

Australian Government Australian Transport Safety Bureau

Main rotor blade crack and precautionary landing involving Robinson R22 Beta, VH-HPH

12 km south-west of Labelle Downs Station, Northern Territory, on 16 December 2016

ATSB Transport Safety Report Aviation Occurrence Investigation AO-2016-174 Final – 5 May 2020 Released in accordance with section 25 of the Transport Safety Investigation Act 2003

Publishing information

Published by:	Australian Transport Safety Bureau
Postal address:	PO Box 967, Civic Square ACT 2608
Office:	62 Northbourne Avenue Canberra, Australian Capital Territory 2601
Telephone:	1800 020 616, from overseas +61 2 6257 2463 (24 hours)
	Accident and incident notification: 1800 011 034 (24 hours)
Email:	atsbinfo@atsb.gov.au
Internet:	www.atsb.gov.au

© Commonwealth of Australia 2020



Ownership of intellectual property rights in this publication

Unless otherwise noted, copyright (and any other intellectual property rights, if any) in this publication is owned by the Commonwealth of Australia.

Creative Commons licence

With the exception of the Coat of Arms, ATSB logo, and photos and graphics in which a third party holds copyright, this publication is licensed under a Creative Commons Attribution 3.0 Australia licence.

Creative Commons Attribution 3.0 Australia Licence is a standard form license agreement that allows you to copy, distribute, transmit and adapt this publication provided that you attribute the work.

The ATSB's preference is that you attribute this publication (and any material sourced from it) using the following wording: *Source:* Australian Transport Safety Bureau

Copyright in material obtained from other agencies, private individuals or organisations, belongs to those agencies, individuals or organisations. Where you want to use their material you will need to contact them directly.

Addendum

Page	Change	Date

Safety summary

What happened

On the afternoon of 16 December 2016, the pilot of a Robinson Helicopter Company (Robinson) R22 Beta, registered VH-HPH and operated by North Australian Helicopters, was conducting mustering operations at Labelle Downs Station in the Northern Territory. About 12 km south-west of the station property, the pilot was alerted to the onset of vibrations and conducted a precautionary landing. The landing was accomplished without incident. A subsequent ground inspection revealed the presence of a large crack through one of the main rotor blades.

What the ATSB found

Laboratory analysis of both main rotor blades (part number A016-6) at the ATSB's facilities in Canberra identified that a significant fatigue crack had propagated almost entirely through the blade chord at rotor station 61.3, which led to instability and vibrations of the aerofoil structure during the occurrence flight. The analysis identified that the fatigue crack initiated at the trailing edge bond line, and propagated through both the upper and lower blade skins until terminating at the leading edge D-spar.

It was possible that a number of variables influenced the initiation of the blade cracking, including the component's design, manufacture and operation. The ATSB was unable to determine conclusively which factors, either individually or in combination, contributed to the crack initiation.

A search of aviation defect databases found no other examples of fatigue cracking in R22 A016-6 main rotor blades. The helicopter manufacturer reported to the ATSB that they were only aware of one other instance of A016-6 blade cracking.

What's been done as a result

Following the occurrence, on 22 December 2016, Robinson issued a Safety Alert 'A016-6 Main Rotor Blade Crack'. It detailed the crack location, and recommended particular attention from pilots and maintainers when visually examining the trailing edges of blades during the daily or pre-flight inspection.

Robinson also redesigned the A016-6 main rotor blades to allow for a longer trailing edge doubler in order to eliminate potential stress gradients from stiffness variations along the trailing edge. A prototype A016-6 blade containing the extended doubler was test flown in January 2017, before entering production as Revision AV blades in February 2017.

The Australian Civil Aviation Safety Authority issued an Airworthiness Bulletin (AWB) 62-006 *(R22 Main Rotor Blade Cracking)* to alert R22 operators and maintainers of the occurrence. The AWB was released on 23 December 2016 and highlighted the need for particular vigilance during the daily or pre-flight checks of the main rotors, and for pilots to be alert to sudden and increased vibrations.

Finally, North Australian Helicopters reinforced with staff the manufacturer's recommended procedures for conducting the daily and pre-flight inspection of the main rotor blades and the need to land immediately should unusual vibrations increase or develop during flight.

Safety message

The ATSB reminds helicopter pilots, operators and maintainers that fatigue cracking can occur on critical flight components. Particular vigilance should be applied during the daily or pre-flight inspections as they represent an important opportunity to detect cracking. As recommended by Robinson in their Safety Alert, *'A016-6 Main Rotor Blade Crack'*, any form of damage such as

paint blistering, denting, and corrosion to the main rotor blade surfaces is cause for further investigation. Pilots are also reminded to heed Robinson's advice contained in Safety Notice 39 'Unusual vibration can indicate a main rotor blade crack'.

A catastrophic rotor blade fatigue failure can be averted if pilots and mechanics are alert to early indications of a fatigue crack.

If main rotor vibration rapidly increases or becomes severe during flight, make an immediate precautionary landing. Do not attempt to continue flight to a convenient destination.

