Australian Government
Australian Transport Safety Bureau

Publication Date: May 2010 ISBN 978-1-74251-055-2

Australian Transport Safety Bureau
PO Box 967, Civic Square ACT 2608
Australia

1800 020 616

+61 2 6257 4150 from overseas

www.atsb.gov.au

May10/ATSB84

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

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation AO-2009-019
Final

Engine cooling fan fracture, VH-IDU Rolleston, Queensland - 3 May 2009

Abstract

On 3 May 2009 at approximately 0620 Eastern Standard Time, a Bell Helicopter Company model 47G-2A-1 helicopter departed Rolleston aircraft landing area, Queensland, on a private flight. At an altitude of approximately 200 ft above ground level during the climbout, the pilot reported hearing a very loud bang and feeling a jolt through the airframe. The helicopter immediately started descending and the pilot noted that the forward/aft cyclic control was unresponsive. The helicopter subsequently landed heavily, resulting in the main rotor blades severing the tail boom and causing some structural damage to the airframe. The pilot reported suffering a minor back injury as a result of the heavy landing.

The Australian Transport Safety Bureau's (ATSB) examination of the helicopter revealed that two blades had separated from the engine cooling fan as a result of fatigue fracture. The fan cowling had fractured and separated from the engine and there was impact damage to the flight control linkages.

The ATSB examination determined that the fan unit had not been correctly assembled in accordance the Bell 47 aircraft maintenance manual, and that this probably had an effect on the vibration and resonance characteristics of the fan, which in turn may have increased the susceptibility of the fan to fatigue failure.

As a result of this occurrence, the Civil Aviation Safety Authority released Airworthiness Bulletin AWB 63-007, reminding operators and maintainers of the importance of adhering to all current manufacturer's approved data for sheet metal cooling fans and their drive assemblies.

FACTUAL INFORMATION

History of the flight

On 3 May 2009 at approximately 0620 Eastern Standard Time[1] a Bell Helicopter Company 47G-2A-1 helicopter departed Rolleston aircraft landing area, Queensland, on a private flight. After warming up the engine for approximately 7 minutes, the pilot, who was the sole occupant, reported spending some time monitoring the helicopter in the hover and that 'everything felt good'.

The helicopter subsequently departed, and during the climb through 100 ft above ground level (AGL), the pilot noticed the onset of vertical vibrations and observed that the main rotor blades were slightly out of track. The pilot reduced the forward speed, and at approximately 200 ft AGL, reduced the collective pitch lever[2], after which the helicopter's behaviour briefly returned to normal, before the pilot heard a very loud bang and felt an airframe jolt.

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

2 A pilot control in rotary wing aircraft directly affecting the pitch of all blades of lifting rotor(s) simultaneously, irrespective of azimuth position; the main control for vertical velocity.

The pilot reported that the helicopter immediately started descending in a violent forward/aft pitching manner. The pilot found that the forward/aft cyclic control[3] had jammed, but he was able to use lateral cyclic control to turn the helicopter away from trees. An increase in engine revolutions was heard, even though the collective lever had not changed position. The pilot reported immediately decreasing the throttle and lowering the collective. Upon approaching the ground, the pilot raised the collective rapidly in an attempt to cushion the landing. Despite this, the helicopter landed heavily, resulting in the main rotor blades severing the tail boom and causing some structural damage to the airframe. The helicopter landed approximately 1 km from the point of departure. The pilot reported suffering a minor back injury as a result of the heavy landing.

