Australian Government
Australian Transport Safety Bureau

Loss of cyclic control and in-flight break-up involving Robinson R22 helicopter, VH-HGU

7 km north-north-west of Cloncurry Airport, Queensland, on 2 August 2017

ATSB Transport Safety Report
Aviation Occurrence Investigation
AO-2017-078
Final – 21 July 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

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Addendum

Page	Change	Date
5	Paragraph 2: 'flight check' changed to 'autorotation RPM check'	23 Jul 2020
19	Paragraphs 2 and 4: addition of 'autorotation RPM check'	23 Jul 2020
30	Paragraph 1: 'flight check' changed to 'autorotation RPM check'	23 Jul 2020
36	Paragraph 1: 'flight check' changed to 'check flights'	23 Jul 2020

Safety summary

What happened

On the morning of 2 August 2017, the pilot of a Robinson R22 Beta II helicopter, registered VH-HGU and operated by Cloncurry Mustering Company, departed Cloncurry Airport, Queensland, on a ferry flight in preparation for an aerial mustering operation. About 3 minutes after take-off, the pilot experienced a loss of control and the helicopter broke-up in-flight. The helicopter collided with terrain about 7 km north-north-west of Cloncurry. The pilot, who was the only occupant, was fatally injured and the helicopter was destroyed.

What the ATSB found

The ATSB found that the helicopter had recently undergone a 2,200-hour overhaul and this was the first commercial flight since that time.

The on-site examination established that the bellcrank in the helicopter cyclic control assembly was missing a fastener, which allowed the assembly to disconnect in-flight. The ATSB concluded that it was likely that the fastener's self-locking nut was either not reinstalled or it was inadequately torqued during the overhaul. While it could not be determined what had occurred to result in this condition, it was noted that Cloncurry Air Maintenance (CAM) did not use the work-pack to record and track all maintenance activities during the overhaul, which extended over a period of almost 4 months.

The ATSB noted that, in the years leading up to the accident, the CAM workforce structure had changed in a manner that reduced the levels of its qualifications and experience. In the month leading up to the accident, the CAM workforce was operating at a very high workload, which likely exceeded their workforce capability and reduced the chief engineer's capacity to oversight maintenance activities.

Cloncurry Air Maintenance (CAM) had limited internal independent oversight of maintenance activities to evaluate its quality performance. The organisation was subject to both contracted and regulator audit activities in the years leading up to the accident. The ATSB reviewed two of the work-packs sampled during the audits and noted that discrepancies in their maintenance documentation practices were visible to the auditors. However, the auditors had not identified any issues associated with those practices, and therefore, the audits were of limited benefit to CAM.

It was also established that CAM were re-using the MS21042L-series nuts on critical fasteners without replacing them with D210-series corrosion resistant nuts in accordance with the manufacturer's instructions. However, the ATSB also found that the re-use of self-locking nuts was a common and accepted industry practice.

What's been done as a result

Cloncurry Air Maintenance have improved their maintenance practices, which has included progressive certification for tasks, adopting the helicopter manufacturer's checklists for their inspections, removing all untracked MS-series self-locking nuts from stores, and completing inspections of the flight controls on all the Cloncurry Mustering Company helicopters with nil defects reported.

In March 2019, the Australian Transport Safety Bureau issued a safety advisory notice advising all Australian maintenance personnel for Robinson helicopters to ensure that before re-using a self-locking nut, that the correct part number is fitted, and that the D210-series corrosion-resistant nuts are used for reassembly of critical fasteners in accordance with the Robinson Helicopter Company instructions for continued airworthiness.

As a result of this accident and other investigations by the Civil Aviation Safety Authority, the regulator issued airworthiness bulletin 67-005: *Robinson Helicopter Flight Controls – Independent Inspections.* The bulletin highlighted the need for independent inspections to be conducted and 'recorded consecutively with each adjustment made during rotor tracking and balancing' activities. In addition to several recommendations, the bulletin identified several human factor elements that could impact maintenance inspection performance, and highlighted the need for extra caution to be exercised during post-maintenance flights as per the guidance provided by Robinson.

Safety message

Although verbal communications are an important method of explaining and understanding problems, they are not a reliable means for capturing essential tasks over an extended time-period. This accident highlights the importance for maintenance organisations to consider the human factors elements associated with their practices, capture them in their documented quality control procedures, and ensure they are complied with.

Audits are essential for independently verifying the effectiveness of an organisation's processes and procedures. This accident reinforces the importance of auditors inspecting the evidence collected during an audit to ascertain whether or not the requirements are being met, specifically conformance with the relevant standards. Audits may also be used to identify potential underlying human factors issues, which may be raised as an opportunity for improvement to inform the auditee of best industry practices.

Contents

The occurrence

On the morning of 2 August 2017, the pilot of a Robinson R22 Beta II helicopter, registered VH-HGU and operated by the Cloncurry Mustering Company (CMC), was conducting a ferry flight from Cloncurry Airport, Queensland in preparation for an aerial mustering operation at a station to the north of Cloncurry.

The helicopter had departed from Cloncurry Airport just after first light, at about 0659 Eastern Standard Time.[1] The pilot's colleagues reported observing the pilot warming up the engine and then take-off with a normal profile to the north. They also stated that the helicopter sounded normal on departure.

Shortly after the helicopter departed, staff from CMC and their maintenance organisation, Cloncurry Air Maintenance (CAM), observed a plume of smoke to the north. A company pilot noted that the smoke was in the general direction of VH-HGU's track and was drifting towards the west. The pilot attempted to contact the accident pilot via mobile phone at 0713, but the call went to message bank. The company pilot departed with a colleague in another R22 towards the smoke.

The helicopter wreckage was located about 7 km north-north-west of Cloncurry Airport at about 0718 (Figure 1). The pilot was fatally injured and the on board global positioning system device indicated the accident occurred at about 0702.

Figure 1: VH-HGU accident site

Source: ATSB

On landing near the wreckage, the company pilot made a phone call to report the accident, and activated an emergency beacon to assist the emergency services with locating the site. The pilot noted there was very little soil disturbance, normally associated with main rotor blade strikes to the ground during an accident sequence. The pilot also considered the location of the accident site was consistent with the track the accident pilot would have flown to the station for the contracted work. Soon after, the emergency services arrived at the accident site and took control of the scene. The accident was not considered survivable.

[1] Eastern Standard Time (EST): Coordinated Universal Time (UTC) +10 hours.

Another company pilot, who departed Cloncurry just prior to the accident pilot, reported hearing no communications on the company's mustering radio frequency. At 0702:29, an unidentified transmission occurred on the Cloncurry Airport common traffic advisory frequency. However, it was only momentary (about 1 second duration) and did not contain any voice data.

Powerline inspection

The most significant feature near the accident site was the Ernest Henry Mine high voltage powerlines, about 70 m to the west of the accident site. The first responders from CMC noted the powerlines were intact and that no other aircraft were known to be in the area at the time. Staff from the powerline company attended the site with a remotely piloted aircraft to inspect the pylons and lines. On completion of that inspection, they concluded there was no evidence of impact damage.

Context

Pilot information

The pilot started flying training in 2002, and had been employed by the Cloncurry Mustering Company (CMC) since 2004, and held a Commercial Pilot Licence (Helicopter) with a flight instructor rating for low-level helicopter operations and aerial-mustering. The pilot's most recent flight review was on 15 November 2016 in an R22 helicopter. The pilot held a Class 1 Aviation Medical Certificate with no restrictions and an expiry date of 2 February 2018. On 6 January 2017, 10,000 flying hours experience was recorded on the pilot's medical examination questionnaire.

On 1 August 2017, the night before the accident flight, the pilot went to bed at about 2000. The next morning, the pilot left home for work at about 0530. Several colleagues spoke with the pilot between 0600 and 0700 at the company's hangar facility at Cloncurry Airport and reported the pilot's demeanour as normal.

From the operator's records, the accident occurred on the pilot's third consecutive day of flying, which included 12.2 hours flying in the previous 2 days. Prior to that period, the pilot had not flown for 8 days. The time of the accident was not in the circadian low period and did not include an extended period of duty.

Helicopter information

General information

VH-HGU was a two-seat Robinson Helicopter Company (RHC) R22 Beta II helicopter, serial number 4335, powered by a 4-cylinder, carburettor Textron Lycoming O-360-J2A engine (Figure 2). It was manufactured in 2008 and registered in Australia in July of the same year. The helicopter was added to the CMC fleet on 16 February 2017.

Figure 2: Example R22 helicopter

Source: Queensland Police Service

Drive system

Engine power is transmitted to a V-belt sheave bolted to the engine output. The V-belts transmit power to the upper sheave, which transmits power forward to the main rotor and aft to the tail rotor. Flexible couplings[2] are located at the main gearbox input (forward flexible coupling) and at each end of the tail rotor drive shaft (intermediate and aft flexible couplings).

Rotor systems

The main rotor has two blades mounted to the main rotor hub by coning hinges.[3] The hub is mounted to the main rotor shaft by a teeter hinge. Droop stops for the main rotor blades, mounted near the top of the main rotor mast, provide a teeter hinge friction restraint, which normally prevents the rotor from teetering (rocking) while stopping or starting. Elastomeric teeter stops,[4] mounted in brackets in-line with the main rotor blades, limit the teetering during normal flight conditions and will provide a damage witness mark if there is excessive teetering of the main rotor system in-flight. The main and tail rotor systems are fitted with pitch links to transmit the flight control inputs to the rotor blades.

Flight controls

Primary controls are actuated through push-pull tubes and bellcranks. Flight control operation is conventional. The tail rotor pedals change the pitch of the tail rotor blades, and therefore the thrust, of the tail rotor system, which provides directional control. The collective[5] lever controls the amount of thrust (lift) produced by the main rotor disc. Raising or lowering the collective lever will raise or lower the swashplate,[6] which will alter the pitch on both main rotor blades to increase or decrease the main rotor thrust. The collective lever also incorporates a twist grip to provide the pilot with full manual control of the engine throttle.

The cyclic[7] control tilts the main rotor disc to point the rotor thrust in the desired direction of flight. Fore-aft movement of the cyclic provides the longitudinal (pitch) control of the main rotor disc. Forward movement will tilt it down at the front and up at the back, and aft movement will tilt it up at the front and down at the back. There is a single push-pull tube connection to the swashplate at the rear of the main rotor mast to provide the pitch control. Left-right movement of the cyclic provides lateral (roll) control of the main rotor disc. There are two push-pull tubes connected to the swashplate, either side of the main rotor mast, to tilt the disc left or right.

Recent maintenance history

The helicopter had accumulated about 4,365 hour's total time-in-service at the time of the accident. When CMC acquired VH-HGU, in February 2017, it had about 80 hours remaining before it was due for its second 2,200-hour overhaul. Therefore, the operator's maintenance organisation, Cloncurry Air Maintenance (CAM), completed a 100-hour inspection at the time of

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2 The flexible couplings in the R22 drive train accommodate differences in drive shaft axial alignment during helicopter operation. They are constructed by bolting a single, four-armed, thin stainless plate between the main rotor gearbox yoke and the drive shaft yoke.

3 Coning of main rotor blades: the upwards movement of the main rotor blades while they are rotating. This is usually in response to an increase in aerodynamic force as a result of a control input from the pilot. It is more pronounced at high weights and/or low main rotor speed.

4 Two elastomeric stops are fitted at the top of the main rotor mast to protect the mast from direct contact with the main rotor blades. Excessive teetering of the main rotor blades in-flight will result in the main rotor blades striking the teeter stops.

5 Collective: a primary helicopter flight control that simultaneously affects the pitch of all blades of a lifting rotor. Collective input is the main control for vertical velocity.

6 The swashplate consists of two main parts: a stationary swashplate and a rotating swashplate. The stationary (inner) swashplate is mounted on the main rotor mast and is connected to the cyclic and collective controls by the push-pull tubes. It is able to tilt in all directions and move vertically. The rotating (outer) swashplate is mounted to the stationary swashplate by means of a bearing, which allows it to rotate with the mast. The swashplates move as one unit. The rotating swashplate is connected to the main rotor blade pitch horns by the pitch links.

7 Cyclic: a primary helicopter flight control that is similar to an aircraft control column. Cyclic input tilts the main rotor disc, varying the attitude of the helicopter and hence the lateral direction.

the acquisition and the helicopter was operated by CMC until the 2,200-hour overhaul was started on 12 April 2017.

The 2,200-hour overhaul involved the disassembly, inspections, reassembly and checks of the helicopter. All flight control push-pull tubes were sent for non-destructive testing and found serviceable. The helicopter was reassembled and a weight and balance, and fuel calibration was completed. The flight controls were rigged and then the helicopter was subject to a 100-hour inspection before a ground run, track and balance[8] of the main rotors, and autorotation RPM check were completed on 28 July 2017.

On 31 July 2017, a 15-minute local area flight was conducted to confirm the serviceability of the helicopter. Following that flight, CAM staff certified for all the tasks in the 2,200-hour overhaul work-pack, including independent inspections[9] of the engine and flight controls, and issued the maintenance release.[10]

The next time the helicopter was operated was the accident flight.

Loading and performance

The ATSB's calculations indicated the helicopter was within the prescribed weight and balance limits for the flight. Using the local environmental conditions, the out-of-ground-effect[11] hover performance weight was within limits at the helicopter's certified maximum all-up-weight of 622 kg.

Meteorological information

The weather conditions recorded at Cloncurry Airport at 0700 included a wind speed of 1 kt from 100°, a temperature and dewpoint[12] of 14 °C and 5 °C respectively, and a QNH[13] of 1015 hPa. The Cloncurry aerodrome forecast[14] for the period from 0400 to 1600 included a wind speed of 6 kt from 170° and CAVOK[15] conditions. Given the insignificant conditions, the ATSB determined that it was very unlikely that the weather contributed to the circumstances of the accident.

Global positioning system data

The pilot's Garmin GPSMAP196 navigation device was recovered from the wreckage for examination and analysis by the ATSB. The global positioning system (GPS) had several track logs, which included the accident flight and a previous mustering flight.[16]

Figure 3 depicts the helicopter's GPS track from take-off to the accident site, and Figure 4 depicts the position of the main wreckage relative to the last reliable GPS data point and vicinity to the

8 The process of smoothing vibrations in the airframe, which are caused by the main rotor.

9 In accordance with the *Civil Aviation Regulations 1988*, Section 42G, any assembly, adjustment, repair, modification or replacement of any part of the flight control system requires an inspection by the person who conducted the work and an independent inspection by another appropriate person.

10 Maintenance release: an official document, issued by an authorised person as described in Regulations, which is required to be carried on an aircraft as an ongoing record of its time-in-service (TIS) and airworthiness status. Subject to conditions, a maintenance release is valid for a set period, nominally 100 hours TIS or 12 months from issue.

11 Out-of-ground-effect: helicopters require less power to hover when in 'ground effect' then when out of 'ground effect' due to the cushioning effect created by the main rotor downwash striking the ground. The height of 'ground effect' is usually defined as more than one main rotor diameter above the surface.

12 Dewpoint: the temperature at which water vapour in the air starts to condense as the air cools. It is used, among other things, to monitor the risk of aircraft carburettor icing or the likelihood of fog.

13 QNH: the altimeter barometric pressure subscale setting used to indicate the height above mean seal level.

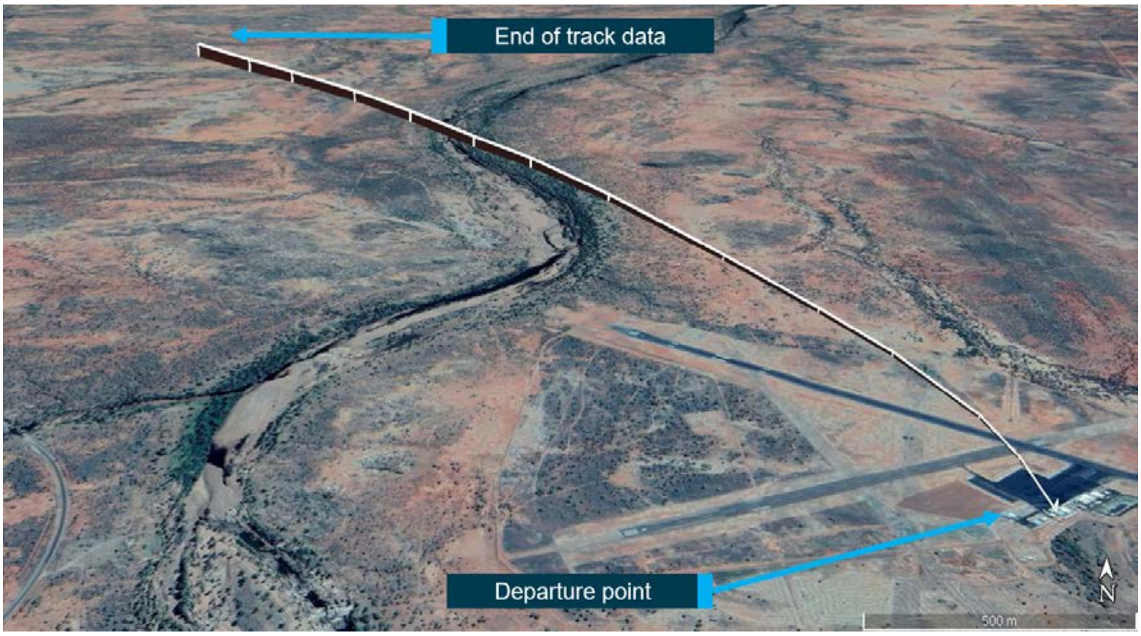
14 Aerodrome forecast (TAF): a statement of meteorological conditions expected for a specific period of time in the airspace within a radius of 5 NM (9 km) of the aerodrome reference point.

15 Ceiling and visibility okay (CAVOK): visibility, cloud and present weather are better than prescribed conditions. For an aerodrome weather report, those conditions are visibility 10 km or more, no significant cloud below 5,000 ft, no cumulonimbus cloud and no other significant weather.

16 The published GPS data accuracy was plus or minus 7.5 m (24.6 ft) in the vertical plane during stable flight. At the time of the accident there were eight satellites visible with a geometric dilution of precision (GDOP) = 2.38, a rating of 'good' (2–5 = good; 1–2 = excellent).