Robinson R22 Beta, VH-HPH



Source: North Australian Helicopters

The occurrence

On the afternoon of 16 December 2016, a Robinson Helicopter Company (Robinson) model R22 Beta (R22) helicopter, registered VH-HPH, was being operated on an aerial stock mustering flight at Labelle Downs Station in the Northern Territory. The helicopter was approximately 12 km from the station homestead when the pilot noted the onset of vibrations. In response, the pilot conducted a precautionary landing and shutdown the helicopter. A subsequent inspection revealed a significant crack in one of the main rotor blades. The crack had progressed almost entirely through the blade cross-section (Figures 1 and 2).



Figure 1: The main rotor blade crack is identified near rotor station 61

The measurement scale positioned along the trailing edge is from the blade tip. Source: North Australian Helicopters, annotated by ATSB

Both main rotor blades were removed from the helicopter, packaged, and transported to the ATSB for laboratory examination. Initial inspection confirmed that an extensive chord-wise¹ crack had propagated from the trailing edge through both the upper and lower blade skins, stopping just short of the leading edge D-spar.

¹ The front of a rotor blade is identified as the leading edge; the rear of the blade is the trailing edge. The chord is the distance from the leading edge to the trailing edge.



Figure 2: Closer view of the cracked main rotor blade from the lower surface

Source: North Australian Helicopters, annotated by ATSB

Context

Helicopter information

The Robinson R22 is a light-utility, two-seat helicopter, powered by a four-cylinder Textron Lycoming piston engine. At the end of 2019, there were 616 R22 helicopters on the Australian civil aircraft register. The Australian fleet is predominantly utilised for aerial stock mustering operations, which is a unique application, conducted in northern Australia during the dry season (April-October).² Flying training, business and private flights make up the remainder of the Australian fleet usage.

Helicopter history

The occurrence helicopter, serial number 3988, was manufactured in the United States (US) in 2005 and first registered in Australia as VH-HPH in January 2006. After importation and registration, the helicopter was introduced into service in northern Australia for mustering and other related purposes.

Over the next 5 years of operation, the helicopter accrued 1,738 hours total time in service (TTIS). In May 2011, during a routine inspection, the blades were identified as unserviceable due to denting and delamination of the aerofoil structure. The unserviceable blades, part number A016-4, were removed and replaced with a latter variant, part number A016-6 (Revision AR), serial numbers (SN) 0119 and 0133.

In November 2014, while operating out of Labelle Downs Station, the helicopter sustained a heavy landing due to the failure of a pitch link within the tail rotor assembly.³ A suspected rotor overspeed occurred during that incident, where the main rotor revolutions per minute (RPM) exceeded the certificated limit of 104 per cent (530 RPM). Both A016-6 main rotor blades were removed and submitted to an overhaul facility for repair.

Component history cards for the A016-6 blades, SN 0119 and SN 0133, indicated that they had accrued 1,018.7 hrs TTIS at the time of the hard landing. The blades were inspected and the blade spindles overhauled. No other defects or repair activity to the main rotor blades were documented in the component history cards. The blades were subsequently reinstalled while the helicopter underwent further repairs from the damage sustained in the heavy landing.

The last maintenance recorded in the helicopter logbooks was on 2 December 2016, at 3,500.9 hours TTIS for the routine 100-hour inspection. The helicopter was operated for an additional 31.8 hours after the 100-hour inspection. At the time of the precautionary landing, the helicopter had accrued 3,532.7 hours TTIS and both main rotor blades had accrued 1,794.7 hours TTIS.

Main rotor blade information

Robinson have progressively changed the main rotor blade design since the R22 Beta was first certified. Each major change in the construction or materials constituted a change to the part number. For example, one of the differences between the part number A016-2 and part number A016-4 blade was a redesigned root fitting. A minor design change was denoted by a change to the blade revision code, for example AR, AV etc.

The A016-6 main rotor blade variant incorporated an aluminium alloy upper and lower skin, replacing the stainless steel skin used in the previous A016-4 blade type. The A016-6 blades were

² Australian Transport Safety Bureau, Research Report BE04/73, Light utility helicopter safety in Australia, 2004

³ Australian Transport Safety Bureau, Investigation AO-2014-181, Tail rotor malfunction involving a Robinson R22, registration VH-HPH, Labelle Downs Station, Northern Territory on 18 November 2014

life-limited⁴ parts that could be operated up until reaching 2,200 hrs TTIS, or 12 years from the date of the factory-issued authorised release certificate, whichever came first.

Blade manufacturing process

Manufacturing records obtained from Robinson for blades SN 0133 and SN 0119 showed that the A016-6 blades were made in separate batch lots over a five-month period commencing in September 2010. Structural adhesive was used to bond the upper and lower skin to the honeycomb core, D-spar and root fitting. A doubler reinforcement strip of stainless steel was bonded between the upper and lower skins at the blade trailing edge, terminating at rotor station 61 (measured 61 inches from the main rotor centreline). The assembled components were then clamped and heated under pressure at elevated temperature, allowing the adhesive to cure. A fillet of flexible epoxy sealant along the trailing edge bond line between the upper and lower skins provided protection from moisture ingress and corrosion.

