate

While possibly unrelated to the clutch shaft failure, both the forward yoke and flex plate also showed evidence of fretting and surface movement between the bearing surfaces (figures 15, 16). In a manner similar to the shaft connection, grey enamel paint was found on the bolt clamping surfaces of the yoke arms (figure 17).

Figs. 15, 16 **Fretting damage on the yoke and forward flex-plate bearing surfaces.**

Fig. 17 **Paint remaining on the bolt seating surfaces.**



ANALYSIS

On the basis of the physical evidence and the similarity to previous events, the investigation attributed the clutch shaft failure to a torsional fatigue cracking mechanism, initiated from a second row bolt hole within the connection to the part number A907-4 forward yoke. Propagating under operational loads, the cracking would not have been visually detectable as it developed within the yoke sleeve and would have only possibly become evident towards the final stages of growth before final failure. The initiation of fatigue cracking was directly attributed to the looseness and instability of the shaft/yoke connection, as confirmed by the extensive surface fretting throughout the joint.

Under normal intended security of the shaft/yoke connection, rotational forces are transmitted uniformly via the friction between the shaft and yoke surfaces. Security of the connection is established by adequate bolt tension and the assembly of the joint with a curing or drying primer paint. Corrosion protection is also enhanced by the use of the approved primer/s.

The assembly of the yoke - shaft connection without first fully cleaning away the external paint from underneath the block seating locations was considered a major factor in the looseness of the connection and the subsequent initiation of cracking. The noted compression and extrusion of the paint underneath the yoke clamping blocks would have allowed a loss of bolt tension and a loss in clamping force within the connection, permitting movement and the observed fretting damage.

Both the helicopter manufacturer's maintenance manual and the Civil Aviation Safety Authority airworthiness directive relating to the inspection of the yoke connection (AD/R22/51 Amdt 1) provided clear and unambiguous instructions in regard to the removal of yoke and clamping block paint coatings before assembly of the connection. The investigation was unable to determine why those instructions were not followed during the last assembly of the yoke connection.

FINDINGS

1. The clutch shaft failed as a result of the initiation and growth of a torsional fatigue crack from within the connection to the forward (A907-4) yoke.

2. Looseness and instability within the shaft – yoke connection created fretting damage between the bolt, shaft and yoke surfaces, producing surface conditions conducive to the initiation of fatigue cracking.

3. The cracking would not have been visible to inspection as it developed within the yoke sleeve.

4. The assembly of the shaft – yoke connection without first fully removing the paint from beneath the clamping block seating locations was a major factor in the development of looseness and movement within the connection.