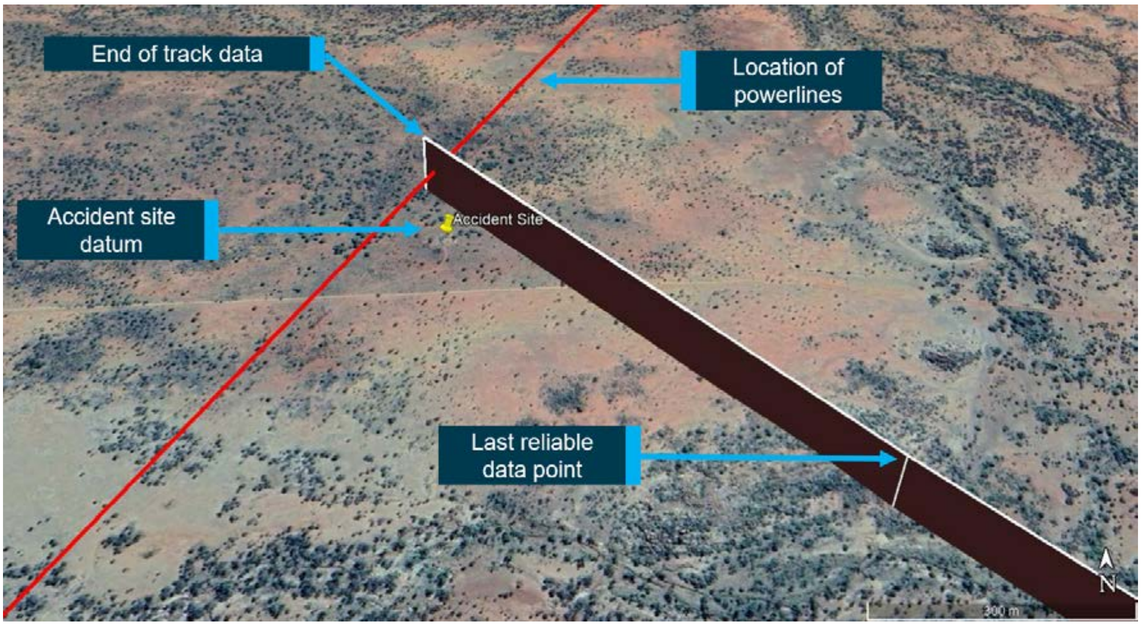
powerlines. Table 1 provides the data points for the accident flight. The ATSB considered the final data point (14), which was beyond the accident site, to be an unreliable point for the purpose of analysis as it very likely represented a predictive point.[17]

Figure 3: Accident flight GPS track



Source: Google Earth, annotate by the ATSB

Figure 4: Accident site datum relative to the last reliable GPS data point



Source: Google Earth, annotated by the ATSB

[17] The Garmin GPS uses a Kalman Filter smoothing algorithm, which is a form of predictive smoothing. Data points may be recorded as predictive points, or as predictive points combined with actual measurements. It also uses an adaptive algorithm (variable sampling rate), which reduces the rate of recording during stabilised flight, and increases the rate of recording as the rate of horizontal or vertical manoeuvring increases. The GPS is designed to assist in normal flight, not to accurately record abnormal (highly dynamic) flight manoeuvres, which may not appear on a track log.

From Table 1, the changes in altitude and vertical speed were all positive from the departure point to the last reliable data point (13). In addition, the average ground speeds between the data points were relatively stable leading up to point 13. This suggested the helicopter had a reasonably steady climb flight profile. At point 13, the helicopter was about 279 ft above the local terrain, and about 82-148 ft above the height of the Ernest Henry powerline towers.[18]

Table 1: Accident flight data points

Data point	Time	Time interval (s)	GPS altitude (ft)[19]	Interval average vertical speed (ft/min)	Interval average ground speed (kt)
1.	0658:51		628		
2.	0659:12	21	645	49.7	20
3.	0659:21	9	655	63.4	45
4.	0659:33	12	669	70.5	65
5.	0659:43	10	675	37.4	71
6.	0659:57	14	693	74.5	78
7.	0700:18	21	715	62.8	81
8.	0700:35	17	756	144.7	81
9.	0700:48	13	773	80.3	83
10.	0701:06	18	802	95.1	83
11.	0701:24	18	830	94.1	82
12.	0701:45	21	860	86.2	84
13.	0701:59	14	901	175.8	89
14.	0702:27	28	964	131.5	66

Medical and pathological information

Pilot's medical history

The pilot was a patient of the Cloncurry Flinders Medical Centre since 2005, which included flight crew medical examinations by the local designated aviation medical examiner (DAME). In 2011, after a diagnosis of mild hypertension, the pilot started a prescribed daily dose of 150 mg Irbesartan.[20]

Post-mortem and toxicology results

The post-mortem examination established that the pilot received extensive injuries associated with a rapid deceleration and the cause of fatality was ruled as multiple injuries as a result of the accident. The examination also found 75 per cent eccentric stenosis[21] in the mid segment of the left anterior descending artery of the pilot's heart. This was characterised as severe atherosclerosis.[22] The forensic pathologist reported:

> It is theoretically possible that this may have precipitated abnormal heart rhythm leading to pilot incapacitation and subsequent accident. This scenario can be neither confirmed nor excluded on the basis of autopsy examination.

[18] The height range for the towers was based on their reported construction height of 40–60 m (131–197 ft).
[19] Above mean sea level.
[20] Irbesartan was an oral medication used to relax the blood vessels in order to lower blood pressure and increase the supply of blood and oxygen to the heart. This was considered to be a moderate dose, as the maximum dose is 300 mg.
[21] Eccentric stenosis is the asymmetric narrowing of a coronary artery.
[22] A build-up of plaque in the inner lining of an artery causing it to narrow or become blocked.

A low concentration of alcohol was detected in the blood, which was considered to be 'likely post-mortem contamination, probably due to decomposition'. No drugs, including Irbesartan, were detected.[23]

Specialist advice

In consideration of the forensic pathologist's scenario, the ATSB conducted a follow-up on the pilot's health with the Cloncurry DAME, the CASA Principal Medical Officer (PMO) and the Director of the Clinical Forensic Medicine Unit for the Queensland Department of Health.

The PMO noted the other arteries and heart were found with no discernible abnormality, therefore, the conditions had not dispersed through the cardiovascular system. The PMO also reported that it could not be determined with certainty if the pilot experienced abnormal heart rhythm unless the heart was being actively monitored. Queensland Health reported that the 'consequences of high blood pressure as a clinical issue were not noted in the autopsy report. In particular, there was no evidence of a stroke and no indication of a heart attack'.

The Cloncurry DAME reported the dosage of Irbesartan was moderate and that it 'would have been unlikely to cause any symptoms of hypotension causing dizziness or disorientation'. Queensland Health and the PMO reported that missing a single dose of Irbesartan would not be likely to cause any issues clinically.

Wreckage and impact information

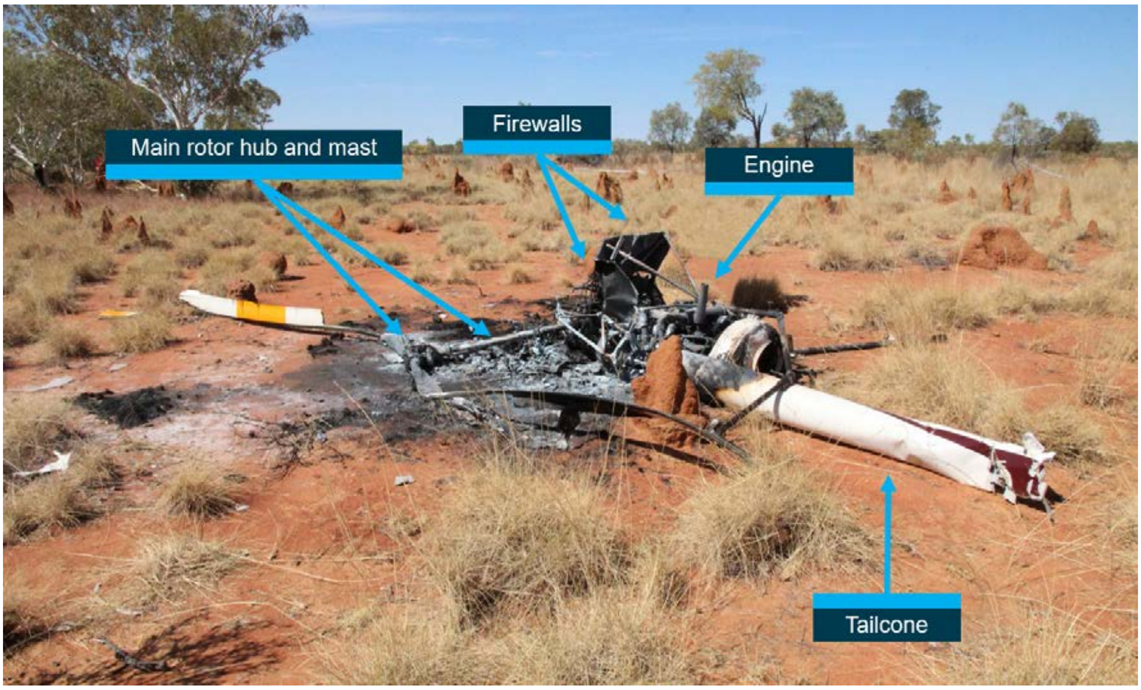
The wreckage examination included an initial on-site inspection, followed by a review of the accident site images. The photographic review resulted in a second accident site visit to excavate the wreckage and retrieve a component of interest, which was the bellcrank from the cyclic control assembly.

Initial on-site examination

The helicopter wreckage was located amongst termite mounds, in a sparsely treed area. The main wreckage had been subject to a significant post-impact fire, which had reduced the cabin area to ash, molten aluminium, and fibreglass mat. The airframe was oriented south-east on a heading of about 140°, which was in the opposite direction to the helicopter's recorded flight path. Small pieces of debris were scattered around the wreckage in a radius of about 20 m in most directions. The windscreen perspex was unburnt, shattered into small pieces and contained in an area of about 2 m^2 just forward of the cabin area. All the major components were identified within the debris field (Figure 5).

[23] The clinical forensic medicine unit reported that there could be several reasons why Irbesartan was not detected. The drug is broken down by the body for excretion with a rate dependent on individual differences. In addition, the level present in the body may have been below the cut-off value for testing and there may have been some post-mortem redistribution of the drug. Therefore, the level in death may not have been the level in life.

Figure 5: Main wreckage



Source: ATSB

The airframe impacted the ground on the front left. Compression damage to the forward vertical firewall of the helicopter indicated that it impacted with a high rate of descent.

The helicopter's main rotor disc had severed the tailcone and tail rotor driveshaft, leaving paint transfer on the driveshaft and tailcone. There were multiple strikes to tail components, which included the tail rotor hub and vertical stabiliser, generating a pattern of tail strike debris. The pattern was noted to be in a semi-circular arc on the right side of the main wreckage with respect to the direction of the GPS track. This was consistent with the helicopter tracking away from the airport and towards the powerlines at the time of the tailcone strike.

The main rotor blades exhibited rearward and upward bending, and there was no evidence of rotor blade ground strike marks or damage to the surrounding termite mounds. This was consistent with a significant loss of main rotor energy before ground impact, which was a near vertical impact. The teeter stops were destroyed by fire, but one teeter stop bracket was damaged and the associated main rotor blade spindle tusk[24] had a slight bend. This indicated the teeter stop bracket was struck by its respective main rotor blade spindle.

There was no evidence of any significant tension on the tail rotor driveshaft aft flexible coupling and little evidence of bending on the severed aft section of driveshaft (Figure 6). This indicated it was likely a power-on, high energy, main rotor strike to the tail.[25] The section of driveshaft forward of the severed section exhibited elongation and a bending overload, which indicated it was rotating during the break-up sequence. Therefore, the damage to the driveshaft was consistent with the main rotor disc striking the tail under normal engine power and rotor speed conditions.

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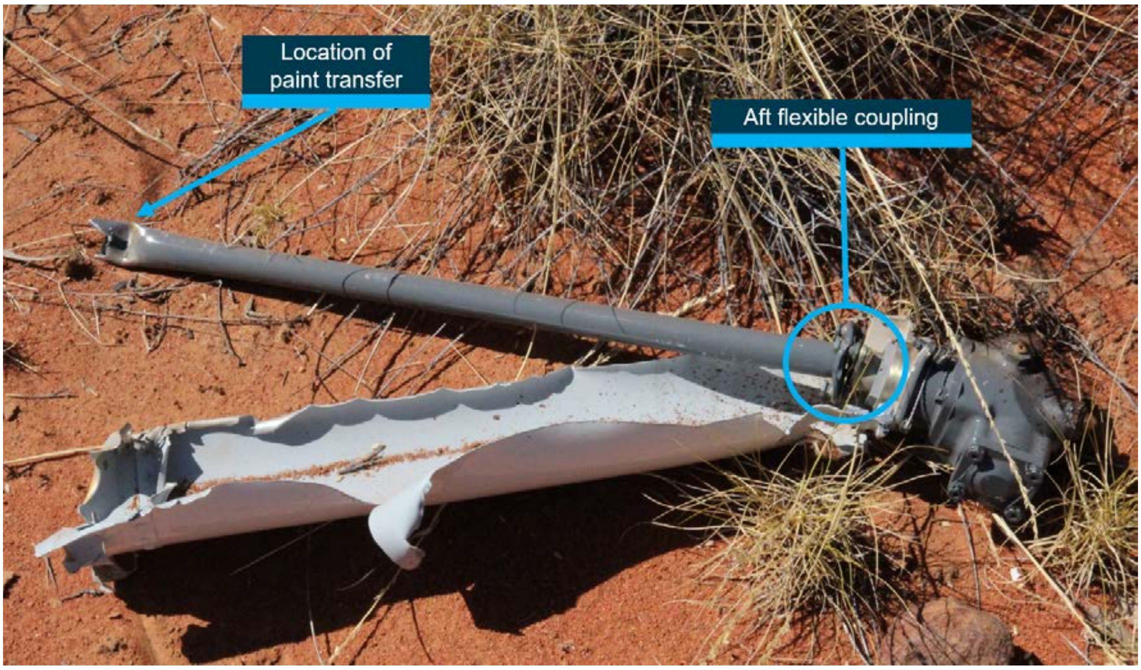
[24] The spindle tusk is part of the main rotor blade spindle, which contacts the droop stops attached to the main rotor shaft to minimise teetering when the blades are not rotating or turning at low speed.

[25] Refer to AO-2016-156: In-flight break-up involving Robinson R44, VH-ZNZ, 41 km NW Mossman, Queensland, 18 November 2016. *Wreckage and impact information: Tailcone and tail rotor system*.

Figure 6: Severed tail rotor driveshaft



Source: ATSB

The forward flexible coupling of the driveshaft exhibited significant tension. According to RHC, flexing of the main rotor mounts will change the angle of the input yoke of the main gearbox, which will cause the yokes at the flexible couplings to move apart. The tension on the forward flexible coupling, damage to the teeter bracket, and angle of the tailcone strike were consistent with a large rearward tilt of the main rotor disc in-flight past its normal limits.

On completion of the ATSB’s initial onsite inspection, the operator and next-of-kin buried the wreckage adjacent to the impact site.

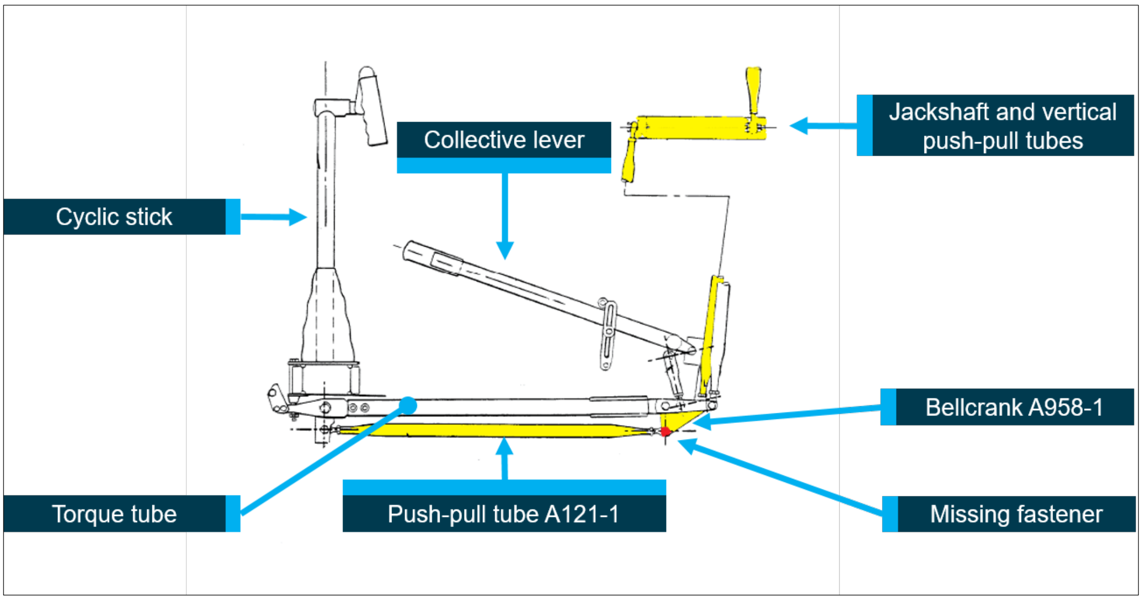
Excavation

During the photographic review of the wreckage after the initial on-site inspection, the ATSB noted an anomaly with a flight control bellcrank (part number A958-1) in the cyclic control assembly. The fastener,[26] which attached the horizontal push-pull tube (part number A121-1) to the bellcrank, was missing. The remaining bellcrank fasteners were all attached. The missing fastener was part of the longitudinal cyclic control, which controls the fore-aft tilt of the main rotor disc (Figure 7). The RHC R22 *Illustrated Parts Catalog* (IPC) showed that the flight controls should be secured at the bellcrank with a National Aerospace Standard (NAS) 6604-15 bolt and D210-4 self-locking nut.[27]

[26] The term fastener refers to an assembly of bolt, washer(s) and nut(s).

[27] A self-locking nut is a nut that resists loosening under vibrations and torque.