Figure 3: Diagram of the A016-6 (Revision AR) blade

Source: Robinson Helicopter Company, annotated by ATSB

Manufacturing quality assurance

Part of the quality assurance checks during manufacture involved an inspection for defects associated with the adhesive bonding process. The surfaces of each blade were non-destructively inspected using a tap-test method to detect for voids between the bonded parts. No defects from the tap testing were noted in the manufacturing batch records for blade SN 0133 and SN 0119.

Coupons⁵ from each blade were also mechanically tested to assess the strength of the adhesive bonding. The results contained in the batch records for each blade confirmed that the cured adhesive was at a maximum strength condition.

⁴ Federal Aviation Administration Code of Federal Regulations, CFR 43.10, Life-limited part means any part for which a mandatory replacement limit is specified in the type design, the Instructions for Continued Airworthiness, or the maintenance manual. Life status means the accumulated cycles, hours, or any other mandatory replacement limit of a life-limited part.

⁵ Robinson main rotor blades contain additional blade material for machining into test coupons. Mechanical testing of the coupons to an industry standard allows the determination of common static or dynamic mechanical properties. In this case, Robinson assessed for cohesive and adhesive bond strength.

History of related main rotor blade failures

Early-variant R22 main rotor blades

Since 1996, state agencies and regulatory authorities have conducted several R22 accident investigations⁶ due to in-flight fracture and separation of the A016-2 main rotor blade-type. Fatigue cracking was found to have initiated within a bolt hole associated with the blade root fitting. Those failures prompted a redesign of the root fitting by Robinson, issuing the A016-4 blade in 2004. The Civil Aviation Safety Authority (CASA) issued an Airworthiness Directive⁷ in February 2006 that required all Australian operators remove the A016-2 blades from service and replace them with the A016-4 variant.

Following a fatal accident⁸ associated with skin-to-spar line delamination of an A016-4 main rotor blade, and further instances of skin-to-spar delamination across the R22 fleet, an Airworthiness Directive⁹ was released by the US Federal Aviation Administration (FAA) in 2011 that enhanced the existing blade inspection requirements. An additional FAA Airworthiness Directive¹⁰ became effective in 2015, requiring the replacement of all A016-4 blades with the alloy-skinned A016-6 variant within a five-year period.

Other A016-6 blade cracking occurrences

The ATSB investigation conducted a search of the CASA and the FAA service difficulty-reporting databases. These databases allow operators, owners and maintainers to report and view major defects with aircraft or parts. No other instances of A016-6 main rotor blade cracking were recorded in either database.

Robinson advised the ATSB that they were aware of one other occurrence of cracking involving an A016-6 main rotor blade. The cracking occurred at a similar location as that identified in blade SN 0133, from VH-HPH. The blade was fitted to an R22 based in Mexico performing tuna spotting operations in a coastal environment (Figure 4). Robinson advised that the operator had attempted an unauthorised repair by stop drilling¹¹ the crack tip, however the cracking progressed to the leading edge spar, prompting the blade to be removed from service prior to complete failure. The defective blade had accrued 1,800 hours TTIS.

⁶ ATSB Aviation investigation 200302820, VH-OHA, Bents Basin State Recreation Area, NSW, 20 June 2003 ATSB Aviation investigation 200003267, VH-LDR, Yarromere Station, Qld, 29 July 2000 ATSB Aviation investigation 19900089, VH-HBS, 27 May 1990 State of Israel Ministry of Transportation investigation, Accident No. 6-04, 4X-BCM, 29 February 2004 New Zealand Civil Aviation Safety Authority investigation 04/3712, ZK-HWP, November 2004

⁷ CASA AD/R22/53, Main Rotor Blades, 2/2006

⁸ NTSB Investigation No. WPR10WA070, Robinson R44, 4X-BDM, Netany Bay, Israel, 24 November 2009

 ⁹ US Federal Aviation Administration, Airworthiness Directive, 2011-12-10 Robinson Helicopter Company Helicopters, 17 June 2011

¹⁰ US Federal Aviation Administration, Airworthiness Directive, 2014-23-16 Robinson Helicopter Company

¹¹ Stop drilling is a technique to enhance the life of a cracked structure that involves drilling a small circular hole at the crack tip.

Figure 4: Cracking in an A016-6 blade from a Mexican R22

Source: Robinson Helicopter Company; annotated by ATSB

A016-6 main rotor blade design change

During the course of this investigation, Robinson advised the ATSB that they had conducted a minor redesign of the A016-6 main rotor blades. The redesign included extending the length of the A302 stainless steel doubler that was adhesively bonded along the trailing edge of the A016-6 blade. The length of the doubler was extended further outboard, terminating beyond the chord transition at rotor station 96 (Figure 5).

Robinson further advised that the intent of the A302 doubler extension was to minimise the potential stress gradient as a result of the change in stiffness at that location. Revision AV A016-6 blades containing the extended doubler were test-flown in January 2017 and subsequently implemented into production in February 2017.