Damage to the helicopter

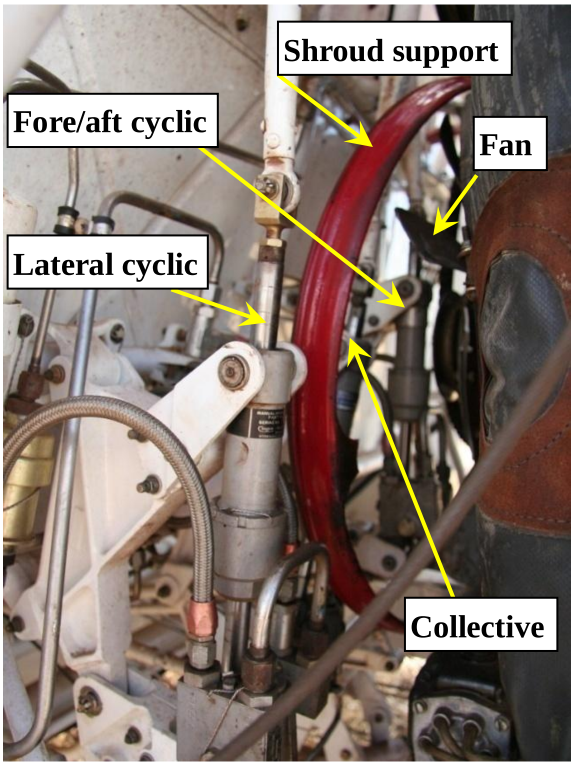
The tail of the helicopter was severed by the main rotor blades and damage was sustained by the airframe as a result of the hard landing (Figure 1). The engine cooling fan had fractured and three of the 16 blades were missing (Figure 2). The fan shroud support was fractured and showed evidence of contact with the rotating fan. Damage was also sustained by the flight controls located forward of the engine cooling fan, including chafing of the control rods and fracture of the lower control rod connected to the fore/aft cyclic servo unit (Figure 3).

Figure 1: VH-IDU

3 The cyclic control is the primary helicopter flight control causing the disc to tilt in desired direction to cause the helicopter to rotate about the pitch or roll axis.

Figure 2: Cooling fan assembly

Figure 3: Fractured cooling fan and shroud support adjacent to the flight controls



Aircraft information

VH-IDU was registered as a Bell Helicopter Company model 47G-2A-1, serial number 6765, and was fitted with a Textron-Lycoming VO-435-AIF engine. Information from the manufacturer, indicated that the airframe had been reconfigured from the original 47G-3B2 model, as manufactured in 1970.

Pilot information

The pilot held a current medical certificate and private pilot's licence, and was originally endorsed on rotary wing aircraft around 2001. The pilot's flying history included approximately 3,000 hours in fixed wing and 200 hours in rotary wing aircraft, including approximately 130 hours in VH-IDU.

Maintenance history

The helicopter had accumulated about 8,470 hours total time in service (TTIS) and the last 100-hourly inspection was carried out in December 2008, at 8,462.8 hours TTIS.

There was a discrepancy between the fan part number etched onto the fan itself (47-661-029-7), compared with that recorded in the maintenance documentation (47-661-029-9). The serial number (A34-7382) was the same in both cases. The installed 47-661-029-7 fan was the correct part for fitment to a model 47G-2A-1 helicopter, whereas the 47-661-029-9 fan was the correct part for the original 47G-3B2 model. The factors contributing to the discrepancy were not determined.

The total time in service for the cooling fan was not recorded, nor was there any requirement for it to be. The fan was operated 'on-condition'[4], with overhaul of the fan assembly conducted at 1,200-hour intervals.

The fan had accumulated 133 hours since the last overhaul, the records of which indicated that it was carried out in 2001 at 8,337 hours TTIS. During that overhaul, the cooling fan was non-destructively inspected for cracks, with 'nil defects' recorded. There was no evidence that rework had been conducted on the fan at, or since that time.

Cooling fan examination

The cooling fan was manufactured from anodised[5] aluminium sheet, and was located forward of the engine and immediately behind the flight control linkages.

Three blades were separated from the fan (Figure 2) as examined after the accident. Separation of two of the blades was associated with a fracture running through the blade disc, whereas the third blade had fractured through the blade root, with the section remaining on the disc being heavily plastically deformed. The separated blades were not recovered. Several of the remaining blades showed deformation consistent with rotational contact. Corresponding damage was observed on the fan shroud support.