Figure 7: Longitudinal cyclic control



Source: Robinson Helicopter Company, modified by the ATSB

The ATSB returned to Cloncurry in February 2018, and with the assistance of the pilot's next-of-kin, the next of kin's support persons, and the Cloncurry State Emergency Service personnel, excavated the majority of the buried wreckage and retrieved the bellcrank minus the missing fastener hardware. In addition to the bellcrank, the ATSB retrieved several pieces of resolidified metal to examine for the presence of hardware (bolt, standard washer, lockwasher, rod-end and self-locking nut).

In May 2018, the next-of-kin, who had continued excavating the remainder of the wreckage, sent a bolt with the same part number as the missing bolt (NAS6604-15) to the ATSB.[28] Following receipt of the bolt, the ATSB, in consultation with RHC and the next-of-kin, verified that all the remaining NAS6604-15 bolts were still attached to their respective assemblies.[29] This included the bolts not identified in the IPC as they are not normally accessible. As such, the bolt recovered from the excavated wreckage was considered very likely to be from the missing fastener. Figure 8 depicts the bellcrank and bolt.

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[28] The bolt was found by a support person, working alongside the next-of-kin on 16 May 2018, as they were sieving through earth excavated from the site where the wreckage was buried. The bolt was photographed by the next-of-kin and images sent to the ATSB that same day. The bolt was received by the ATSB on 24 May 2018.

[29] The verification process included physical examination of the smaller assemblies by the ATSB, and photographic review of the larger assemblies, which revealed the presence of the fasteners as a result of the fire damage.

Figure 8: Bellcrank with missing fastener (left) and bolt (right)

Source: ATSB (left) and next-of-kin (right)

Effect of loss of longitudinal cyclic control

The ATSB enquired with RHC about the expected response of the main rotor system to a disconnection of longitudinal cyclic control. They advised that:

> During straight and level flight the A121-1 push-pull tube is under compression load. This pushes the cyclic aft [pilot's cyclic stick]. A bungie cord is attached to the forward end of the tube (pulling aft, below the cyclic pivot point) to counteract the forces and neutralizes the loads felt by the pilot. The loads increase with airspeed.

With reference to Figure 7, a compression load on the A121-1 push-pull tube is consistent with a force tilting the main rotor disc aft and pushing downwards on the aft vertical push-pull tube. In forward flight, the advancing main rotor blade is at a higher airspeed than the retreating blade, which increases the lift on the advancing blade relative to the retreating blade. The reaction to this dissymmetry of lift is that the advancing blade flaps up and the retreating blade flaps down, which the pilot corrects with forward cyclic input as airspeed increases (Wagtendonk, 2011). Therefore, a disconnection of the longitudinal cyclic control in forward flight will result in the rotor disc tilting aft, potentially striking the tailcone.

Tests and research

Following identification that the rear fastener for the cyclic assembly horizontal push-pull tube was missing from the bellcrank, a number of items were recovered from the accident site and retained for further examination at the ATSB's technical facilities in Canberra. The items included:

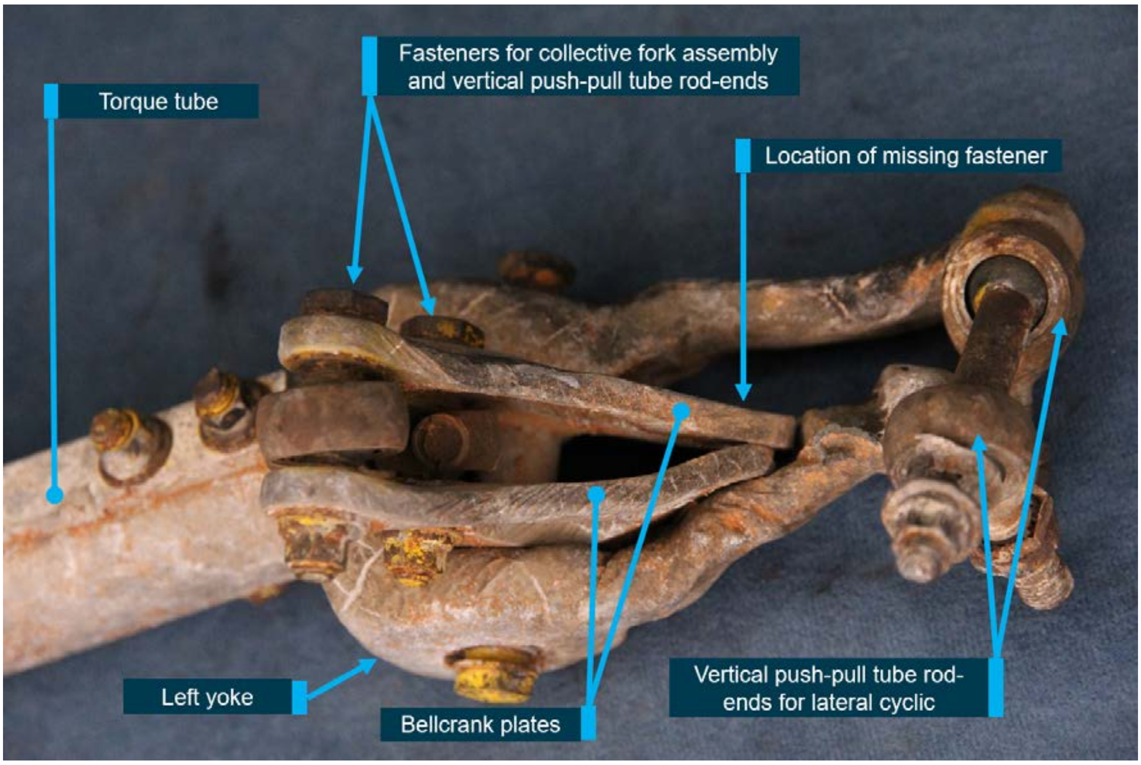
- the bellcrank – part number A958-1
- a bolt – part number NAS6604-15 (recovered by the next-of-kin on 16 May 2018)
- metallic debris (that had melted during the post-accident fire then resolidified on cooling)
- a number of loose nuts and washers
- a jackshaft – part number A337-1 – including attachment nuts and bolts
- the forward support assembly – part number A014-6.

A summary of the main findings from the examination is provided here, for full details of the examination refer to *Appendix A – Materials examination report*. The scope of the examination was to analyse the bellcrank and related components to determine how the fastener came to be missing. In addition, the metallic debris recovered from site was examined to determine if any additional fastener parts were entrapped within the solidified mass.

Bellcrank and related components

The bellcrank and torque tube yoke assembly had been subject to significant mechanical damage such that the rod ends had fractured in overstress and the left side of the yoke assembly and bellcrank plate had significantly distorted. While the distortion of the plates was similar where the fasteners remained in position, the plates had been pushed together where the fastener was missing (Figure 9). The yoke assembly also exhibited heat damage in this area, with the left side moulding around the bellcrank plate. The combination of mechanical and heat damage meant that an exemplar bolt could not be reinserted through the bellcrank.

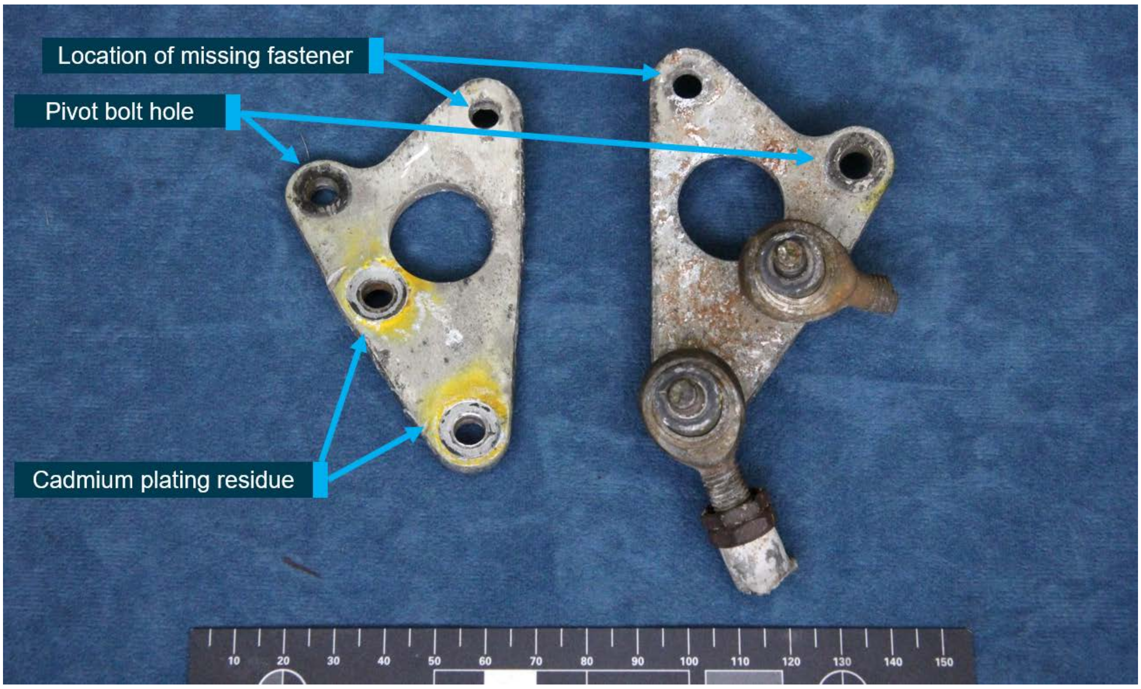
Figure 9: Bellcrank showing deformation observed on the torque tube yoke assembly and bellcrank plates



Source: ATSB

The bolt holes where the fastener was missing did not exhibit gross deformation or elongation of the holes to indicate that the fastener assembly had been forcibly removed during the accident sequence. Yellow colouration was observed around the other bolt holes where the fasteners had remained in position. While some yellow colouration was observed around the bolt hole of the missing fastener, it was much less than for the other holes, and none was observed around the internal surfaces of the hole (Figure 10).

Figure 10: Bellcrank internal surfaces with yellow colouration



Source: ATSB

Robinson reported that the yellow residue surrounding the fasteners was from the cadmium plating on the bolts, washers and screws.[30] The remnants of cadmium plating from the fastener assembly components had melted and subsequently oxidised during the post-accident fire. The residue surrounding the bolt hole for the missing fastener indicated the missing bolt was previously torqued, resulting in a transfer of cadmium from the washer to the bellcrank. However, as there was no outward flow, or streaking, as per the remaining fasteners, RHC considered it 'highly unlikely that the missing bolt was present during the fire'.

The combination of the above observations indicated that the missing bolt was not fitted to the bellcrank at the time of the impact with terrain and post-impact fire.

The remaining two bolts installed on the bellcrank were identified as NAS6604-15 bolts and the nuts were consistent with the MS21042L4/NAS1291 nut-type with manufacturer markings consistent with Ronson Manufacturing Inc.

Metallic debris

The metallic debris was dissolved and a number of fasteners and other components were recovered. However, examination of the pieces did not identify any parts from the missing fastener.

Recovered bolt

The solitary bolt found on 16 May 2018 by the next-of-kin was identified as a NAS6604-15 bolt. The bolt had the same manufacturer identification ('LFC') as the other two bolts fitted to the bellcrank, but exhibited greater fire damage (Figure 11).

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30 Cadmium plating is a surface finish provided for corrosion resistance.

Figure 11: Comparison between the bolts removed from the bellcrank (left and centre) and the fire damaged bolt (right) subsequently recovered from the accident site

Note: The recovered bolt is shown after it had undergone ultrasonic chemical cleaning.
Source: ATSB

The recovered bolt was thermally damaged from the post-accident fire, but was otherwise in good condition with no evidence of distortion along its length or to the threads. A small groove was identified on the thread flank, which was likely from contact with a self-locking nut during installation (Figure 12).

Figure 12: Magnified image of the bolt found 16 May 2018 showing thread groove

Source: ATSB

Jackshaft

Examination of the jackshaft assembly recovered from the wreckage found that three of the four self-locking nuts had the same manufacturer markings as the nuts fitted to the bellcrank. Fire damage precluded identification of the markings on the fourth nut.

Semi-quantitative chemical analysis of the nuts was conducted using a scanning electron microscope equipped with an Oxford energy dispersive x-ray spectrometer. The analysis confirmed that all four nuts were consistent with a carbon/alloy steel. While the spectrometer cannot determine the exact amount of alloying additions, the spectrographs for the four nuts were inconsistent with the CRES (corrosion resistant – stainless steel) D210-4 nuts specified to be used by RHC. Specifically, the nickel, chromium and molybdenum additions, where detected, were not of sufficient quantities to designate the nuts as stainless steel (see *Previous safety issues - self-locking nuts*).

Maintenance of the cyclic control assembly

During their interviews with the ATSB in 2018, the CAM staff[31] could not recall the specific details of the work they individually performed on the cyclic control system of VH-HGU during the 2,200-hour overhaul. However, they were able to provide a description of the normal process they followed for the removal, inspection, installation and inspection of the cyclic control assembly. The physical process, as described by CAM staff, was consistent with the process published and described by RHC.

Removal

The removal process involved the vertical push-pull tubes being unscrewed from the bellcrank and yoke rod-ends, then the remaining components from the cyclic stick through to the bellcrank would be removed from the airframe as a single unit. After removal from the airframe, the length between the bolt holes for the horizontal push-pull tube would be measured for use during reassembly. There was no record of this measurement in the work-pack for VH-HGU, however, the maintenance manual provided a standard length that could be used for the installation.

The horizontal push-pull tube forward fastener would then be disconnected from the cyclic stick and the horizontal push-pull tube unscrewed from the bellcrank rod-end. Therefore, the bellcrank fasteners were not required to be disassembled during this part of the process. The cyclic stick is separated from the torque tube, but the bellcrank can remain attached to the torque tube with the fasteners and rod-ends fitted, as neither of these components required non-destructive testing.

Inspection

The bellcrank is inspected for cracks and corrosion, and the rod-ends are tested for axial and radial play (Figure 13). According to RHC, the play in the rod-ends can be checked without removal from their respective fastener. The CAM staff reported that the rod-ends would initially be checked for play without their removal, and then only removed for measurement with a dial test indicator if there was doubt. The chief engineer reported that the rod-end would be replaced if it had reached half the permitted tolerance as the wear will accelerate and it was preferable to replace them at the 2,200-hour overhaul, rather than at a 100-hour inspection.

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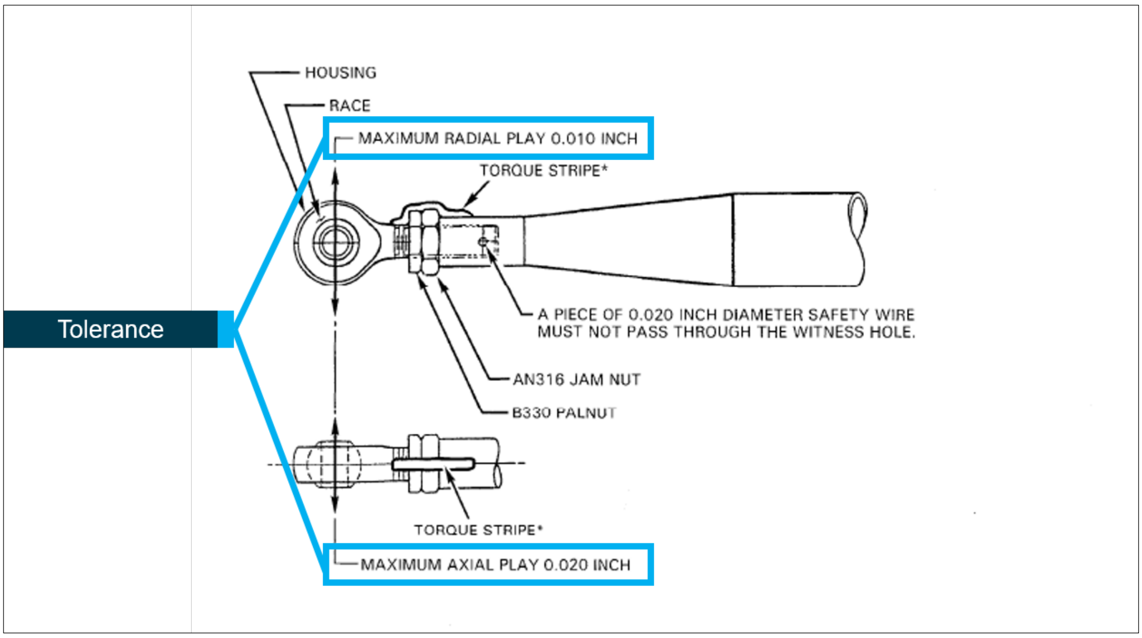
[31] Refer to section titled *Cloncurry Air Maintenance* for the composition of the CAM workforce.

Figure 13: Rod-end and spherical bearing play limits



Source: Robinson Helicopter Company, annotated by the ATSB

There was no record in the work-pack to indicate that any of the bellcrank rod-ends were replaced or disturbed for inspection. However, other than what the maintenance manual specified for the overhaul, disturbances of the flight controls were not recorded in the work-pack unless a part was replaced. Several rod-ends from other assemblies were replaced during the overhaul, and they were accounted for by a cross-check between the ‘parts list’ and ‘aircraft work-sheet’ sections of the work-pack.

Installation

After removal and disassembly, the push-pull tubes and cyclic stick would then be stripped of their paint and sent for non-destructive testing. All parts for VH-HGU were found serviceable from non-destructive testing, and on return, they were painted and re-assembled. One of the apprentices reported the cyclic assembly could be removed and installed by an individual, but it was more common to use two persons, ‘depending on what was going on’. In August 2017, the chief engineer could not recall who refitted the parts returned from non-destructive testing. The installation was certified as having been performed by the AME (aircraft maintenance engineer). However, in February 2018, the AME could not remember anything about this work.

The AME reported that the chief engineer would normally inspect the cyclic when re-assembled, and again when it was installed. After installation, the chief engineer would assist the AME with the rigging process and then perform an ‘inspection and make a list and get them to fix it… and then get [head engineer] in to check’. The fourth year apprentice was reportedly involved in the disassembly, reassembly and rigging, but was unsure about the first year apprentice’s involvement. The first year apprentice was reportedly involved in the disassembly, but was at trade school 1–13 July 2017, and missed some of the reassembly.