For the newer Revision AV main rotor blades, the trailing edge doubler was extended outboard from rotor station 61 (near the point of cracking in this occurrence) to rotor station 96. Source: Robinson, modified by ATSB.

Previous research – R22 aerial mustering usage profile

The ATSB previously¹² commissioned an engineering analysis to study the forces acting on a Robinson R22 while engaged in aerial mustering operations. The study provided a comparison of the flight profiles in Australian aerial mustering operations and compared these with the flight profiles used for certification.

The published report found that for the R22, aerial mustering exhibited frequent low-speed manoeuvring and rapid power changes. The report found that throughout a mustering season, many flights were short in duration, with the major proportion spread over a time period ranging from 10 to 60 minutes. Higher loads and associated peak stresses were also found to develop in the helicopter drive system (including the main rotor blades) during those flights when compared against the certification flight profile. The report concluded that:

Light utility helicopters are likely to remain engaged in aerial mustering operations. The R22 has been the most popular model for these types of operations, but owners and operators need to fully appreciate the stresses placed on aircraft during mustering operations, and the characteristics of aerial mustering operations, which may be quite different to the type of flying for which the type originally received certification.

Major stresses within a helicopter main rotor blade are created at the commencement of each flight cycle when the blades are accelerated and lift forces generated, (Prouty, 1988). Three types of primary blade loading conditions create variable alternating stresses in the blades during operation of the helicopter, (FAA, 2019):

- loading from rotation of the main rotor assembly as a function of main rotor speed leading to axial stresses at the blade hub
- out-of-plane loads that are produced by lift that result in upward bending of the outer sections
 of the main rotor blades
- in-plane bending loads from drag forces that are generated by main rotor rotation and helicopter flight.

Main rotor blade inspection requirements

Guidelines for the scheduled inspection of the main rotor blades are contained in the *Robinson R22 Maintenance Manual* and the *Pilot's Operating Handbook* (POH). Until the 2,200 hour or 12 year life-limit is reached, the required inspections that relate to the main rotor blades consist of the daily or pre-flight, and the 100-hourly or 12 month annual inspection, whichever comes first.

100-hour inspection

A detailed visual inspection and a tap test¹³ of fatigue critical areas of each main rotor blade was required as part of the 100-hour inspection outlined in Section 2.410 of the *R22 Maintenance Manual* was. The specific detail for that inspection listed in Section 9.410 of the manual required inspection for damage such as scratches, dents, voids and local deformations.

Visual inspection is widely used for detecting and examining aircraft surfaces for cracks, which are particularly important because of the relationship to structural failures, (FAA, 2018). Visual inspection aids such as a flashlight, a mirror, or a magnifying glass may be used to aid the inspection process. A work stand or platform is typically required to access the main rotor blades due to their height above the ground.

¹² ATSB Aviation Research and Analysis report – B2004/0292, Robinson R22 helicopter aerial mustering usage investigation, October 2007.

¹³ A basic non-destructive method using a coin to determine voids and areas of debonding in composite materials via the change in sound associated with these defects when the surface is tapped.

No defects associated with the main rotor blades of the occurrence helicopter were recorded in the maintenance records from the last 100-hour inspection.

Daily or pre-flight inspections

It is an Australian regulatory requirement that the daily or pre-flight inspection be performed in accordance with the *R22 Pilot's Operating Handbook* (POH) by either a licensed aircraft maintenance engineer, a pilot endorsed on the aircraft type, or an otherwise approved person. The daily or pre-flight inspections of the helicopter are intended to provide a regular opportunity to ensure the airworthiness and satisfactory general condition of the helicopter. Section 4 of the R22 POH provides a list of items that require direct inspection. With regard to the main rotor blades, the POH issues the following requirement:

Main Rotor

Blades Clean and no damage / cracks

The maintenance release issued to VH-HPH that was current at the time of the occurrence confirmed the completion of the required daily inspections, with no record of any blade defects.

Manufacturer's safety advice

Safety notice

In July 2003, Robinson published Safety Notice SN-39, *'Unusual Vibration Can Indicate a Main Rotor Blade Crack'*. The notice was required to be inserted at the rear of the R22 POH, and provided advice to pilots and operators on the association between main rotor vibrations and the potential development of fatigue cracks:

UNUSUAL VIBRATION CAN INDICATE A MAIN ROTOR BLADE CRACK

A catastrophic rotor blade fatigue failure can be averted if pilots and mechanics are alert to early indications of a fatigue crack. Although a crack may be internal to blade structure and not visible, it will likely cause a significant increase in rotor vibration prior to final failure. If a rotor is smooth after balancing but then goes out of balance again within a few flights, it should be considered suspect. Have the rotor system thoroughly examined by a qualified mechanic before further flight.

If main rotor vibration rapidly increases or becomes severe during flight, make an immediate safe landing. Do not attempt to continue flight to a convenient destination.