The bearings in the fan assembly were free and smooth when turned by hand. The pilot also reported that the drive belts had adequate tension when inspected on the morning of the accident.

Examination of the fan assembly found three fan rings on the forward side and a single fan ring on the aft side (Figure 4). This differed from the maintenance manual specification of three fan rings on the forward side and a *fan spacer* on the aft side (Figure 5).

The fatigue crack originated on the aft side of the fan, adjacent to the bolt circled in Figure 4, and progressed predominantly in an anticlockwise direction as viewed from the front - opposite to the direction of fan rotation. The bolt at the location of the fatigue origin had an extra washer under the nut – presumably for the purpose of static balancing.

The fracture surface through the fan disc showed 'beach' or 'crack arrest' marks consistent with fatigue crack progression. Due to the presence of the fan rings, the fatigue cracking would not have been visible without disassembly of the unit. The fracture through the third blade root was consistent with ductile overload.

Microscopic examination revealed no defects or anomalies at the fatigue crack origin. Examination of the fatigue fracture surface by scanning electron microscope showed a regular striated patterning, consistent with high-cycle fatigue cracking.

---

4 Periodically inspected and returned to service if satisfactory.

5 A protective treatment creating a heavy and impervious surface oxide layer.

Figure 4: Cooling fan assembly (side). Additional fan ring arrowed

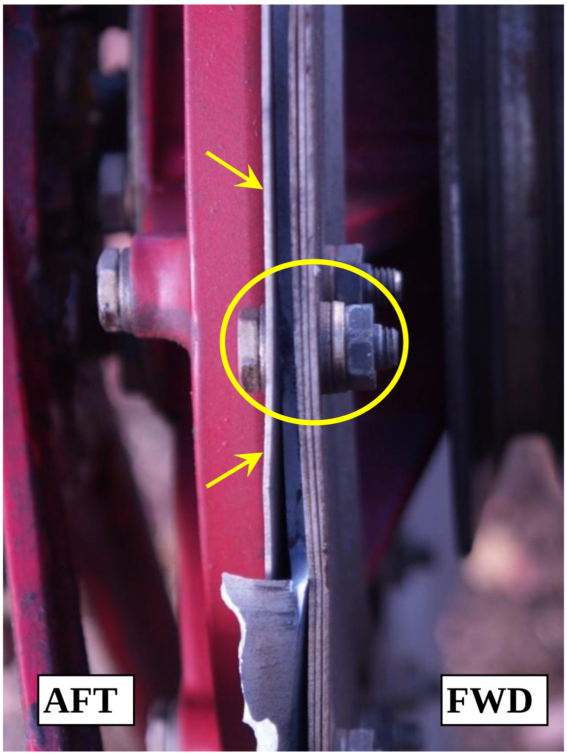
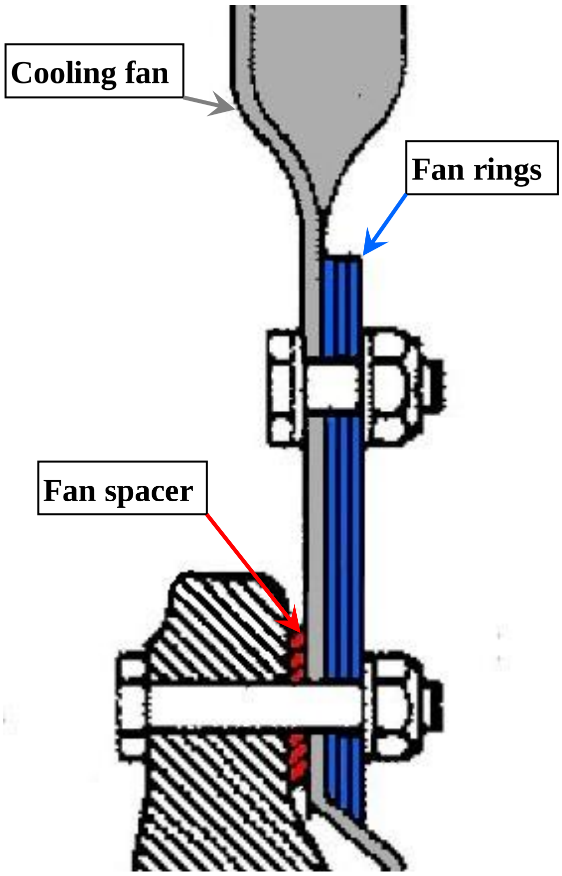