According to RHC, if the cyclic assembly is installed and the horizontal push-pull tube has the incorrect length between bolt holes, then it is easier to remove the aft rod-end (bellcrank fastener) to make the length adjustment. However, this is most likely to be discovered during the rigging process and compensated for by adjusting the vertical push-pull tube lengths or pitch links, unless it is excessively far from the specified dimension. The chief engineer reported that for the rigging adjustments they ‘generally do it on the upper push-pull tubes—wind them all the way in and then adjust at the top—sometimes the lower push-pull tube, but don’t recall having any trouble with the accident helicopter’.

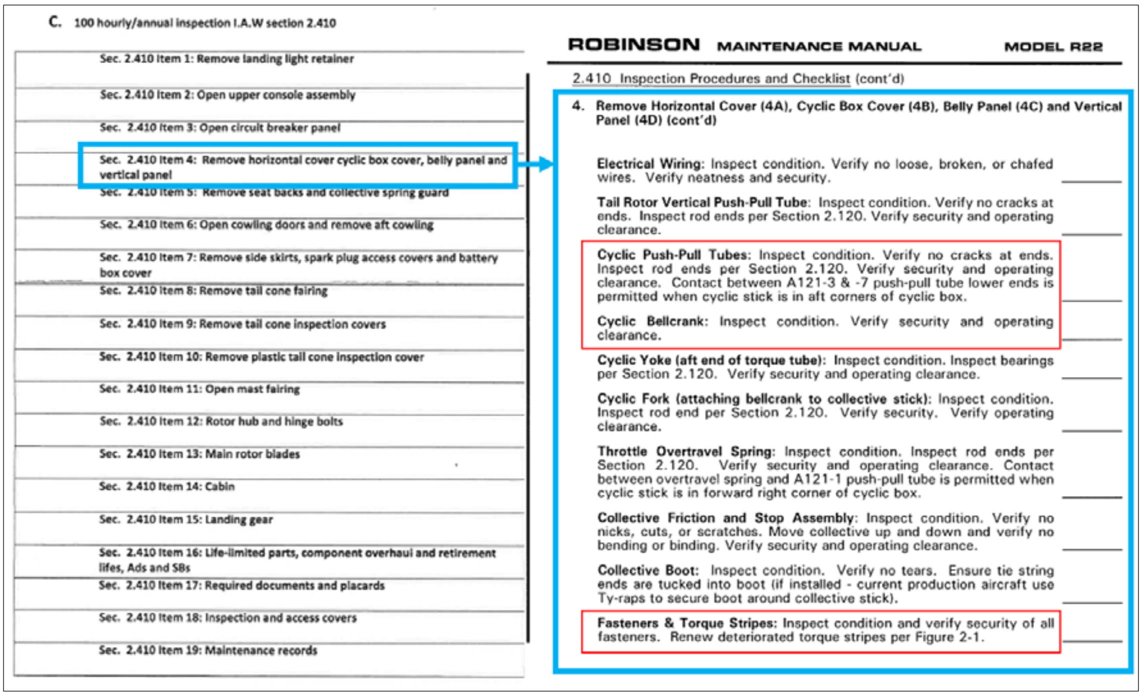
The head engineer reported that the cyclic assembly fasteners are torqued and torque striped[32] before the assembly is installed, which is when the independent inspections for correct assembly would be performed. After installation, the head engineer would perform an independent inspection for correct fitment and clearances. The head engineer would then provide a list of discrepancies to the chief engineer, and then re-inspect after any adjustments had been made. As the work-pack was not used to record discrepancies and adjustments, it could not be determined if any discrepancies were found or if any adjustments were performed.

100-hour inspection

After the helicopter had been assembled and the flight controls rigged, the next step in the overhaul procedure was for a 100-hour inspection to be performed. For VH-HGU, this inspection was certified by the AME and chief engineer using a CAM form, which was a one-page abbreviated checklist. The CAM checklist condensed the RHC R22 maintenance manual certification requirements from 226 items to 19 items. Consequently, each item in the CAM checklist accounted for between 1-30 separate inspection items. However, the CAM checklist specifically stated that the 100-hour inspection checklist was to be used in conjunction with RHC maintenance manual.

Figure 14 shows a comparison of the CAM checklist item (left) with the RHC R22 maintenance manual (right) for the removal of the horizontal cover cyclic box cover, belly panel and vertical panel. The depiction below of the maintenance manual is one of three pages under the heading 4 task certifications. Inspection of the cyclic push-pull tubes, bellcrank and fasteners were items 19, 20 and 26. These items were covered as item 4 in the CAM abbreviated checklist.

Figure 14: Comparison of the CAM 100-hour inspection checklist (left) and the R22 maintenance manual (right)


C. 100 hourly/annual inspection I.A.W section 2.410

Sec. 2.410 Item 1: Remove landing light retainer
Sec. 2.410 Item 2: Open upper console assembly
Sec. 2.410 Item 3: Open circuit breaker panel
Sec. 2.410 Item 4: Remove horizontal cover cyclic box cover, belly panel and vertical panel
Sec. 2.410 Item 5: Remove seat backs and collective spring guard
Sec. 2.410 Item 6: Open cowling doors and remove aft cowling
Sec. 2.410 Item 7: Remove side skirts, spark plug access covers and battery box cover
Sec. 2.410 Item 8: Remove tail cone fairing
Sec. 2.410 Item 9: Remove tail cone inspection covers
Sec. 2.410 Item 10: Remove plastic tail cone inspection cover
Sec. 2.410 Item 11: Open mast fairing
Sec. 2.410 Item 12: Rotor hub and hinge bolts
Sec. 2.410 Item 13: Main rotor blades
Sec. 2.410 Item 14: Cabin
Sec. 2.410 Item 15: Landing gear
Sec. 2.410 Item 16: Life-limited parts, component overhaul and retirement lifes, Ads and SBs
Sec. 2.410 Item 17: Required documents and placards
Sec. 2.410 Item 18: Inspection and access covers
Sec. 2.410 Item 19: Maintenance records

ROBINSON MAINTENANCE MANUAL MODEL R22

2.410 Inspection Procedures and Checklist (cont'd)

4. Remove Horizontal Cover (4A), Cyclic Box Cover (4B), Belly Panel (4C) and Vertical Panel (4D) (cont'd)

Electrical Wiring: Inspect condition. Verify no loose, broken, or chafed wires. Verify neatness and security.

Tail Rotor Vertical Push-Pull Tube: Inspect condition. Verify no cracks at ends. Inspect rod ends per Section 2.120. Verify security and operating clearance.

Cyclic Push-Pull Tubes: Inspect condition. Verify no cracks at ends. Inspect rod ends per Section 2.120. Verify security and operating clearance. Contact between A121-3 & -7 push-pull tube lower ends is permitted when cyclic stick is in aft corners of cyclic box.

Cyclic Bellcrank: Inspect condition. Verify security and operating clearance.

Cyclic Yoke (aft end of torque tube): Inspect condition. Inspect bearings per Section 2.120. Verify security and operating clearance.

Cyclic Fork (attaching bellcrank to collective stick): Inspect condition. Inspect rod end per Section 2.120. Verify security. Verify operating clearance.

Throttle Overtravel Spring: Inspect condition. Inspect rod ends per Section 2.120. Verify security and operating clearance. Contact between overtravel spring and A121-1 push-pull tube is permitted when cyclic stick is in forward right corner of cyclic box.

Collective Friction and Stop Assembly: Inspect condition. Verify no nicks, cuts, or scratches. Move collective up and down and verify no bending or binding. Verify security and operating clearance.

Collective Boot: Inspect condition. Verify no tears. Ensure tie string ends are tucked into boot (if installed - current production aircraft use Ty-raps to secure boot around collective stick).

Fasteners & Torque Stripes: Inspect condition and verify security of all fasteners. Renew deteriorated torque stripes per Figure 2-1.

Source: Cloncurry Air Maintenance (left) and Robinson Helicopter Company (right), annotated by the ATSB

Certification for the work

Item 18 of the CAM checklist was for the installation and closure of all access panels on completion of the 100-hour inspection. At interview in August 2017, the chief engineer reported

[32] Torque striping is the application of a thin lacquer to a bolt/nut to indicate it has been torqued to the correct value and provide a visual indication of any movement of the bolt/nut, which indicates a loss of torque.

that the certification for independent inspections was after the rigging, but before the panels were installed and the fuel tanks calibrated. However, the work-pack suggested that the fuel calibration was recorded before certification for independent inspections, which was the last entry in the 'aircraft work-sheets' section of the work-pack.

At the completion of the 100-hour inspection, the helicopter was to undergo a ground run, track and balance of the main rotors, autorotation RPM check and flight check. The work-pack showed that the AME certified for the ground check and run-up, a fanwheel and tail rotor balance, the track and balance of the main rotor and autorotation RPM check.

Of note, the AME was not qualified to ground run the helicopter, and the pilot for the track and balance flights was reportedly following the chief engineer's instructions for the flights, not the AME. The pilot and chief engineer both reported that several flights were required for the track and balance of the main rotor, with adjustments made between the flights.

No entries in the work-pack were found for any track and balance adjustments, or for the check flight, which was required to follow the track and balance, and autorotation RPM check flights. The chief engineer reported that they were not using the maintenance manual checklists for these steps of the overhaul procedure. Instead, loose paper was used, which was not retained in the work-pack. Therefore, it was unknown what adjustments were made to the helicopter.

The work-pack showed that the AME certified for all the tasks in the aircraft work-sheets on 31 July 2017 and the chief engineer certified for the supervision on the same date.[33] Although there was no date recorded for the certification for independent inspections, it was considered likely that it was on the same date as this was the last entry in the work-sheets. Similarly, the 100-hour inspection certification was also not dated, but considered likely to have also occurred on the same date.

The ATSB noted that the single date certification at the end of the overhaul was not in accordance with the CAM *Maintenance Procedures Manual* (MPM). The MPM Part 6.10: *Scrutiny of Work and Certification*, required progressive certification for each 'item as it is completed on the work package'.

Organisational and management information

Organisational structure

Cloncurry Mustering Company's primary operations were cattle mustering and other airwork from their main base at Cloncurry Airport. The majority of maintenance conducted on their fleet of 23 R22 and four R44 helicopter's was performed by CAM, which was an associated company. In addition to this, CAM also performed work on external helicopters for other operators.

The facilities in Cloncurry were used by both CAM and CMC, and they had the same managing director (MD) and shareholders. The shareholders included the MD, chief engineer and several of the CMC senior pilots, including the accident pilot. The chief engineer for CAM also held the position of maintenance coordinator [34] for CMC.

One of the key positions in an operator's organisational structure is the Head of Aircraft Airworthiness and Maintenance Control (HAAMC). The position of HAAMC provides an interface with maintenance organisations for the planning and preparation of maintenance activities, and an independent check of the completion of those activities when an aircraft is returned to service.

The MD was issued with the CMC HAAMC approval by CASA in June 2005. According to the letter of approval, the HAAMC 'has the responsibility for all airworthiness matters relating to the

33 The chief engineer had completed the Robinson factory-sponsored maintenance course in 2009.

34 This was not a maintenance controller, which is a CASA approved position for class A aircraft operations, but had similar responsibilities.

aircraft operated under the AOC [Air Operator Certificate]'. Within the CMC operations manual, the responsibilities of the HAAMC were delegated to the maintenance coordinator (chief engineer). The ATSB considered this a pragmatic decision, as the chief engineer was the individual most suitably qualified and experienced for the role and responsibilities. However, it resulted in the two key positions of interface between CAM and CMC for maintenance and airworthiness matters being held by the same person.

Cloncurry Air Maintenance

Maintenance approval

Cloncurry Air Maintenance had a Certificate of Approval for the maintenance of piston-engine helicopters with a maximum take-off weight not exceeding 3,175 kg. Their approval included the maintenance of airframe, engines, engine components, and electrical components fitted to, or eligible to be fitted to, R22 and R44 helicopters. In accordance with *Civil Aviation Regulation 1988,* Section 30, CAM had a documented set of quality control procedures, published as their *Maintenance Procedures Manual* (MPM).

Workforce

In 2013, the CAM workforce comprised of four licenced aircraft maintenance engineers (LAMEs) and two apprentices. By the time of the accident, in August 2017, the workforce structure had changed to two LAMEs (the chief engineer and head engineer), one AME and three apprentices. All of these employees had been trained by CAM from the time of their apprenticeships.

The division of work for CAM required the chief engineer to manage the CMC helicopters, while the head engineer managed the external helicopters. The two LAMEs would support each other for independent inspections, with the chief engineer certifying for the independent inspections of external helicopters, and the head engineer certifying for the independent inspections of CMC helicopters. The AME and two apprentices were allocated to the CMC helicopters and the third apprentice allocated to support the head engineer working on the external helicopters. The two apprentices working on the CMC helicopters were a first year and fourth year apprentice. The first year apprentice was required to attend trade school and therefore not always present.

The chief engineer reported that it was difficult to recruit a LAME workforce into Cloncurry, due to its remote locality, and that alternative apprenticeship schemes might be perceived as less demanding with more attractive remuneration. The MD believed that the LAME recruitment problem was not limited to their business and that it was a wider problem, which also affected businesses on the east coast.

Workload

The cattle mustering season from April to September required an increase in the maintenance workload through the middle of the year to keep the CMC helicopters operating. The CAM hangar space facility was divided between a main area, where several helicopters could be parked for 100-hour inspections, and two separate 2,200-hour overhaul rooms dedicated for one CMC helicopter and one external helicopter.

At interview, none of the maintenance staff could recall any specific details associated with the disassembly and reassembly of the cyclic control assembly during the overhaul on VH-HGU. All staff reported it was a busy period and that the overhaul was routinely interrupted for 100-hour inspections. In the month of July 2017, 21 100-hour inspections were commenced on CMC helicopters and 20 were completed, in addition to progressing the overhaul of VH-HGU to completion on 31 July (plus one external helicopter in overhaul).

Robinson reported that a 100-hour inspection should take about 24 labour-hours to complete. Therefore, to complete 20 inspections in the month of July would require about 480 labour-hours. This would have required about three qualified staff (LAME/AME) working full time on the 100 hour-inspections for CMC helicopters, plus additional staff to progress the overhaul of VH-HGU. A calendar break-down of the 100-hour inspections and 2,200-hour overhauls for the CMC helicopters over the months of July and August is provided at *Appendix B – Maintenance workload*.

Quality assurance

Internal audits

Part 8 of the CAM MPM described the purpose of their internal audit program was:

> …to ensure that the effectiveness and performance of the Company and the procedures documented in the Maintenance Procedures Manual are continually being measured and assessed.

As they did not have a quality manager position, and none was required, CAM contracted an external auditor to perform their internal audits. The ATSB reviewed the two internal audit reports produced for CAM in 2015 and 2016, and noted that each had been performed by a different auditor.

The December 2015 audit included a review of three work-packs and 'nil findings' were recorded against them. The November 2016 audit included a review of one work-pack and 'nil defects' were recorded. Both audit reports concluded with 'nil non-conformances', 'nil requests for corrective action' and 'nil suggestions for system improvement'.

The work-pack sampled for the 2016 audit was for an R22 100-hour inspection. The ATSB reviewed this and noted the CAM 100-hour inspection abbreviated checklist was used and that all work was certified on the same day as performed by one LAME. In this instance, a single certification was provided for the ground check, run up and all 19 items on the abbreviated checklist.

Civil Aviation Safety Authority oversight

The CASA Cairns office was responsible for oversight of CAM. In the period from June 2013 to January 2018, 22 entries were made in the CASA database for their oversight of CAM. They included nine references to 'nil' or 'no major issues' and five references to CAM as a 'compliant organisation'

On 13 May 2015, an audit was conducted on CAM by one CASA airworthiness inspector for one day. On 22 June 2015, the auditor entered into the database for CAM 'recent audit carried out on Western Planes [plains] Sweep – compliant organisation'. The May 2015 visit was their last audit of CAM prior to the accident on 2 August 2017.

2015 audit

In the May 2015 CASA audit report summary, the auditor reported that CAM 'was assessed against the regulatory requirements within the system listed below (scope)'. The elements included:

- maintenance activity
- data and documents
- tooling and equipment
- stores and distribution.

The auditor assessed CAM compliance against the MPM and did not identify any breaches of the regulations. Two observations were issued as opportunities for improvement.[35]

The audit report stated that:

> Control of Maintenance Activity was assessed compliant when audited against Chapter 6 of the MPM. The Chief Engineer is conducting all duties as detailed in the MPM and controls the company workpacks and maintenance activities.

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[35] The two observations were for control of parts and documents.

> Sampling was conducted on three workpacks…with no issues identified.

The ATSB obtained a copy of the 2,200-hour overhaul work-pack sampled by the auditor. This was for an R22 helicopter, for which the overhaul was completed in 2015. The work-pack omitted several steps of the overhaul procedure, specifically, there were no entries for the 100-hour inspection, ground run, run up and check flight. While the track and balance was recorded and certified in the work-pack, there were no records for any adjustments. The entire work-pack was certified with a single date, which indicated progressive certification was not employed as required by the CAM MPM.

The auditor's notes did not reveal any further information about the CAM audit than what was recorded in the report. However, of note, the auditor did not retain copies of the work-packs sampled. Instead, the auditor's notes included photographs of the front pages of the work-packs. The report was certified by the auditor and approving officer on 25 May 2017.

2018 audit

After the accident, on 10–11 April 2018, CASA conducted an unscheduled Level 1 surveillance audit of CAM. The team comprised one airworthiness inspector and one engineering officer. During the course of the CAM audit, several findings were identified as airworthiness matters. This resulted in the expansion of the scope of the audit to include CMC.

The expansion of the scope resulted in CASA issuing two reports, one for CAM (the maintenance organisation) and one for CMC (the operator). The audit sampled several work-packs, which included the 2,200-hour work-pack for the R22 helicopter that started overhaul on 1 August 2017. The auditors made similar findings to what the ATSB noted for the work-pack for VH-HGU and the CASA 2015 audit of CAM. They included the following issues:

- Use of abbreviated checklists: The certification points in the company abbreviated 100-hour inspections checklists did not reflect the content of the inspection items listed under them in accordance with the RHC R22 maintenance manual. The use of abbreviated checklists relied on the maintenance staff continually referring to the maintenance manual to identify all the inspection items under each heading. The inspectors recommended CAM review the suitability of using abbreviated inspection checklists.
- Independent inspections: The 2,200-hour work-packs sampled found one independent inspection performed at the end of the overhaul. Given the scope of the overhaul and level of disassembly, reassembly and adjustments required, the auditors recommended that independent inspections are certified progressively and noted that additional inspections would be required for each adjustment of flight control components during the tracking and balancing procedure.
- Flight without a maintenance release: The chief engineer confirmed that it was their standard procedure to complete the flying tasks within the 2,200-hour overhaul before issuing a new maintenance release. Therefore, the helicopters were being flown without a valid maintenance release.
- Maintenance coordinator responsibilities: A number of helicopters were released to service without complying with their approved maintenance program. The CMC operations manual required the maintenance coordinator check all maintenance was completed before an aircraft was returned to service.