Laboratory examination

Visual examination

The upper surface of each blade is shown as it was received at the ATSB's engineering laboratory in Figure 6. Manufacturing identifiers were contained on a data plate fixed to the blade root region, containing the following detail:

Cracked blade: part number A016-6, Revision AR, Serial Number 0133 Partner blade: part number A016-6, Revision AR, Serial Number 0119

Measurements showed that the crack in SN 0133 was located approximately 156 cm (61.3 inches) from the rotor centreline, or alternately, approximately 226 cm (90 inches) when measured from the blade tip. Design drawings supplied by Robinson identified that the location of cracking was coincident with the termination of the adhesively bonded trailing edge A302 doubler at rotor station 61. An overall condition assessment of the blade did not identify any surface damage representative of a main rotor strike to a foreign object. No rippling, creasing or deformation to the main rotor blade aerofoil surfaces were identified that might have otherwise been attributable to vibration or a hard landing.

The trailing edge of blade SN 0133 surrounding the cracking was examined in detail at higher magnification using a stereo optical microscope. Minor surface corrosion, sealant and paint loss

was evident at the trailing edge bond line (Figure 7). Qualitatively, very little corrosion product was present on the surfaces surrounding the trailing edge crack, with no evidence of deeper corrosion pitting identified. No other damage such as denting, notches or mechanical abuse was identified along the crack line that might otherwise have been contributory.

A visual examination of the partner blade, SN 0119, was also conducted. Blade SN 0119 was undamaged. There was no evidence of buckling, denting, gross deformation, or impact marks that might have provided an indicator of an operational abnormality such as a tree or wildlife strike, or a hard landing. Importantly, examination of the surfaces surrounding rotor station 61 did not reveal any cracking, corrosion or paint loss.

Figure 6: Both main rotor blades from VH-HPH, as received and compared against the A016-6 plan drawing

Source: Blade diagram Robinson, blade images ATSB

Figure 7: Trailing edge corrosion damage and paint loss to the lower surface of blade SN 0133 at rotor station 61.3

Minor surface corrosion, paint loss and bead sealant damage was identified near the crack origin on both the upper and lower surfaces. Source: ATSB

Fractography - optical examination

Blade SN 0133 was destructively cross-sectioned at rotor station 60 and 62 to allow separation of the blade halves and further detailed assessment. The surface features indicate that cracking of the blade aerofoil occurred from the trailing edge bond line, propagating through the upper and lower skins, the adhesive and the honeycomb core, before terminating close to the leading edge D-spar. The mechanism of crack growth was established to be fatigue, that is, crack initiation and progressive crack extension in response to the development of a number of repeated localised alternating stresses during operation.

The significant fracture features show three distinct regions (Figure 8):

- A region of flat, transgranular fatigue cracking extending from the trailing edge bondline forward approximately 16 mm.
- A region from 16 mm to 91 mm comprising a mixed-mode crack growth mechanism. The features in the mixed-mode region were predominantly flat and transgranular in nature, consistent with metastable, high-cycle crack growth; however, these were punctuated by pockets of tensile tearing.
- A region of ductile overstress tearing from 91 mm to 151 mm at the crack tip.

A high-magnification optical study of the surfaces at the trailing edge fatigue crack origin identified a minor level of surface corrosion that had developed up to the transition into the mixed-mode region (Figure 9). The presence of the corrosion was consistent with an extended period of environmental exposure. Though difficult to quantify, corrosion of this nature takes time to form, indicating that it had been present for considerably longer than the occurrence flight. Aside from the surface corrosion, no macro features were identified that might have contributed to the initiation of the cracking.

Further along the crack surface, in the mixed-mode region, approximately 58 major progression bands were identified. There was an absence of corrosion in this region, and the surfaces appeared bright and fresh, which suggested that the cracking through the blade surface was relatively recent. An example of a progression band is shown at Figure 10.

Figure 8: Fracture surface measurements of main rotor blade SN 0133

The cracked blade was cut open, exposing separate areas along the fracture surface; fatigue, fatigue mixed-mixed-mode and overstress. Corrosion was identified along the blade fracture surfaces up until the crack had reached approximately 16mm in length. Source: ATSB

Figure 9: Fatigue crack surface showing minor corrosion close to the origin

The corrosion extended for approximately 16mm along the blade skin crack surfaces, up until the mixed-mode region. Source: ATSB.

Figure 10: Progression bands (arrowed) in the mixed-mode region along the fracture surfaces of the upper and lower skins

Source: ATSB

Scanning electron microscopy

A scanning electron microscope (SEM) was used to further characterise the crack surfaces of the upper and lower skins. The SEM examination confirmed that many of the finer features of the fatigue portion of the fracture were obscured by a fine flayer of surface oxidation. Cracking in the initial fatigue portion of the blade was confirmed to be entirely transgranular with many finely spaced striations of less than 1 micron in length (Figures 11 and 12). The fine detail of the striation spacing, in combination with the lack of tensile tearing, would suggest that the crack growth rate up until the mixed-mode boundary was due to high cycle fatigue. The SEM examination was unable to identify any micro or macroscopic features at the trailing edge bond line that might otherwise have initiated the cracking.