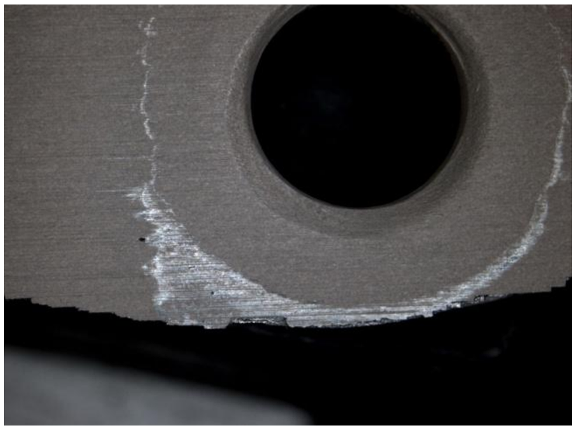
Figure 5: Cooling fan assembly (Bell 47 maintenance manual)



Fretting[6] between the fan and fan ring surfaces was evidenced by paint wear adjacent to most of the outer ring of boltholes and at discreet locations on the fan surface (Figure 6). The damage adjacent to the boltholes was at the outside (blade side) of the disc, where it was expected that fretting would most likely occur as a result of vibration of the fan blades. Bolt torque was not measured during disassembly; however the absence of fretting damage directly under the bolt bearing surfaces suggested that the torque had been sufficient to prevent relative movement between these surfaces. Superficial abrasion marks were also observed over the fan surface and may have been present as a result of the manufacturing process.

The alloy composition was assessed by quantitative energy dispersive spectroscopy (EDS) and was consistent with a 2024 aluminium alloy. The measured hardness was also appropriate for 2024 in an age-hardened (strengthened) condition.

Figure 6: Abrasion marks and fretting damage at bolthole



Previous occurrences

A search of the Civil Aviation Safety Authority (CASA) service difficulty report (SDR) system from 1982 to 2009, found five reports relating to corrosion, fatigue, or separation of blades from Bell 47 / Kawasaki KH4 engine cooling fans.

6 Fretting refers to the wear process that occurs at the contact area between two materials under load and subject to minute relative motion by vibration or some other force (ASM Handbook).

The then Bureau of Air Safety Investigation (later becoming part of the ATSB) investigated one cooling fan failure from a Kawasaki 47G3B-KH4 in 1995 (investigation number 199501019[7]). In that occurrence, a loud bang was heard by the pilot, followed by a restriction felt in the flight controls. Subsequent inspection of the helicopter revealed that a two-bladed segment of the fan had been released as a result of the initiation and propagation of a fatigue crack. A single blade was released due to an overstress condition and considered secondary to the fatigue.

The investigation concluded that the noise and restriction of the cyclic controls may have been a result of damage caused by the fan failure. Furthermore, the investigation found that aspects of the fan surface finish and assembly differed from the maintenance manual and probably affected the vibration characteristics of the fan, as well as having a detrimental effect on resistance to fatigue.