Previous occurrences involving fasteners

CASA R44 service defect report

On 17 May 2018, another operator's Robinson R44 helicopter completed a 2,200-hour overhaul, which included the replacement of the flight control hydraulic servo assemblies. The overhaul was certified by a LAME and with an accompanying independent inspection certification. On

26 February 2019, the operator submitted a service defect report to CASA following a pilot report of ‘deterioration of flight control inputs along with banging sound coming through airframe’.

On inspection, the bolts used to secure the hydraulic servos to the support bracket were found to have insufficient torque. The MS21042L-series nuts had not been replaced with D210-series nuts (see *Re-use of self-locking nuts* below), and no Palnuts®[36] were fitted as secondary locking devices in accordance with the instructions for continued airworthiness. The inadequate torque allowed movement of the servos, which resulted in elongation of the NAS6600-series bolts and the bracket bolt holes. Of note, despite the insufficient torque and elongation of the bolts, the MS21042L-series self-locking nuts fitted to the bolts had not failed or undone.

United States National Transportation Safety Board (NTSB/AAR-13/01)

On 7 December 2011, a Eurocopter AS350-B2 helicopter, operating as a ‘Twilight tour’ sightseeing trip, crashed in mountainous terrain about 14 miles east of Las Vegas, Nevada. The pilot and four passengers were fatally injured, and the helicopter destroyed. The United States National Transportation Safety Board (NTSB) found that the accident was a result of an in-flight disconnect of the flight controls, specifically, the separation of the servo control input rod from the main rotor fore-aft servo, which rendered the helicopter uncontrollable. The bolt, washer, self-locking nut, and split pin that normally secured the input rod to the fore-aft servo were not found. It was concluded that the hardware had been improperly secured during maintenance the day before the accident

The NTSB found there was inadequate maintenance of the helicopter, including (1) the improper reuse of a degraded self-locking nut, (2) the improper or lack of installation of a split pin, and (3) inadequate post-maintenance inspections. They reported the contributing factors included personnel fatigue for the mechanic and inspector, and the lack of clearly delineated maintenance task and inspection steps.

ATSB investigation AO-2011-135

On 12 October 2011, the pilot of a Robinson R22 helicopter, registered VH-JNP, was performing aerial work near Saxby Downs, Queensland, when a rattling noise from behind the cabin was heard by the pilot, who also noted the clutch light had illuminated. The pilot opened the clutch actuator circuit breaker and, at the same time, noted a burning rubber smell. The pilot made an immediate precautionary landing and shut down the helicopter.

The problems with the helicopter’s drive system were traced to the clutch assembly where a group of MS21042L-4 self-locking nuts on the drive belt upper sheave had cracked and fractured. This premature nut failure had stemmed from the likely embrittling effect of residual hydrogen generated during the cadmium electroplating process applied during manufacture. All of the affected self-locking nuts were identified as Airfasco Industries Fastener Group (affected batches identified as 12 June 2009, 23 October 2009 and 19 October 2010). They were fitted in April 2011, at the last 2,200-hour overhaul. Since that time, the helicopter had operated for a further 408 hours and was subject to four 100-hour inspections during that period.

ATSB investigation AO-2011-016

On 4 February 2011, a Robinson Helicopter Company R44 Astro helicopter, registered VH-HFH, commenced circuit operations at Cessnock Airport, New South Wales. Following a landing as part of a simulated failure of the hydraulic boost system for the helicopter’s flight controls, the instructor elected to reposition the helicopter to the apron. As the helicopter became airborne, it became uncontrollable and collided with the runway and caught fire. The pilot survived, but the instructor and a passenger were fatally injured.

[36] A Palnut® is a secondary locking mechanism fitted to critical fasteners in most areas on the helicopter.

The ATSB found that a fastener had detached from a hydraulic-boost servo, rendering the helicopter uncontrollable. The hydraulic-boost servo was repaired and functionally tested by the manufacturer in February 2009. The servo spent the majority of its time as a spare in storage before it was installed on VH-HFH in October 2010 during the last 100-hour inspection. The helicopter accrued 93.6 hours in-service prior to the accident. The bolt was recovered and noted that there was no distortion, and its threads and shank were visually undamaged. However, the remaining fastener parts were not recovered.

Previous safety issues - self-locking nuts

Hydrogen embrittlement

In the final investigation report of AO-2011-016, as mentioned above, the ATSB examined three cracked self-locking nuts from other R22 helicopters, of the same specification as that fitted to the detached fastener on the accident helicopter. These nuts were found to have cracked due to hydrogen embrittlement. Specifically, the report stated that:

> When high-strength steel, which has been exposed to hydrogen is sufficiently stressed, it can fail prematurely in a sudden, brittle manner. In the case of the examined self-locking nuts, the source of hydrogen was likely to have been from the cadmium plating process that was specified during manufacture for corrosion resistance. Under conditions of sustained stress, such as that associated with an assembled fastener, plus any residual tensile stresses from manufacturing, the presence of hydrogen can result in brittle cracking, typically less than 1 week from the time of application of the sustained stress.

In response to the identification of the hydrogen-embrittled self-locking nuts, the ATSB raised the following safety issue (AO-2011-016-SI-01 – *Self-locking nut failure*) on 30 April 2012, affecting owners and operators of RHC helicopters:

> A number of self-locking nuts from other aircraft, of the same specification as that used to secure safety-critical fasteners in VH-HFH, were identified to have cracked due to hydrogen embrittlement.
>
> During the course of the investigation the ATSB was provided with three self-locking nuts from other aircraft that had cracked in service. Detailed examination of those nuts identified that they had failed due to hydrogen embrittlement. In response to that finding, the ATSB notified the helicopter manufacturer, the Civil Aviation Safety Authority (CASA) and the United States National Transportation Safety Board and Federal Aviation Administration.

At the time of publishing that investigation report and safety issue, RHC had reported the following proactive safety action in response to the safety issue:

> In response to the identification of hydrogen-embrittled self-locking nuts during this investigation, the helicopter manufacturer issued service letters (SL-58, SL-38 and SL-01),[37] which detailed the hydrogen-embrittlement risk, including the expected failure characteristics.

The Civil Aviation Safety Authority also reported the following proactive safety action at the time of publishing:

> In response to the identification of hydrogen-embrittled self-locking nuts, CASA issued Airworthiness Bulletin 14-002, on 12 October 2011, alerting aircraft owners, operators and maintenance personnel to the possibility of in-situ failures of MS21042 and NAS1291-series self-locking nuts. The bulletin provided background information on previous occurrences and the mechanism and hazards associated with hydrogen embrittlement, and recommended that:
>
> Pilots and maintenance personnel closely monitor the occurrence of hydrogen-induced delayed cracking in high-strength steel standard aircraft hardware, such as nuts via close inspection following installation and thereafter at Daily / Preflight and periodic inspections.

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37 Service letters SL-58, SL-38 and SL-01 preceded service letters SL-64, SL-50 and SL-09.

> Before simply replacing cracked/failed nuts with new items, consider contacting the manufacturer for advice regarding replacement of associated fasteners which may have suffered over-loading as a result of the failure of one of more nuts.
>
> Report all MS21042 and NAS1291-series nut failures to CASA via the SDR [Service Difficulty Reporting] system.

Re-use of self-locking nuts

As explained above, cracking from hydrogen embrittlement of nuts fitted to Robinson helicopters has been previously identified.[38] In October 2014, RHC published service letters for the R22 (SL-64), R44 (SL-50) and R66 (SL-09) helicopters on the subject of *D210 Corrosion-Resistant (CRES) Nuts*.[39] The service letters stated that, whenever maintenance that involves the disassembly and reassembly of a critical fastener is performed, the MS21042L or NAS1291-series nut should be replaced with a D210-series nut. The R22 maintenance manual was amended in October 2014 to incorporate what was stated in SL-64. For specific instances of cracked nuts, RHC have published service bulletins for their replacement within a compliance period.[40]

The R22-series maintenance manual included the following information under section 1.300 Fastener Torque Requirements:

> **D. Critical Fastener:** A critical fastener is one which, if removed or lost, would jeopardize safe operation of the helicopter. This includes joints in the primary flight control system, and non-fail-safe structural joints in the airframe, landing gear, and drive system.
>
> **CAUTION:** D210-series nuts, which supersede MS21042L-series and NAS1291-series nuts, are required on critical fasteners.

In the course of interviewing maintenance personnel employed by CAM, the ATSB noted a low-level of awareness of the need to replace self-locking nuts with the D210-series nuts when critical fasteners were reassembled. However, the staff were aware of the limitation on the re-use of them, specifically, that they could not be reused if they had lost their friction torque. It is a standard practice within sectors of the aviation industry to re-use self-locking nuts provided the nut cannot be turned onto the bolt thread by hand and the published torque value for the fastener is achieved.[41]

During the course of the investigation, the ATSB spoke with another maintenance organisation, who reported that they employ the same practice of re-using self-locking nuts, and RHC confirmed that the described practice was considered acceptable. The United States NTSB reported on this practice as accepted by the manufacturers of light helicopters in their accident report AAR-13/01.[42] They noted that guidance on the re-use of self-locking nuts was provided by Eurocopter (now Airbus Helicopters), Sikorsky, Bell and the United States Federal Aviation Administration.

In December 2018, the ATSB received the accident helicopter's jackshaft, which had the fasteners attached. The jackshaft was one of a number of parts within the flight control system that was disassembled and sent for non-destructive testing during the 2,200-hour overhaul. The bellcrank was not subject to non-destructive inspection and therefore not required to be disassembled. In

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[38] Also refer to Civil Aviation Safety Authority Airworthiness Bulletin: 14-002, Cracked MS 21042 / NAS 1291 – Series Nuts – Hydrogen Embrittlement; and Transport Canada Civil Aviation Safety Alert 2013-04: Defective Standard Aircraft Hardware – Self-Locking Nuts – MS21042 and NAS11291.

[39] In August 2018, Textron published an information letter to owners and operators of Bell helicopters to inform them of the supersession of MS21042 and NAS1291 series nuts in response to reports of cracking from hydrogen embrittlement.

[40] For example, R44 Service Bulletin SB-88: *Landing Gear Attach Nuts*, required the replacement of NAS1291-7 nuts with D210-7 within 100 flight hours or by 28 February 2015.

[41] Previous work during the conduct of the ATSB investigation involving R44 helicopter VH-HFH (AO-2011-016) found that a MS21042L-series self-locking nut could be reused up to 15 times without compromising the friction torque.

[42] AAR-13/01: Loss of Control Sundance Helicopters, Inc. Eurocopter AS350-B2, N37SH, Near Las Vegas, Nevada, December 7, 2011.

late January 2019, the ATSB completed semi-quantitative chemical analysis of the nuts fitted to the jackshaft and found they were consistent with a carbon/alloy steel, and therefore not consistent with D210-series stainless steel corrosion-resistant nuts. The nuts fitted to the jackshaft had similar markings to the nuts fitted to the bellcrank, which were consistent with MS21042L/NAS1291-series nuts.

At the time of the reassembly of the accident helicopter, the current R22 *Illustrated Parts Catalog* listed the part number D210-4 for the nuts fitted to the jackshaft, and RHC confirmed there were no alternate part numbers to the D210-series nuts.

In consideration of the evidence, the ATSB concluded that the industry practice of re-use of self-locking nuts on Robinson helicopters may result in the omission to install D210-series nuts when critical fasteners are reassembled. Therefore, as part of this investigation, the ATSB issued a safety advisory notice (AO-2017-078-SAN-001) on 28 March 2019.

Memory-related errors

In the 2008 ATSB research report *An Overview of Human Factors in Aviation Maintenance* (AR-2008-055), it was noted that 'poor maintenance procedures can lead to a range of errors including memory lapses, technical misunderstandings, and rule violations'.

Certification for a task after an extended period of time, in which multiple similar tasks were performed, can result in the misattribution of the source of memory at the time of certification. Misattribution of the source of a memory occurs when an individual recalls an item or fact from a past experience, but attributes it to an incorrect source of experience (Schacter, 1999). In the case of aviation maintenance, certifying for an inspection on aircraft *A*, when in fact it was performed on aircraft *B*, would be an example of possible source misattribution.

Closely related to source misattribution is the phenomena of suggestibility. The difference is that suggestibility includes an overt suggestion (Schacter, 1999). Presenting maintenance staff with a work-pack of recorded tasks for certification may introduce the suggestion of work completed, particularly if this is associated with the knowledge of a serviceable assessment from an operational check. This could result in staff certifying for tasks because they are listed on the work-pack for certification, rather than because they remember performing them.

Source misattribution and suggestibility are examples of retrospective memory errors at the time a certification is made. However, maintenance documentation is also important for prospective memory, which is remembering to complete a task in the future. According to Dismukes and Nowinski (2007), prospective memory is distinguished by three features: (1) an intention to perform an action at some later time when circumstances permit; (2) a delay between forming and executing the intention, typically filled with activities not directly related to the deferred action; and (3) the absence of an explicit prompt indicating that it is time to retrieve the intention from memory.

If an inspection of a system identified a requirement for re-work, and the re-work was completed at a time that the inspector was not available to re-inspect the work, then an omission to re-inspect would be an example of a possible prospective memory error. In this case, recording the disturbance (re-work) in the work-pack would provide a prompt to all relevant staff members that an independent inspection is required before the aircraft can be released from maintenance.

Safety analysis

Introduction

On the morning of 2 August 2017, the pilot of a Robinson R22 Betta II helicopter, registered VH-HGU and operated by Cloncurry Mustering Company (CMC), departed Cloncurry Airport, Queensland on ferry flight in preparation for aerial mustering operations at various stations. About 3 minutes after take-off, the pilot experienced a loss of control and the helicopter broke-up in-flight. The helicopter collided with terrain about 7 km north-north-west of Cloncurry. The pilot, who was the only occupant, was fatally injured and the helicopter was destroyed. The accident flight was the first commercial flight of the helicopter after completing its second 2,200-hour overhaul.

While the pilot's post-mortem examination identified coronary atherosclerosis, there was no evidence of a heart attack or stroke. Although it was noted that any conclusions could not be based on the examination alone. Despite this, the witnesses who encountered the pilot on the morning of the accident reported the pilot's demeanour as normal. Further, a review of the GPS data did not find any indication of the pilot operating the helicopter erratically or attempting a descent to land. Therefore, it was unlikely that the pilot had experienced a medical event during the flight.

This analysis will discuss the likely reasons for the accident, the maintenance human factors issues of tracking tasks and workload, and organisational factors related to the quality assurance of the maintenance practices.

Loss of control and in-flight break-up

The condition of the tail rotor driveshaft indicated the tailcone was severed under normal engine power and rotor speed conditions. During a photographic review of the wreckage evidence, the ATSB noted the rear fastener for the cyclic assembly horizontal push-pull tube, which connected it to the bellcrank, was missing. All other bellcrank fasteners were in situ, and correctly assembled. The bellcrank and a bolt, believed to be from the missing fastener, were then recovered from the wreckage for examination.

The heat damage to the bolt, and lack of cadmium residue surrounding the bellcrank bolt hole, indicated the fastener was not fitted during the fire. In addition, the deformation of the bellcrank plates at the location of the missing fastener indicated the fastener was not fitted when the yoke and bellcrank were bent. Further, there was no damage to the bolt or bellcrank bolt holes to indicate the bolt was forcibly removed during the accident sequence. Therefore, it was concluded the bolt had separated from the bellcrank before impact. The absence of the fastener would have resulted in a disconnection of the longitudinal cyclic control. This in turn would have allowed the main rotor disc to tilt aft beyond the normal operating limits (rigging limits), striking the tailcone. Therefore, the severed tailcone was consistent with the separation of the longitudinal cyclic control in forward flight conditions.

The separation of the longitudinal cyclic control would result in the pilot losing pitch control of the main rotor disc. It was very likely that this occurred with little or no warning to the pilot, as there was no indication in the GPS data of an attempted landing. In addition to the loss of pitch control, the severed tail rotor driveshaft would have resulted in the pilot losing directional control. The impact damage and lack of ground witness marks from the main rotor blades, indicated that the helicopter broke-up in-flight.

Therefore, the loss of cyclic control was considered unrecoverable and was consistent with the helicopter colliding with the ground with a very high deceleration after the tailcone was severed.

Separation of the bolt

On consideration as to why the bolt had separated from the cyclic control bellcrank assembly, the ATSB had considered that the self-locking nut failed due to (1) over-torqueing, (2) fatigue cracking, (3) hydrogen embrittlement, (4) loosening, or (5) it was either not installed or was inadequately torqued. The most likely scenario was that the self-locking nut was either not reinstalled or was inadequately torqued.

Over-torqueing

The recovered bolt did not exhibit any damage (elongation) to the grip or threads to indicate it was exposed to excessive torque. Therefore, failure of the nut from over-torqueing was considered very unlikely.

Fatigue cracking

For the bellcrank, the design of the assembled joint is such that loads experienced by the fastener are predominantly a combination of tension within the bolt from axial preload of the joint as the nut is torqued to specification, shear loading of the bolt from operation of the cyclic, and high and low frequency dynamic loading from the rotor system, engine and other rotating components. In each case, the nut is under compression, rather than tension, predicating the likelihood of a nut failure by fatigue to be unlikely.