Figure 11: SEM image of the trailing edge origin also identifying the direction of fatigue crack growth

Source: ATSB

Figure 12: SEM image of the fracture within the fatigue region identifying fine striations consistent with high-cycle fatigue

Source: ATSB

Non-destructive inspection

The main rotor blade section was submitted¹⁴ for non-destructive inspection. The cracked blade section was x-rayed using micro-computed tomography (micro-CT). That technique created a series of x-ray images subsequently processed into a high-resolution three-dimensional model (Figure 13). The structure of the blade was studied for characteristic features and defects that might have contributed to the development of cracking in the blade.

The high-resolution micro-CT model confirmed that cracking in the skin was located 7 mm outboard of the A302 stainless steel doubler termination. Some porosity was identified in the adhesive that bonded the upper and lower skins. Porosity is an artefact of the curing process related to the pre-cured adhesive absorbing moisture from high-humidity environments. Porosity can lead to cohesive failure between the adhesive and substrate, (Davis, 2008). In this instance, the porosity was forward of the trailing edge crack origin and was therefore considered unlikely to have influenced the cracking through the blade skins.

The high-resolution model of the blade also allowed the investigation to discount the presence of defects such as significant voids or regions of adhesive disbonding that might have otherwise contributed to the crack growth at rotor station 61.3.

¹⁴ The National Laboratory for X-ray Micro Computed Tomography (CTLab) is based at the Australian National University in Canberra and the blade was imaged using their HeliScan micro-CT system.

Figure 13: Micro-computed tomography images of the cracked region in blade SN 0133

Scan detail: Australian National University CT Lab, Heliscan micro-CT instrument, x-ray energy 120 kilovolts, resolution 24-micron. Source: ATSB

Safety analysis

Introduction

The precautionary landing involving a Robinson Helicopter Company (Robinson) R22 Beta helicopter, VH-HPH, near Labelle Downs Station, Northern Territory, on 18 December 2016 was precipitated by the development of undetected fatigue cracking through the aerofoil of one of its main rotor blades. The cracking led to increased vibrations, prompting the pilot to conduct a precautionary landing. Although Robinson R22 main rotor blades have previously exhibited critical failures (root fitting cracking in the A016-2 variant, and skin-to-spar bond line deterioration and delamination in the A016-4 variant), the issue of fatigue cracking through the blade chord for the A016-6 variant has not previously been investigated. This analysis will examine the potential factors that may have led to the blade cracking.

Blade cracking

The ATSB's technical examination of the fracture surfaces revealed that the main rotor blade, part number A016-6, serial number 0133, Revision AR, had cracked due to exposure to cyclic loading. The cracking initiated just outboard of rotor station (RS) 61 on the trailing edge of the blade and progressively grew forward along the chord line toward the D-spar. No initiating defects were identified. A high-magnification study of the fatigue crack origin did not identify any contributing defects such as corrosion pitting, external damage, deformation, or metallurgical anomalies in the blade skins that might otherwise have contributed to the crack initiation.

The physical appearance and morphology of the fracture surfaces, in combination with the development of the corrosion along the fracture, suggested an extended period of comparatively slow and stable growth, greater than the duration of the occurrence flight. While the examination was unable to conclusively determine the period over which the cracking had developed, corrosion product formation suggested that the blade crack was at least 16 mm in overall surface length before the occurrence flight.

Major stresses within a helicopter main rotor blade are created at the commencement of each flight cycle when the blades are accelerated and lift forces generated. Of the three types of primary loading conditions that create alternating stressing in the blades during operation of the helicopter, the location of the cracking in this instance was consistent with it being driven predominantly by alternating out-of-plane bending loads. The magnitude of this load will vary with the magnitude of the lift forces on the rotor blade. As the blade crack grew and transitioned from almost pure fatigue to a mixed-mode mechanism, manoeuvring loads in combination with flight cycles are likely to have influenced its growth.

Crack initiation factors

The investigation considered the elements that may have been a contributor, either individually, or in combination, to the development of cracking of the main rotor blade. These included the:

- operation of the helicopter and its previous heavy landing and associated overspeed
- manufacture of the main rotor blades
- main rotor blade design.

Operation - heavy landing and overspeed

In December 2014, while operating out of Labelle Downs Station, the helicopter sustained a heavy landing and a suspected main rotor overspeed after losing tail rotor control. The incident necessitated blade removal and inspection. After the blades were inspected and the spindles repaired, they were returned to service. Both blades were operated for an additional 778 hours up until the failure, accumulating 1,794.7 hours total time in service, well short of their life-limit of

2,200 hours. It is possible that the heavy landing overstressed the rotor system and, in combination with its mustering usage, produced a level of fatigue damage to the aerofoil of blade SN 0133 that was not detectable during the blade inspection. This potential damage was unable to be quantified by the investigation, and it could not be concluded that the operation-type or previous damage sustained was a contributing factor to the blade cracking.

Manufacture

The integrity of the adhesive bonding between the assembled parts is a critical factor in assuring ongoing airworthiness of the main rotor blades. The ATSB's technical examination did not identify any gaps or delamination in the adhesive and surrounding areas at the trailing edge that might have contributed to the crack initiation. Some entrained porosity was identified in the adhesive bonding between the upper and lower blade skins forward of the fatigue crack origin. Although significant porosity can affect the bond strength between parts, in this instance the location and minor extent of porosity was unlikely to have influenced the crack initiation.