ANALYSIS

The loud noise and jolt reported by the pilot was as a result of the high-cycle fatigue cracking, failure and release of a two-bladed segment from the engine cooling fan, as well as the secondary fracture of the third fan blade and of the fan shroud support. It was likely that the subsequent jamming of the fore/aft cyclic control was a result of interference between the failed components and the flight controls.

The rate of fatigue crack growth is a function of the number and frequency of alternating stress cycles of a magnitude sufficient to incrementally propagate the crack. Variations in the fan condition or assembly could increase the magnitude or frequency of stresses.

Vibratory loading can potentially contribute to thousands of fatigue cycles for every minute of operation. Furthermore, the fan could enter a state of resonance if the forces acting on the fan match its natural frequency. In the case of a resonant condition developing, the amplitude of oscillation would be much larger than that expected under normal operating conditions and could lead to rapid fatigue initiation and failure.

Factors that could contribute to the development of damaging fatigue stress cycles include:

- operation of a fan that was out of balance,
- exceeding aircraft operational limits in the critical RPM band (as indicated by markings on the engine RPM gauge), which may result in a resonant condition, and
- variations in the cooling fan condition or assembly outside maintenance manual specifications.

In this occurrence, the substitution of the fan ring for the fan spacer on the aft side of the fan assembly would probably have affected the relative stiffness of the assembly, as well as slightly altering the distance between the blades and surrounding structures, such as the shroud supports. This could result in a change to the frequency and amplitude of vibrational stresses, or change the fan's inherent resonance characteristics. Experimentation in this area would need to be conducted to quantify the extent of influence on fatigue crack initiation and propagation.

Resistance to fatigue initiation is also sensitive to surface finish. The presence of scratches in the fan surface may have acted as local stress concentrators and increased the susceptibility of the fan to fatigue cracking. The scratches were present underneath the anodised coating and were regular in appearance, despite their random orientation. This suggested they were probably present from manufacture rather than any specific maintenance action.

FINDINGS

Context

From the evidence available, the following findings are made with respect to the engine cooling fan failure and loss of control of the Bell 47G-2A-1 helicopter, registered VH-IDU, and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The resonance and vibration characteristics of the cooling fan were probably altered by the incorrect assembly of the fan drive unit, which

7 Available at www.atsb.gov.au.

differed from that specified in the helicopter's maintenance manual.

- The separation of two blades from the engine cooling fan was as a result of the initiation and propagation of a fatigue crack.
- It was likely that the loss of aircraft control was as a result of interference between the failed engine cooling fan components and the adjacent flight controls
- The co-location of the engine cooling fan and flight control systems increased the susceptibility of the helicopter to control problems in the event of a cooling fan failure *[Minor safety issue]*.

Other safety factors

- The fatigue endurance of the fan (its ability to resist crack initiation) may have been reduced by the presence of superficial abrasion scratches in the surface of the disc.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Action 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 organisations. In addressing those issues, the ATSB prefers to encourage relevant organisations 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.

Civil Aviation Safety Authority (CASA)

Safety issue

The co-location of the engine cooling fan and flight control systems increased the susceptibility of the helicopter to control problems in the event of a cooling fan failure.

Action taken by CASA

As a result of this occurrence CASA released airworthiness bulletin AWB 63-007 on 20 January 2010, reminding operators and maintainers of the importance of adhering to all current manufacturer's approved data for cooling fans manufactured from sheet metal and their drive assemblies.

CASA also advised that the European Aviation Safety Agency (EASA) has identified AWB 63-007 for wider distribution.

ATSB assessment of action

The action taken by CASA appears to minimise the risks associated with this minor safety issue.

SOURCES AND SUBMISSIONS

Sources of information

- pilot of VH-IDU
- maintenance provider of VH-IDU
- Civil Aviation Safety Authority (CASA)
- Bell 47 Aircraft Maintenance Manual.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the 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 aircraft manufacturer, pilot in command and one of the maintenance providers of VH-IDU, as well as CASA and the US National Transportation Safety Board (NTSB).

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