Hydrogen embrittlement

There have been several previous instances of self-locking nuts found cracked due to hydrogen embrittlement. In 2014, Robinson Helicopter Company released a service letter, which introduced the replacement by attrition of existing MS21042L-series and NAS1291-series nuts with D210-series corrosion-resistant nuts. However, in this case the evidence did not support hydrogen embrittlement as a failure mechanism of the missing nut due to the following:

- The known batches of affected nuts were Airfasco, and the markings on the nuts installed on VH-HGU were not consistent with this manufacturer.
- VH-HGU had been manufactured in 2008, prior to the manufacture of the affected batches of nuts in 2009 and 2010.
- The nuts fitted to the bellcrank of VH-HGU had been in service for many years. Delayed hydrogen embrittlement generally occurs in the order of days and weeks, not years. In this time, the maintenance schedule meant there were many opportunities where the nuts would have been visible for inspection.
- None of the remaining nuts on the bellcrank, or from the same manufacturer in other locations, exhibited any evidence of cracking associated with hydrogen embrittlement.

Therefore, failure of the self-locking nut from hydrogen embrittlement was considered very unlikely.

Loosening

While the repeated re-use of a self-locking nut could result in degradation and loss of its self-locking capability, Cloncurry Air Maintenance (CAM) staff were aware of the limitation on their re-use, specifically that they could not be re-used if they had lost their friction torque. Previous work by the ATSB found that a MS21042L-series self-locking nut could be re-used up to 15 times without compromising the friction torque. The cyclic control is not disassembled during the 100-hour inspection as the non-destructive inspection of parts is only performed at the 2,200-hour overhaul. If the bellcrank was disassembled at each 2,200-hour overhaul then the nut would only have been re-used twice since production. So while it is possible that the nut had been re-used during the service life of the helicopter, separation of the bolt from the bellcrank from loosening of the nut as a result of a loss of torque in-service was considered unlikely.

Not installed or inadequately torqued

The bolt and bellcrank were found at the accident site and neither exhibited any physical evidence to indicate the fastener may have been predisposed to premature failure. The evidence indicated that the bolt was not installed in the bellcrank at the time of impact, which was about 3 minutes after take-off. It was therefore likely that the self-locking nut was either not installed, or that it was inadequately torqued, at the time of take-off. As it is not possible that there could have been ongoing operation of the helicopter with the nut not attached to the fastener, the most likely reason that the nut was either not installed or inadequately torqued on the accident flight, was due to the maintenance activities that were conducted during the previous 2,200-hour overhaul, completed 2 days prior to the accident.

The maintenance personnel could not recall the details of their work performed on the helicopter. However, they indicated that the bellcrank fasteners would not normally be disturbed when removing the cyclic assembly. Further, although there was no maintenance recorded to indicate that the fastener was disturbed during the overhaul, there were several reasons why the fastener may have been disturbed.

The possible reasons for disturbance of the fastener included inadvertent disassembly to separate the horizontal push-pull tube from the bellcrank, disassembly to measure play in the rod-end with a dial test indicator, or disassembly to adjust the length of the horizontal push-pull tube during the flight control rigging process. There were no records of any of these disturbances in the work-pack. However, the ATSB noted that disturbances of the flight controls were not recorded in the work-pack, except for the standard overhaul requirements and for the replacement of parts.

The work-pack recorded several certifications for inspections. These inspections would have provided maintenance personnel with the opportunity to observe the bellcrank assembly. It could not be determined why none of these inspections detected an anomaly with the bellcrank fastener.

However, it was noted that the organisation’s maintenance practices relied significantly on human memory. The chief engineer and the head engineer both reported that after they conducted their inspections they would provide a list of corrective actions. As these defects and corrective actions were not being tracked in the work-pack, and the maintenance staff were carrying a significant workload in the month leading up to the accident, their practices were considered to be conducive to a memory-related error event. These factors are discussed further in the following sections.

Maintenance practices

The 2,200-hour overhaul was the largest scope of maintenance activity for an R22 helicopter. It involved the disassembly of the helicopter, inspections and replacement of a significant number of parts with new or overhauled parts, and reassembly of the helicopter. A ground check and run up is required before the disassembly to capture any additional work for the overhaul. A 100-hour inspection, ground check, run up, track and balance, flight check, and weight and balance are conducted after reassembly and before return to service.

In order to track the progress of work, the CAM *Maintenance Procedures Manual* (MPM) required all tasks to be progressively certified. That is, certified at the time each item of work was completed. For VH-HGU, the aircraft work-sheets were all certified at the end of the overhaul period, on 31 July 2017. Additional disturbances of the flight controls for adjustments and inspections were not recorded. Therefore, without recording all tasks and practicing progressive certification, the work-pack was not an accurate record of the condition of the helicopter while under maintenance, or of all the work performed on completion of the overhaul.

In addition to the normal certification, any disturbance of the flight controls required an independent inspection. This required the inspector to verify that the work was carried out in accordance with the approved maintenance data and check that the system functioned correctly. The certification for independent inspections was not dated, but considered likely to be 31 July 2017 as it was the last entry in the aircraft work-sheets. If it was on this date, then the helicopter was operated for the track and balance, autorotation RPM check and local area flight, without certification for independent inspections. As the disturbances of the flight controls for adjustments were not recorded in the work-pack, the integrity of the independent inspection process was reliant on informal methods of communicating additional work requirements and reporting their completion for re-inspection.

The work-pack included the 100-hour inspection, for which CAM had introduced an abbreviated checklist where a single certification could apply up to 30 separate inspection items. There were no dates recorded for the certifications, but they likely occurred on 31 July 2017. This suggested the checklist was not used to track the 100-hour inspection tasks and manage any interruptions during the process.

When the ATSB reviewed work-packs from other maintenance activities in 2015 and 2016, and the observations made by the Civil Aviation Safety Authority (CASA) audit of 2018, it was apparent that the maintenance documentation practices for VH-HGU were not an isolated case. The evidence suggested a systemic issue within CAM of not using the maintenance documentation to track the condition of helicopters while under maintenance and to record all maintenance activities.

The use of work-packs at CAM was consistent with the culture of recording and certifying for maintenance for oversight purposes, rather than for quality control in accordance with their MPM. Circumventing the quality control procedures may render them ineffective as a means for ensuring all tasks have been completed correctly.

Extended periods of time between performing and certifying for tasks increased the likelihood of an individual’s memory being subject to source misattribution or suggestibility, or combination of both, when the certification was made. Omissions to record and capture all flight control disturbances in the work-pack increased the likelihood of a prospective memory error during the overhaul period. Therefore, the maintenance practices at CAM exposed the organisation to an increased risk of memory-related errors and the omission of tasks.

Organisational structure and workload

In the period 2013 to 2017, the CAM workforce structure changed from a majority of licenced aircraft maintenance engineers to three apprentices with one aircraft maintenance engineer and two licenced aircraft maintenance engineers. CAM undertook maintenance for CMC helicopters as one part of its operation, as well as maintenance of helicopters from external operators as another part. With one licenced aircraft maintenance engineer and apprentice assigned to the external helicopters, and one apprentice attending trade school in the period leading up to the accident, there were effectively three members of staff for the CMC helicopters (chief engineer, aircraft maintenance engineer and a fourth year apprentice).

Further, the structure of the workforce required the chief engineer to assume responsibility for the planning, supervision and coordination of maintenance for the CMC jobs. When the ATSB attempted to obtain details about the maintenance of the cyclic assembly on VH-HGU, the staff consistently reported that they could not recall specific details, and that it was a busy period with the overhaul constantly interrupted for 100-hour inspections. The month leading up to the accident included 20 100-hour inspections on CMC helicopters, which was consistent with the staff reports of it being a busy period.

The ATSB used a labour-hour plan to review the CAM staffing levels over this period and established that 100-hour inspections should have taken about 480 labour-hours. This equated to a requirement for three full-time qualified staff members, in addition to what was required to progress the overhaul for VH-HGU.

The volume of work and turn-around times were consistent with the peak mustering season and the staff reports of regular interruptions to the overhaul for other jobs. If the workforce structure does not change as the production requirements increase, it is likely that junior personnel will be allocated more responsibilities. This may occur concurrently with less supervision if the supervisor's workload must also increase to deliver the production goals.

Therefore, the volume of work and interruptions to the overhaul in the month of July 2017, combined with the low levels of staff experience and qualifications, and maintenance practices, increased the risk of a maintenance error event. In addition, the intensity of the work likely reduced the chief engineer's capacity to effectively supervise all the activities related to the CMC helicopters.

Internal independence

The CMC-CAM managing director was the CASA approved Head of Aircraft Airworthiness and Maintenance Control. This position is intended to provide an interface with maintenance organisations for the planning and preparation of maintenance activities, and an independent check of the completion of those activities.

The managing director, who had a pilot background, had delegated the Head of Aircraft Airworthiness and Maintenance Control responsibilities to the position of maintenance coordinator, which was filled by the chief engineer at the time of the accident. This decision resulted in the same individual holding the two key positions of airworthiness and maintenance management within CMC and CAM. As a result of this structure, the chief engineer had a considerable number of responsibilities and there was no independent assurance of maintenance quality from the Air Operator Certificate holder. In addition, there was no requirement for CAM to have a quality manager to routinely monitor, measure and evaluate the organisation's performance, and advise the managing director and chief engineer of the results.

In the absence of an independent maintenance coordinator or quality manager, the organisation was operating with very few checks and balances. In addition, the ATSB noted that all maintenance staff, including the chief engineer, were trained through their apprenticeships at CAM. The home-grown workforce, combined with no permanent internal independent oversight, limited CAM's exposure to alternative maintenance practices and continuous improvement.

Audit oversight

In the absence of a quality manager for CAM, the role of internal audit was managed by contracting an external auditor. The ATSB reviewed the two internal audits performed in 2015 and 2016, and noted there were no findings, no requests for corrective action and no suggestions for improvements. Upon review of the work-pack sampled in the 2016 audit, the ATSB noted there was no evidence of progressive certification, an abbreviated 100-hour inspection checklist was used, and a single certification was made for the entire 100-hour inspection on the airframe, ground check and run up.

The observations of the sampled work-pack suggested it was not used to track the progress of maintenance, which presented the risk of the omission of inspections during periods of interruptions. In contrast, the Robinson Helicopter Company maintenance manual checklist for the 100-hour inspection provided points of certification for each item. Chapter 6 of the CAM MPM included the requirements to conduct maintenance in accordance with approved data and to progressively certify for each item as it is completed. Use of the Robinson Helicopter Company checklist would have provided the auditor with evidence that approved data was used and current, and that it facilitated progressive certification, thereby demonstrating that requirements were being met.

Similarly, in 2015, CASA performed their last system-based audit of CAM prior to the accident. The auditor sampled three work-packs, which included a 2,200-hour overhaul for an R22, with no issues identified. The reported criteria for the sampling was Chapter 6 of the CAM MPM. The ATSB's review of that work-pack found that it did not capture all the requirements of the overhaul procedure or progressive certification. Therefore, it did not conform to Chapter 6 of the MPM.

However, a post-accident audit conducted by CASA identified a number of findings similar to those observed by the ATSB.

From the ATSB's review of the sampled work-packs, it was noted that the maintenance practices employed by CAM during the overhaul of VH-HGU were present before the helicopter was acquired by CMC in February 2017 and entered overhaul. These practices were visible to auditors engaged in internal and external audits of CAM and indicated that the work-packs were not being used for progressively recording and tracking tasks. Consequently, the audits were missed opportunities to identify and recommend improvements to the practices employed by CAM staff, which limited their benefit to CAM as a quality assurance tool.

Re-use of self-locking nuts

In the course of interviewing personnel employed by CAM, the ATSB noted a low level of awareness of the need to replace MS21042L/NAS1291-series nuts with the D210-series nuts when critical fasteners were reassembled. In accordance with the R22 maintenance manual, critical fasteners include a self-locking nut in their assembly. It is a standard practice within sectors of the aviation industry to re-use self-locking nuts provided the nut cannot be turned onto the bolt thread by hand and the published torque value for the fastener is achieved.

In December 2018, the ATSB received the accident helicopter's jackshaft, which had the fasteners attached. The jackshaft was one of a number of parts within the flight control system that was disassembled and sent for non-destructive inspection during the 2,200-hour overhaul. In late January 2019, the ATSB completed semi-quantitative chemical analysis of the nuts fitted to the jackshaft and found they were consistent with a carbon/alloy steel, and therefore not consistent with D210-series stainless steel corrosion-resistant nuts.

At the time of the reassembly of the accident helicopter, the current *R22 Illustrated Parts Catalog* detailed the part number D210-4 for the nuts fitted to the jackshaft, and RHC confirmed there was no alternate part number to the D210-series nuts. Therefore, the ATSB concluded that the industry practice of re-use of self-locking nuts on Robinson helicopters may result in the omission to install D210-series nuts when critical fasteners are reassembled.

Findings

From the evidence available, the following findings are made with respect to the loss of control and in-flight break-up involving the Cloncurry Mustering Company Robinson R22 helicopter, registered VH-HGU, 7 km north-north-west of Cloncurry Airport, Queensland, on 2 August 2017. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Safety issues, or system problems, are highlighted in bold to emphasise their importance. A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

Contributing factors

- About 3 minutes after take-off, a bolt separated from the cyclic control bellcrank, which resulted in an unrecoverable loss of control, in-flight break-up and collision with terrain.
- The bolt separated from the bellcrank during flight, likely due to either the self-locking nut not being reinstalled or inadequate torque of the nut on completion of the 2,200-hour overhaul. The accident flight was the first commercial flight after the 2,200-hour overhaul.

Other factors that increased risk

- **Cloncurry Air Maintenance had adopted a number of practices, which included using abbreviated inspection checklists, not recording all flight control disturbances and not progressively certifying for every inspection item as the work was completed, which increased the risk of memory-related errors and the omission of tasks. [Safety Issue]**
- The number of helicopters for which maintenance was performed in the month leading up to the accident likely exceeded the workforce capability, given the staffing levels and qualifications. This likely reduced the capacity of the chief engineer to conduct oversight activities and increased the risk of a maintenance error not being captured.
- Cloncurry Air Maintenance had limited internal independent oversight and increased reliance on audits for the evaluation of its quality performance. This was partly due to:
  - the absence of an independent maintenance coordinator or quality manager, and
  - all maintenance staff had worked almost exclusively for Cloncurry Air Maintenance, which limited the organisation's exposure to other maintenance practices.
- The most recent contracted audit of Cloncurry Air Maintenance, performed as part of the organisation's quality activities, and the previous audit conducted by the Civil Aviation Safety Authority, did not provide any observations of error-conducive maintenance practices, although they were present at the time. These were missed opportunities to identify and recommend improvements to the tracking and certification of maintenance tasks.
- During reassembly of the helicopter after the 2,200-hour overhaul, self-locking nuts, consistent with MS21042L-series nuts, were re-used on critical fasteners without replacing them with D210-series corrosion resistant nuts in accordance with the manufacturer's instructions for continued airworthiness. The D210-series nuts were introduced to reduce the risk of hydrogen embrittlement cracking from the MS21042L-series and NAS1291-series nuts.

Other findings

- There was no recorded maintenance on the helicopter to indicate that the bellcrank fastener was removed, and it was not always necessary to disassemble it during the 2,200-hour overhaul. However, there were several reasons why it could have been disturbed. These included disturbance as part of the disassembly of the cyclic control assembly, disassembly to inspect the attached rod-end with a dial test indicator, or disassembly to adjust the length of the horizontal push-pull tube as part of the main rotor rigging process. However, based on the evidence available, the ATSB could not establish if any of these tasks were performed.

- On completion of the helicopter's 2,200-hour overhaul, there were several certifications for inspection of the cyclic control assembly. The reason why these inspections did not detect an anomaly with the cyclic bellcrank fastener could not be determined.

Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and actions 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 organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation, or the desirability of directing a broad safety message to the aviation industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

All of the directly involved parties were provided with 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.

The initial public version of these safety issues and actions are provided separately on the ATSB website to facilitate monitoring by interested parties. Where relevant the safety issues and actions will be updated on the ATSB website as information comes to hand.

Maintenance practices

Safety issue number:	AO-2017-078-SI-01
Safety issue owner:	Cloncurry Air Maintenance
Operation affected:	Aviation: Aircraft maintenance
Who it affects:	Cloncurry Air Maintenance

Safety issue description

Cloncurry Air Maintenance had adopted a number of practices, which included using abbreviated inspection checklists, not recording all flight control disturbances and not progressively certifying for every inspection item as the work was completed, which increased the risk of memory-related errors and the omission of tasks.

Proactive safety action

Action taken by:	Cloncurry Air Maintenance
Action number:	AO-2017-078-NSA-024
Action date:	15 November 2018
Action type:	Amendments to documents, completion of inspections and toolbox meeting briefings.
Action status:	Closed

Cloncurry Air Maintenance

Cloncurry Air Maintenance advised the ATSB that they had replaced their existing abbreviated checklists with the Robinson maintenance manual checklists for the ground run, run-up and 100-hour inspection procedures. In addition, they removed all MS-series nuts from stores and completed inspections of the cyclic controls for all the helicopters they maintained with nil defects reported.

The chief engineer briefed all maintenance staff at their toolbox meeting in April 2018 of the requirement to certify for completed tasks progressively on job sheets at the completion of the task, rather than the completion of the job. Further, in May 2018, the chief engineer briefed all maintenance staff on the requirement for the maintenance release to be issued before the

2,200-hour check flights and therefore any subsequent flight control disturbances would require additional certification for independent inspections.

Status of the safety issue

Issue status: Adequately addressed

Justification: The ATSB is satisfied that, improvements in Cloncurry Air Maintenance's use of the job sheets to track the progress of maintenance should reduce their reliance on human memory for the condition of helicopters under maintenance and therefore reduce the risk of memory-related errors.

Additional 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:

Australian Transport Safety Bureau

ATSB safety advisory notice to maintenance personnel for Robinson helicopters

Action number: AO-2017-078-SAN-001

In March 2019, the Australian Transport Safety Bureau issued a safety advisory notice advising all Australian maintenance personnel for Robinson helicopters to ensure that before re-using a self-locking nut, that the correct part number is fitted, and that the D210-series corrosion-resistant nuts are used for reassembly of critical fasteners in accordance with the Robinson Helicopter Company instructions for continued airworthiness.

Civil Aviation Safety Authority

Airworthiness bulletin 67-005

On 5 June 2019, the Civil Aviation Safety Authority released airworthiness bulletin (AWB) 67-005 Issue 1: *Robinson Helicopter Flight Controls – Duplicate Inspections* [independent inspection]. The purpose of AWB 67-005 was to advise all operators and maintainers of the need to replace MS2104 hardware during removal or replacement of such hardware and the requirement to complete a duplicate inspection of each stage of maintenance on the primary flight controls.