Design

A design feature of the A016-6 blades was the use of an adhesively bonded, thin strip of stainless steel that acted as a doubler along the trailing edge between the upper and lower skins. The doubler extended outboard from close to the hub, stiffening the trailing edge and terminating at RS 61. The investigation identified that crack growth in the blade had initiated close to where the doubler had ended. A reduction in stiffness and an associated stress gradient within the upper and lower skins was likely to be present as a result of the doubler termination.

The manufacturer has taken steps to redesign the part, extending the trailing edge doubler from RS 61 to RS 96. Though a stress gradient likely existed at RS 61, without the conduct of a detailed strain analysis, the ATSB was unable to determine if the doubler termination likely influenced the cracking.

Fatigue crack detectability

Part of the scheduled maintenance for the helicopter involved inspecting the main rotor blades throughout their service life. A detailed visual inspection and tap test of the blades for dents, delamination, debonding, scratches and corrosion was required during each 100-hourly inspection. The helicopter's maintenance records indicated that no defects were detected in the blades from the previous inspection, which was completed approximately two weeks prior to the occurrence.

Similarly, the daily pre-flight inspections were signed off in the maintenance release, indicating that no defects were present. Although the records indicated that both types of inspection had been conducted, the corrosion product on the blade skin fracture surfaces (which takes time to develop) suggests that the cracking was, at the very least, present prior to the occurrence flight. It could not be determined with certainty whether the crack was present during the last 100-hourly inspection.

The R22 pilot's operating handbook did not define specific criteria while conducting a visual inspection of the main blades during the daily inspection, for example: preparation of the surface, ambient lighting requirements, the use of a work platform, or visual aids such as a torch or magnifier. The daily instructions are non-specific and are intended for the identification of gross and obvious defects, therefore reducing the potential for a relatively short surface crack to be detected.

The fine detail describing the crack features was possibly concealed due to the effects of surface compression from natural blade droop. Further reducing the probability of detection was the fact that only the black painted underside of the blade would have been visible during the pre-flight inspection. The dark surface, in combination with its overhead position and the short surface

length of the crack may have masked subtleties in surface contrast on the underside of the blade during an inspection.

Other factors that can influence the probability of detection include the frequency and history of cracking in the subject area or component. This was the first instance of A016-6 main rotor blade cracking within the Australian R22 fleet. If there is no history of a defect, there is less expectation for finding a fault, potentially affecting the level of scrutiny that an area with a history of cracking might prompt. Conversely, a special inspection that is triggered to address a particular airworthiness consideration, such as a Service Bulletin, Airworthiness Directive, Airworthiness Bulletin or Service Letter, adds to the expectation that a defect is likely to be found in the subject location.

Precautionary landing

The action to land was appropriate in respect of the published advice contained within the Robinson safety notice SN-39, stating that:

Unusual vibration can indicate a main rotor blade crack.

If main rotor vibration increases or becomes severe during flight, make an immediate safe landing.

Had the pilot elected to continue operating the helicopter, there was an increased potential for an in-flight loss of control due to further deterioration of the blade aerofoil surfaces.

Findings

From the evidence available, the following findings are made with respect to the main rotor blade cracking and precautionary landing of a Robinson Helicopter Company R22-Beta, registered VH-HPH that occurred 12 km south-west of Labelle Downs Station, Northern Territory on 16 December 2016. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing factors

• The A016-6 (Revision AR) main rotor blade developed progressive fatigue cracking that initiated at the trailing edge of the blade. The crack propagated through the upper and lower skins until its growth became unstable, leading to vibration in the rotor system that prompted the pilot to conduct a precautionary landing.

Other findings

- The ATSB was unable to determine conclusively the factors that influenced the fatigue crack initiation and propagation in the A016-6 (Revision AR) main rotor blade.
- The fatigue cracking was probably present in the main rotor blade prior to the occurrence flight, however the cracking may have been difficult to detect during the conduct of the daily inspection.
- The pilot's action to land the helicopter prevented further deterioration of the main rotor blade surface and eliminated the potential for an in-flight blade separation and subsequent loss of control.

Safety issues and actions

Proactive safety action

Whether or not the ATSB identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk. The ATSB has been advised of the following proactive safety action in response to this occurrence

Robinson Helicopter Company

- On 22 December 2016, Robinson Helicopter Company issued a Safety Alert that detailed the location of the incident blade's crack, and recommended close visual inspections of the trailing edges of blades during daily pre-flight inspections (Appendix A).
- Following this occurrence, in February 2017 Robinson commenced a minor redesign of the A016-6 blades. The reinforcing doubler at the trailing edge of the blade was extended further outboard from rotor station 61 to rotor station 96, with the intention of reducing any potential stress gradients over that region of the blade.