On 20 June 2019, the Civil Aviation Safety Authority released AWB 67-005 Issue 2: *Robinson Helicopter Flight Controls – Independent Inspections.* Issue 2 highlighted the need for independent inspections to be conducted and 'recorded consecutively with each adjustment made during rotor tracking and balancing' activities. In addition to several recommendations, Issue 2 identified several human factor elements that could impact inspection performance, and highlighted the need for extra caution during post-maintenance flights in accordance with Robinson Helicopter Company safety notice SN-43:

> …any work completed on the flight control system deserves special attention because a flight control disconnect is almost always catastrophic.

General details

Occurrence details

Date and time:	2 August 2017 – 0702 EST	
Occurrence category:	Accident	
Primary occurrence type:	Flight controls	
Location:	7 km north-north-west of Cloncurry Airport, Queensland	
	Latitude: 20º 36.883' S	Longitude: 140º 28.450' E

Pilot details

Licence details:	Commercial Pilot (Helicopter) Licence, issued April 2010
Endorsements:	Low level, sling and aerial-mustering helicopter training
Ratings:	Single-engine aeroplane, single-engine helicopter, flight instructor and low level helicopter
Medical certificate:	Class 1, valid to 2 February 2018
Aeronautical experience:	Approximately 10,000 hours
Last flight review:	Flight instructor proficiency check 15 March 2016, valid to 31 March 2018

Aircraft details

Manufacturer and model:	Robinson Helicopter Company R22 Beta	
Registration:	VH-HGU	
Operator:	Cloncurry Mustering Company	
Serial number:	4335	
Type of operation:	Aerial work - ferry	
Departure:	Cloncurry Airport, Queensland	
Destination:	Cloncurry Airport, Queensland	
Persons on board:	Crew – 1	Passengers – 0
Injuries:	Crew – 1 (fatal)	Passengers – 0
Aircraft damage:	Destroyed	

Sources and submissions

Sources of information

The sources of information during the investigation included the:

- Civil Aviation Safety Authority
- Cloncurry Air Maintenance
- Cloncurry Flinders Medical Centre
- Cloncurry Mustering Company
- Ergon Energy
- Pilot’s next-of-kin
- Queensland Department of Health
- Queensland Police Service
- Robinson Helicopter Company
- United States National Transportation Safety Board.

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Australian Transport Safety Bureau 2014, AO-2011-135: Embrittled nut and related failures Robinson R22 Beta helicopter, VH-JNP, 22 km N of Saxby Downs, Queensland, 12 October 2011, ATSB, Canberra.

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Australian Transport Safety Bureau 2008, *AR-2008-055: An Overview of Human Factors in Aviation Maintenance*, report prepared by A Hobbs, Canberra.

Dismukes, K and Nowinski, J 2007, ‘Prospective memory, concurrent task management, and pilot error’. In AF Kramer, DA Wiegmann and A Kirlik (Eds.), *Series in human-technology interaction. Attention: From theory to practice* (pp. 225–236), Oxford University Press.

National Aerospace Standard, NAS6603 thru 6620, Bolt, tension, hex head, close tolerance, alloy steel, long thread, reduced major dia., self-locking and non-locking, 160 KSI Ftu, Revision 8, June 12, 2009.

Schacter, LD 1999, ‘The seven sins of memory: Insights from psychology and cognitive neuroscience’, *American Psychologist,* vol. 54, no. 3, pp. 182-203.

United States National Transportation Safety Board 2013, NTSB/AAR-13/01: Loss of Control, Sundance Helicopters, Inc. Eurocopter AS350-B2, N37SH, Near Las Vegas, Nevada, December 7, 2011, NTSB, Washington.

Wagtendonk, WJ 2011, *Principles of helicopter flight,* 2nd edn, Aviation Supplies & Academics Inc., Washington.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (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, Cloncurry Air Maintenance and Cloncurry Mustering Company personnel, pilot's next-of-kin, pilot's designated aviation medical examiner, Queensland Department of Health, Queensland Northern Coroner, Robinson Helicopter Company and the United States National Transportation Safety Board.

Submissions were received from the Civil Aviation Safety Authority, Cloncurry Air Maintenance and Cloncurry Mustering Company, pilot's next-of-kin, pilot's designated aviation medical examiner, Queensland Northern Coroner and the Robinson Helicopter Company. The submissions were reviewed and where considered appropriate, the text of the draft report was amended accordingly.

Appendices

Appendix A – Materials examination report

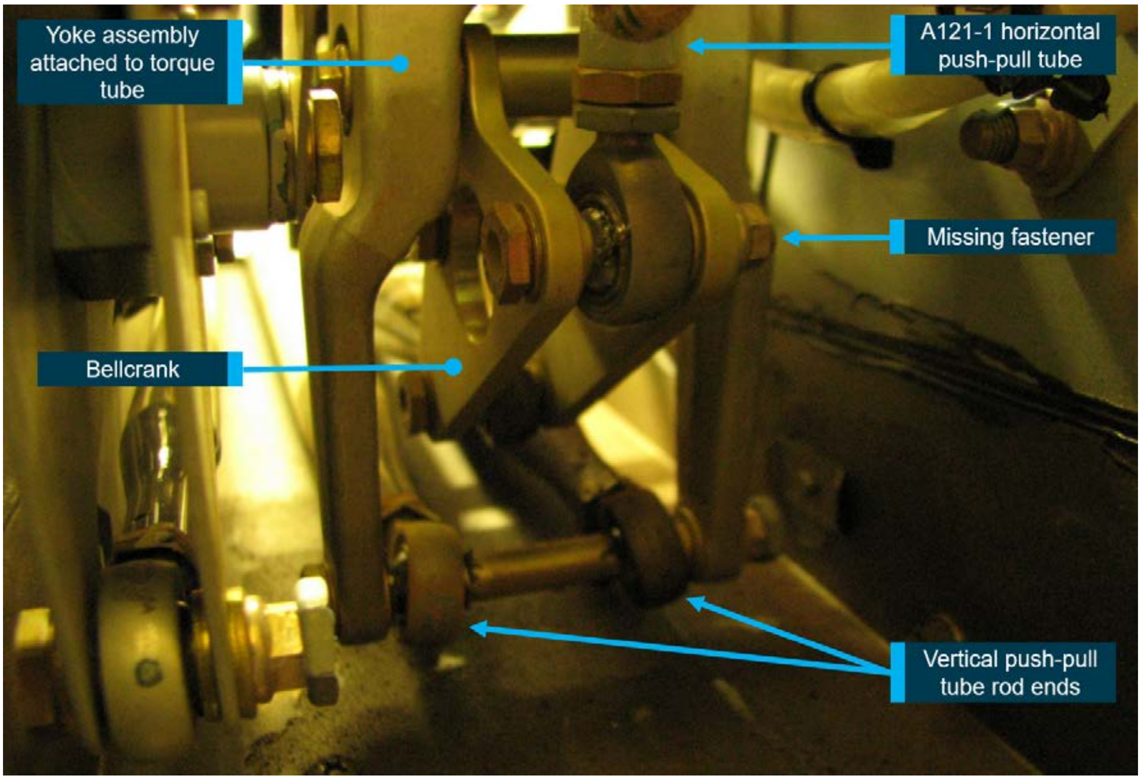
Introduction

Following a review of the site images for the wreckage of VH-HGU and impact information, a critical fastener from the cyclic control system was identified to be missing. The cyclic is one of the primary controls that a pilot must use during flight. It allows flight to be controlled in any direction of travel by tilting the main rotor disc. The cyclic stick within the R22 cabin was coupled to a non-rotating swashplate by a mechanical linkage comprising push-pull tubes, pivots, a bellcrank and its associated fasteners (e.g. bolts and nuts, rod ends, spacers and washers). The underfloor bellcrank provided the linkage between the horizontal and vertical push-pull tubes. It transmitted horizontal push-pull tube movement to vertical movement that tilted the swashplate, producing an associated tilting of the main rotor disc.

The missing fastener was normally installed in the bellcrank, connecting through the rod end of the horizontal push-pull tube (Figure A1). Due to the criticality of this fastener in relation to the operation of the cyclic control and its absence predicating an in-flight loss of control, several items from the wreckage were recovered from the accident site. The retained items were examined in closer detail at the ATSB's technical facilities in Canberra. They included:

- bellcrank (part number A958-1) and associated componentry
- recovered pieces of metallic debris
- jackshaft (part number A337-1) and associated componentry
- a single NAS6604-15 bolt
- additional loose nuts and washers
- forward support assembly (part number A014-6).

Figure A1: View looking upwards of an exemplar R22 control system, showing the bellcrank and location of the missing fastener



Source: ATSB

Scope

The scope of the examination was to analyse the bellcrank, yoke, and related components to determine how the fastener came to be missing, and to examine the pieces of metallic debris to determine if any additional components could be recovered. The jackshaft shared the same fastener type as the bellcrank assembly and was examined for comparative purposes. Additionally, the forward support assembly was used to verify the presence and security of NAS6604-15 bolts.

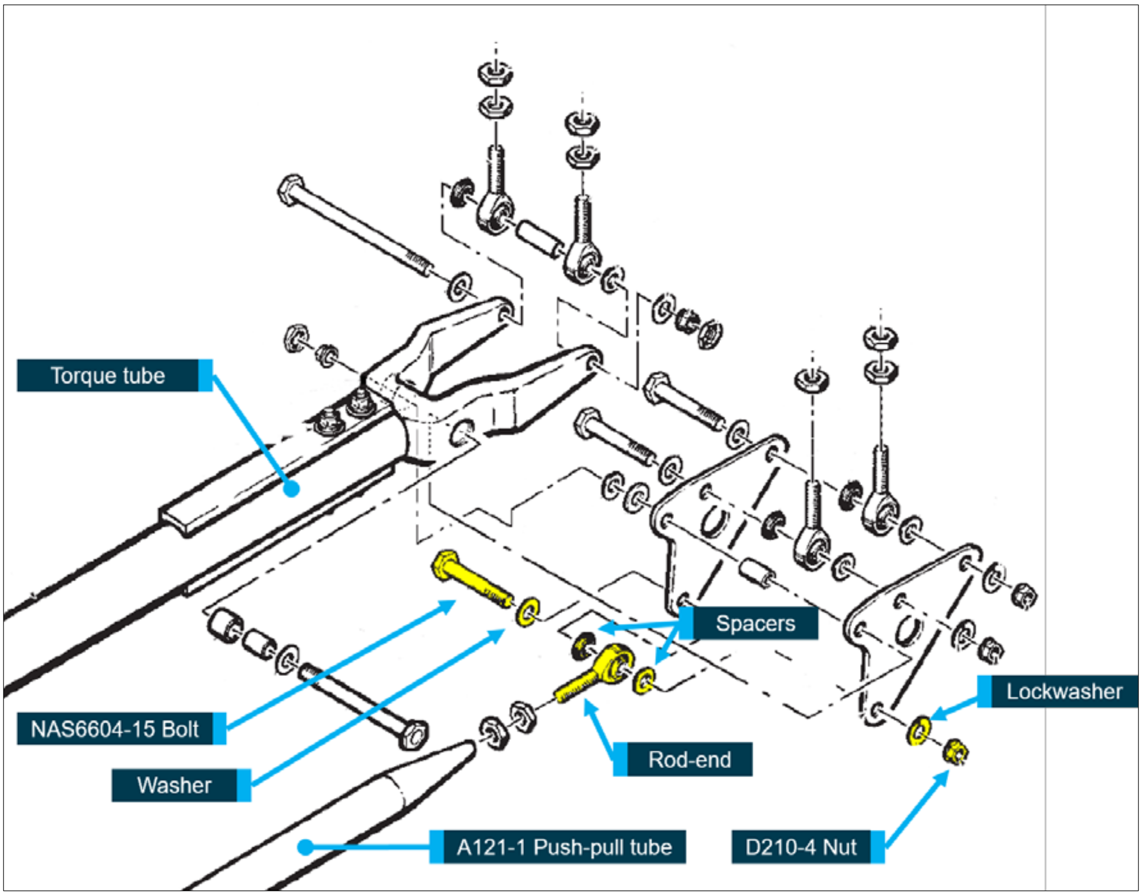
Examination

Bellcrank fasteners

The missing bellcrank fastener was an assembly of components comprised of the following (Figure A2):

- NAS6604-15 bolt
- NAS1149F0432P washer
- A115-1 spacer
- B332-441 lockwasher
- D210-4 nut
- rod-end.

Figure A2: Modified image from the R22 *Illustrated Parts Catalog* showing missing fastener assembly components and location



Source: Robinson Helicopter Company, annotated by the ATSB

Specified bolt

The current Robinson Helicopter Company (RHC) R22 *Illustrated Parts Catalog* (IPC) showed that the horizontal and vertical push-pull tubes from the cyclic control assembly were required to be attached to the bellcrank with a National Aerospace Standard (NAS) 6604-15 bolt[43] and D210-4 nut. The NAS specification listed the material type as alloy steel, grade 4140, 4340, or 8740. Table A1 provides the bolt dimensions from that specification.

Table A1: NAS6604-15 bolt specifications

Bolt	Thread UNJF-3A	Width (flats) (in)	Shank diameter (in)	Thread length (in)	Grip length (in)	Length (in)	Height (head) (in)
NAS6604-15 bolt	0.2500-28	0.429-0.439	0.2485-0.2495	0.425	0.938	1.363	0.125

Specified nut

Prior to 2014, the specified nut was an MS21042L-series or NAS1291-series. However, RHC issued a R22 service letter SL-64, *D210 Corrosion-Resistant (CRES) nuts*, on 13 October 2014, which addressed potential cracking of MS21042L-series nuts.

The D210-series CRES nuts, which supersede MS21042L-series and NAS1291-series nuts, are not susceptible to cracking. The service letter directed that when performing maintenance that

43 National Aerospace Standard, NAS6603 thru 6620, Bolt, tension, hex head, close tolerance, alloy steel, long thread, reduced major dia.,self-locking and non-locking, 160 KSI Ftu , Revision 8, June 12, 2009.

involved disassembly of a critical fastener (joints with a secondary lock), the fastener should be reassembled using a D210-series nut. The IPC was updated in February 2017 to reflect these changes. Table A2 provides the dimensions of the nuts.

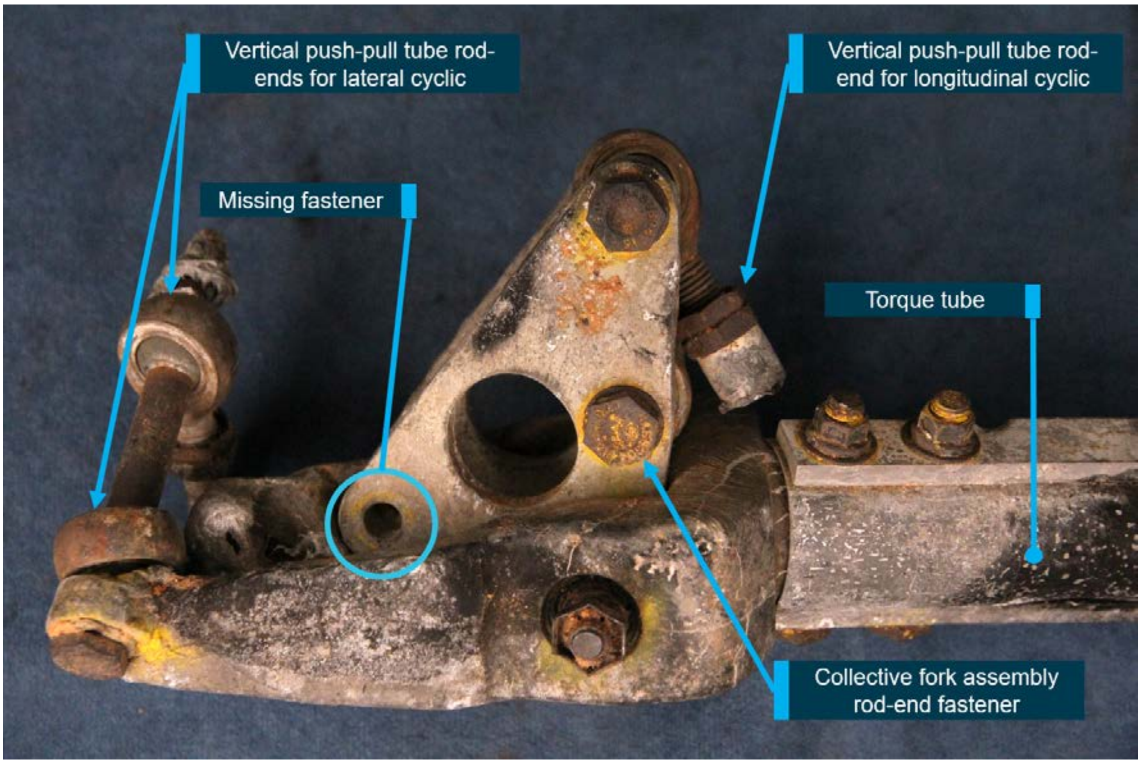
Table A2: Bellcrank nut specifications

Nut	Height (in)	Width (flats) (in)	Material
MS21042-L4 / NAS1291	0.204-0.219	0.304-0.316	Alloy steel, grade 1035, 1042, 1050, 4027, 4037, 8630 or 8740. Cadmium plated
D210 corrosion-resistant (CRES) nut	0.205-0.219	0.304-0.316	Stainless steel 660

Recovered bellcrank

The recovered bellcrank remained attached to the torque tube yoke assembly, which had fractured at the termination of the attached stiffening brackets. The submitted assembly exhibited significant damage as a result of mechanical and heat effects. All remaining rod ends, including those attached to the vertical push-pull tubes and collective fork assembly, had fractured in overstress (Figure A3).