Civil Aviation Safety Authority

On 23 December 2016, the Civil Aviation Safety Authority issued an Airworthiness Bulletin AWB 62-006 'Alert – R22 Main Rotor Blade Cracking' (Appendix B). The AWB was intended to alert R22 operators to the development of a significant crack that was identified from this occurrence. The AWB also highlighted the need for particular vigilance during the daily pre-flight checks of the main, and for pilots to be alert to sudden and increased vibrations.

North Australian Helicopters

North Australian Helicopters reinforced with staff the manufacturer's recommended procedures for conducting the daily and pre-flight inspection of the main rotor blades and the need to land immediately should unusual vibrations increase or develop during flight.

Appendix A: R22 safety alert

ROBINSON

2901 Airport Drive, Torrance, California 90505

Phone (310) 539-0508 Fax (310) 539-5198

R22 SAFETY ALERT

Issued: 22 December 2016

A016-6 MAIN ROTOR BLADE CRACK

RHC has received a report of a cracked A016-6 main rotor blade on an R22 used for cattle mustering. The crack began at the trailing edge approximately 90 inches inboard of blade tip. Careful visual inspection of this area during preflight will provide early detection and prevent a catastrophic failure.

During daily preflight inspection, visually inspect the trailing edge in the area shown on upper and lower surfaces of blade (a stepladder may be necessary). A felt-tip marker can be used to outline areas to be inspected. Verify no indication of corrosion, paint blistering, nicks, scratches, or other damage which may initiate a crack. If any damage is detected have blade repaired prior to further flight per R22 Maintenance Manual § 9.140. Chromated epoxy primer is recommended for refinishing.

If unusual rotor system vibration is detected in flight, land immediately and have blades examined by a qualified technician.

Appendix B: Airworthiness bulletin

Figure 1 – Location of crack

Page 1 of 3

Australian Government Civil Aviation Safety Authority The crack location is in the vicinity of blade station RS61 which, measured from the blade tip (with tip cap removed) is approximately 2285mm inboard of the blade end. Evidence of very minor corrosion was observed on the trailing edge in the vicinity of the crack. The operator reported that the total time in service of this blade was 1782.7 hours, the manufacturer stipulates a life limit of 2200 hours or 12 years for part number A016-6 Main Rotor blades. Robinson Helicopter Company will soon be issuing a Safety Alert on the reported findings to date. The blade is currently being investigated by the ATSB however at this stage details are limited with the root cause yet to be determined. Figure 2 – Size of crack

4. Recommendations

CASA can only make preliminary recommendations at this time as the cracking mechanism/s are unknown.

CASA highly recommends that when carrying out the MR blade inspection required as part of the Daily or Preflight checks contained in the Robinson R22 Pilot's Operating Handbook (POH) particular attention should be directed to the MR blade trailing edges.

This inspection may provide more reliable results by conducting the inspection on the white upper surface of the blades due to colour contrast.

Page 3 of 3

General details

Occurrence details

Date:	16 December 2016		
Occurrence category:	Incident		
Primary occurrence type:	Component failure		
Location:	12 km south-west of Labelle Downs Station, Northern Territory		
	Latitude: 13° 8.992' S	Longitude: 130° 22.982' E	

Aircraft details

Manufacturer and model:	Robinson Helicopter Company R22 Beta		
Year of manufacture:	2005		
Registration:	VH-HPH		
Operator:	North Australian Helicopters		
Serial number:	3988		
Total Time In Service	3,732 hours		
Type of operation:	Aerial stock mustering		
Persons on board:	Crew – 1	Passengers – 0	
Injuries:	Crew – 0	Passengers – 0	
Damage:	Minor		

Sources and submissions

Sources of information

The sources of information during the investigation included:

- Robinson Helicopter Company
- North Australian Helicopters
- United States National Transportation Safety Board
- New Zealand Transport Accident Investigation Commission
- United States Federal Aviation Administration
- Civil Aviation Safety Authority.

References

Drury, C. and Watson, J. (2007). Good practices in visual inspection

Federal Aviation Administration. (1997). *Visual Inspection for Aircraft*, Advisory Circular AC No: 43-204

Federal Aviation Administration. (2008) Aviation Maintenance Technician Handbook – General Davis, M. and Bond, D. (2008). The importance of failure mode identification in adhesive bonded aircraft structures and repairs, Royal Australian Air Force

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), 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 Civil Aviation Safety Authority, North Australian Helicopters, Robinson Helicopter Company, the pilot-in-command, the United States Federal Aviation Administration and National Transportation Safety Board.

Submissions were received from the Robinson Helicopter Company, North Australian Helicopters, the pilot-in-command and the Civil Aviation Safety Authority. The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Australian Transport Safety Bureau

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

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within ATSB's 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 operations involving the travelling public.

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

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

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

Developing safety action

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

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

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

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

Terminology used in this report

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing factor: a factor that, had it not occurred or existed at the time of an occurrence, then either:

(a) the occurrence would probably not have occurred; or

(b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or

(c) another contributing factor would probably not have occurred or existed.

Other factors that increased risk: a safety factor identified during an occurrence investigation, which did not meet the definition of contributing factor but was still considered to be important to communicate in an investigation report in the interest of improved transport safety.

Other findings: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.