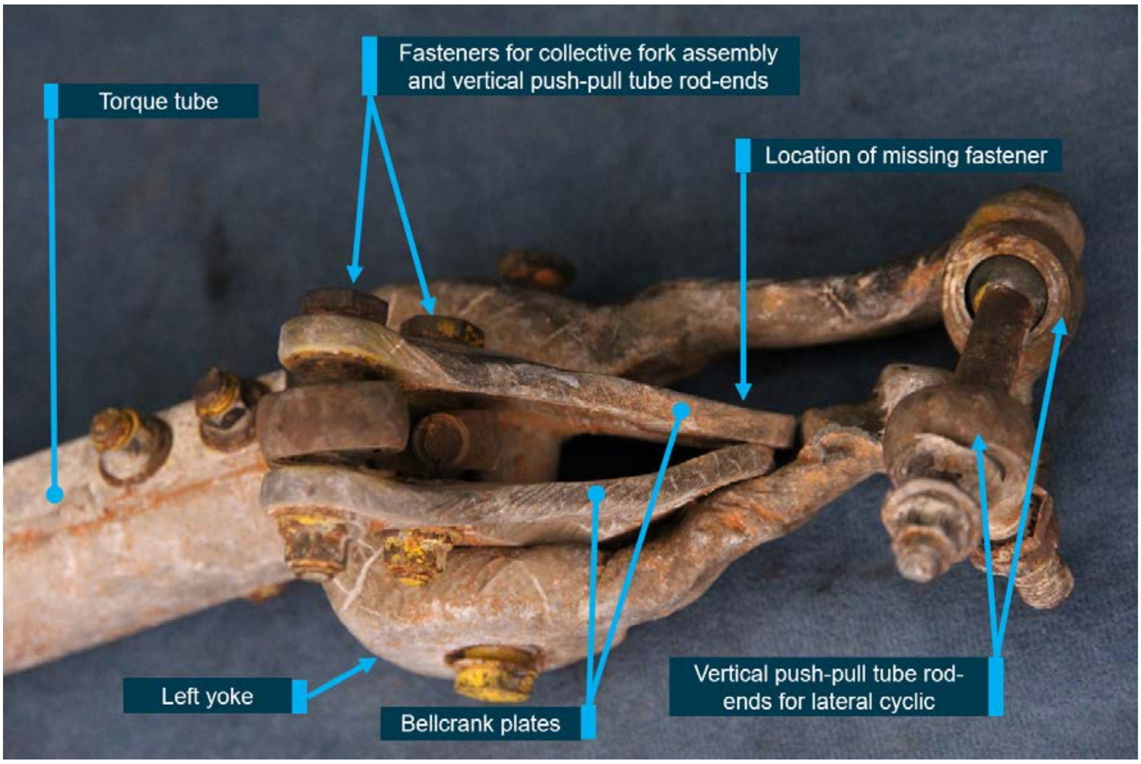
Figure A3: Side view of the bellcrank as received, location of missing fastener circled



Source: ATSB

The torque tube yoke assembly had separated from the bolt for the lateral cyclic vertical push-pull tube rod end on the left side, and was distorted from a combination of mechanical impact and heat. The left side of the yoke assembly exhibited significant distortion, and had been plastically deformed inward, towards the right side. The left bellcrank plate had been distorted in a similar way, causing the two plates to come together at the location of the missing fastener. The yoke assembly also exhibited heat damage in this area, with the left side moulding around the bellcrank plate (Figure A4).

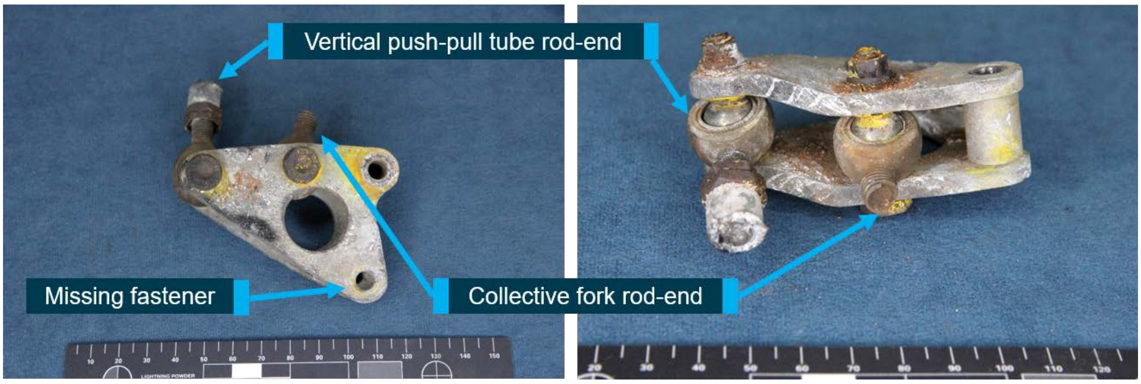
Figure A4: Side view of the bellcrank as received showing deformation of yoke and plate



Source: ATSB

Following initial visual examination and photography, the bellcrank was removed from the torque tube yoke assembly for further examination. The bellcrank exhibited distortion from a combination of mechanical stress and heat effects. The two plates of the bellcrank had been deformed along the length between the vertical push-pull tube and torque tube attachment ends (Figure A5). Where the fasteners remained in position, the two plates had deformed in parallel. However, as above, where the fastener was missing, the two plates of the bellcrank had been pushed closer together.

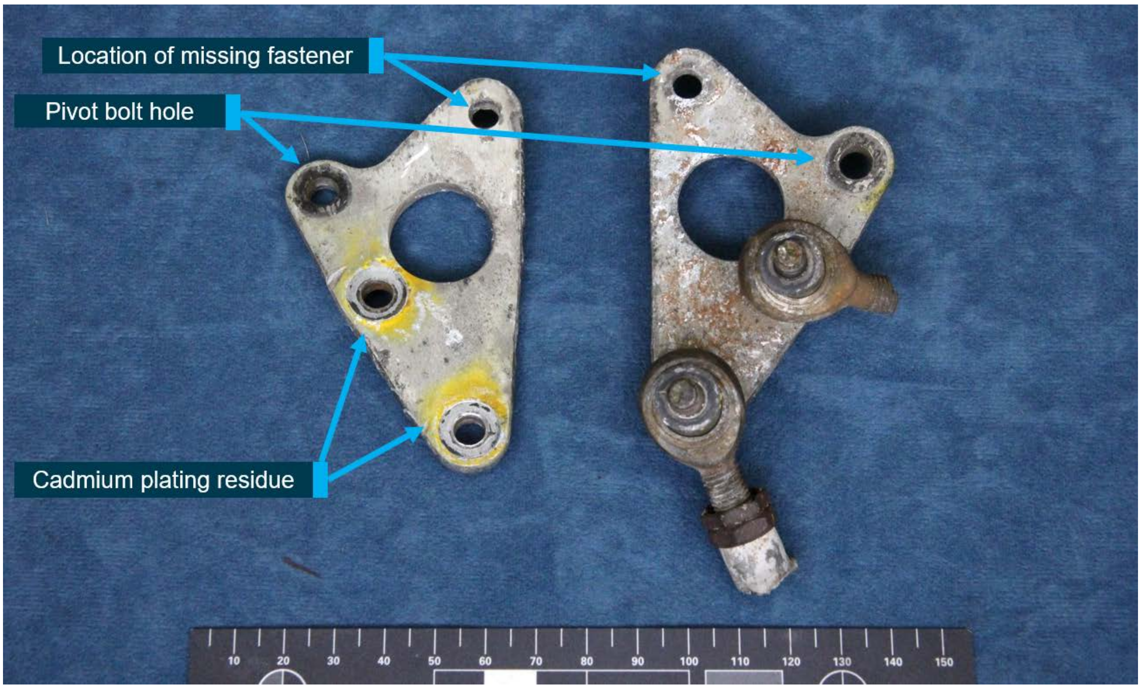
Figure A5: Bellcrank following removal from the torque tube and showing parallel deformation of both plates



Source: ATSB

Closer examination of the bellcrank plates showed that a yellow residue had been deposited around the holes where the bolts had been in position. However, there was minimal residue around the hole where the fastener was missing (Figure A6). The manufacturer advised the residue was likely cadmium plating from components within the fastener assembly that had melted during the fire. They were also of the opinion that the minimal residue observed around the hole where the fastener was missing was likely from cadmium plating transfer from a previous installation. The presence of cadmium within the residue was confirmed by semi-quantitative chemical analysis using a scanning electron microscope (SEM) equipped with an Oxford energy dispersive x-ray spectrometer (EDS).

Figure A6: Bellcrank internal surfaces showing the cadmium plating residue



Source: ATSB

There was no evidence of deformation or elongation of the bellcrank fastener hole to suggest that the nut and bolt had detached forcefully during the collision. The surface of the bellcrank in the region adjacent to the missing bolt, and the internal surface of the bolt hole, was rippled as a result of high temperatures associated with the fire. Minor damage in the form of scrapes and dents were observed in the region adjacent to the bolt hole of the missing fastener, coincident with where it had been in contact with the torque tube yoke assembly (Figure A7).

Figure A7: Comparison between the bolt hole where the fastener was missing (left) showing deformation due to heat and a bolt hole where a fastener remained in position (right)

Source: ATSB

An exemplar bolt could not be inserted through the bellcrank bolt holes where the fastener was missing. This was due to a combination of misalignment of the two plates as a result of impact damage, and the heat damage observed on the internal surfaces of the holes.

Remaining bellcrank bolts

Markings on heads of the two remaining bolts from the bellcrank indicated they were a NAS6604-15 bolt. The marking 'LFC' stamped on the bolt head identified the manufacturer (Figure A8). As per United States Department of Defence Handbook, MIL-HDBK-57G (IS) 16 October 2012, *Listing of Fastener Manufacturer's Identification Symbols*, the manufacturer was likely to be: LFC Industries, Texas, USA.

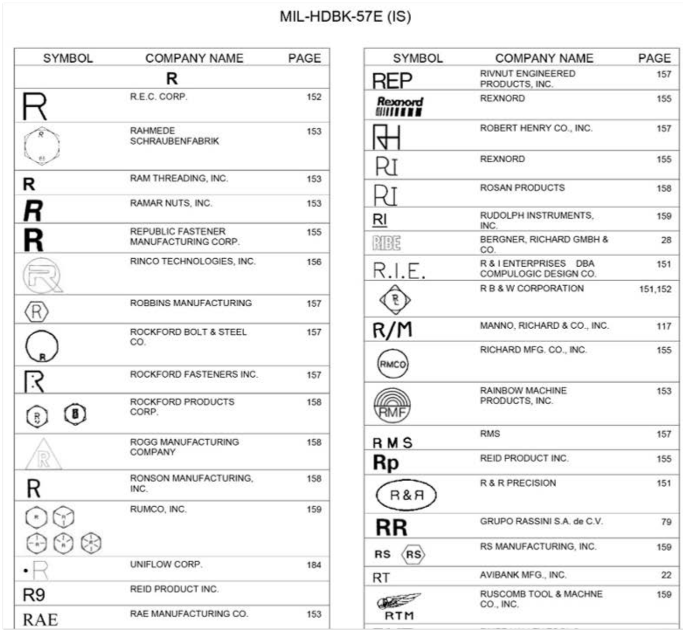
Figure A8: Bolt head markings from one of the remaining bellcrank bolts

Source: ATSB

Remaining bellcrank nuts

The nuts of the two remaining fasteners were stamped with an 'R' symbol on two of the hexagon flats on opposite sides. As per United States Department of Defence Handbook, MIL-HDBK-57E *Listing of Fastener Manufacturer's Identification Symbols,* the nuts were most likely manufactured by Ronson Manufacturing Inc. (Figure A9). The two remaining nuts were in relatively good condition, with no evidence of any cracking or damage observed. The chemical analysis results, provided in Table A3, confirmed the nuts were manufactured using 4037 alloy steel. Measurements and chemical analysis confirmed that they were consistent with MS21042-L4/NAS1291-series nuts.

Figure A9: Nut markings from one of the remaining fasteners (left) and relevant page from MIL-HDBK-57 showing manufacturers marks (right)



MIL-HDBK-57E (IS)

SYMBOL	COMPANY NAME	PAGE
	R	
R	R.E.C. CORP.	152
	RAHMEDE SCHRAUBENFABRIK	153
R	RAM THREADING, INC.	153
R	RAMAR NUTS, INC.	153
R	REPUBLIC FASTENER MANUFACTURING CORP.	155
	RINCO TECHNOLOGIES, INC.	156
	ROBBINS MANUFACTURING	157
	ROCKFORD BOLT & STEEL CO.	157
	ROCKFORD FASTENERS INC.	157
	ROCKFORD PRODUCTS CORP.	158
	ROGG MANUFACTURING COMPANY	158
R	RONSON MANUFACTURING, INC.	158
	RUMCO, INC.	159
• R	UNIFLOW CORP.	184
R9	REID PRODUCT INC.	
RAE	RAE MANUFACTURING CO.	153

SYMBOL	COMPANY NAME	PAGE
REP	RIVNUT ENGINEERED PRODUCTS, INC.	157
Rexnord	REXNORD	155
	ROBERT HENRY CO., INC.	157
RI	REXNORD	155
RI	ROSAN PRODUCTS	158
RI	RUDOLPH INSTRUMENTS, INC.	159
RIBE	BERGNER, RICHARD GMBH & CO.	28
R.I.E.	R & I ENTERPRISES DBA COMPULOGIC DESIGN CO.	151
	R B & W CORPORATION	151,152
R/M	MANNO, RICHARD & CO., INC.	117
RMCO	RICHARD MFG. CO., INC.	155
RMF	RAINBOW MACHINE PRODUCTS, INC.	153
R M S	RMS	157
Rp	REID PRODUCT INC.	155
R & R	R & R PRECISION	151
RR	GRUPO RASSINI S.A. de C.V.	79
RS RS	RS MANUFACTURING, INC.	159
RT	AVIBANK MFG., INC.	22
RTM	RUSCOMB TOOL & MACHNE CO., INC.	159

Source: ATSB

Table A3: Chemical analysis results for a nut removed from the bellcrank

Specification	Fe	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	V	Al
Bellcrank nut	Bal	0.39	0.75	0.26	0.01	0.01	0.05	0.19	0.23	0.12	0.01	0.023
Alloy 4037	-	0.35-0.40	0.70-0.90	0.15-0.35	0.04	0.35	-	-	0.20-0.30	-	-	-

Units are weight %

Additional recovered bolt

The bolt found on 16 May 2018 by the pilot's next-of-kin displayed the same markings as those that remained in position on the bellcrank (NAS6604-15 manufactured by LFC) (Figure A10). The surfaces of the bolt were severely heat affected, with areas of material loss and areas where additional material had adhered to the surface. Ultrasonic chemical cleaning of the bolt was unable to remove much of the adhered material. There was no damage observed to the head, shank or threads of the bolt. A dial indicator was used to check the bolt run-out, which confirmed it to be straight without significant distortion along the length.

Figure A10: NAS6604-15 bolt found 16 May 2018

Source: ATSB

Closer examination of the bolt threads confirmed significant heat damage, and a small groove located on the second to third threads from the end of the bolt (Figure A11).Other than the small groove, the bolt threads did not show any other markings such as grooves, score marks or galling.[44] A similar marking was observed on the other bellcrank bolts. This indicated that a nut had been installed at some point on the examined bolt. The bolt was examined using a scanning electron microscope equipped with an Oxford energy dispersive x-ray spectrometer. No evidence of remnant cadmium plating was detected on the bolt surfaces.

Figure A11: Magnified image of the NAS6604-15 bolt found 16 May 2018 showing thread groove

Source: ATSB

[44] Galling: a form of wear caused by adhesion between sliding surfaces.

Radiography of metallic debris

Aluminium alloy portions of the helicopter had melted during the post-accident fire and then resolidified into blobs of metallic debris. The debris was gathered from the wreckage and submitted to the Australian National University for radiography[45] to determine the presence of entrapped hardware (e.g. nuts, bolts, washers) that may have been similar in size or shape to the components from the fastener assembly missing from the bellcrank.

While some samples did show evidence of steel componentry, including nuts and bolts, within the solidified metallic debris, nothing was identified that was similar in size or shape to a NAS6604-15 bolt, D210-4 nut, or MS21042-L4/NAS1291-series nuts. The fasteners identified were too long or short, threaded the entire length, were a complete assembly (nut was still attached), had a different shaped head or were attached to other componentry (Figure A12).

Figure A12: One of the metallic pieces recovered from the accident site and the corresponding radiograph that highlighted the presence of entrapped steel hardware

Source: ATSB (left) and Australian National University (right)

Dissolution of metallic debris

Following the suspected recovery of the missing bolt from the bellcrank, an internal technical review of the radiography questioned if that technique was capable of resolving a small part, such as a D210-4 or MS21042-L nut. When taking into account potential for hydrogen embrittlement and cracking of the MS21042-L series nuts, it was considered that, if the nut had fractured into thirds, it may not have been visible on the radiographs. As such, the metal pieces were dissolved in a caustic soda (sodium hydroxide) solution. The resulting solution was sieved using a 352 mesh (minimum captured particle size of 1.5 mm) to recover the entrapped hardware.

A number of fasteners and other components were recovered following dissolution of the aluminium (Figure A13). The missing nut to the bellcrank fastener was not amongst the entrapped hardware. Neither a D210-4 nor MS21042-L series (whole or in part) nut was among the recovered items.

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[45] Radiography was performed by the National Laboratory for X-ray Micro Computed Tomography (CTLab) at the Australian National University.

Figure A13: Recovered items following dissolution of the metallic debris

Source: ATSB

Additional hardware

Additional hardware was received in June 2018 by the ATSB, which included:

- additional fastener parts (four small bags of nuts and washers)
- forward support assembly (part number A014-6) with two NAS6604-15 bolts.

The samples were examined to identify the fastener designations, verify that the NAS6604-15 bolts were installed and to determine if any of the nuts may have been the missing nut.

The received nuts were examined in the ATSB laboratories with the measurements and observations recorded (Table A4). Due to fire damage, some of the markings on a number of the nuts were unable to be determined.

Table A4: Evaluation of various nuts

Sample	Height (in)	Width (flats) (in)	Material/markings
MS21042L4/NAS1291	0.204-0.219	0.304-0.316	Alloy steel, grade 1035, 1042, 1050, 4027, 4037, 8630 or 8740. Cadmium plated
D210-4 nut Corrosion-resistant (CRES)	0.205-0.219	0.304-0.316	Stainless steel alloy 660
VH-HGU remaining bellcrank nuts	0.213 (5.4mm)	0.309 (7.85mm)	Alloy steel – 4037 ‘R’ on flats
A014-6 (2 of)	0.215 (5.5mm)	0.307 (7.8mm)	‘R’ on flat
Nut found 16-5-2018	0.215 (5.45mm)	0.311 (7.9mm)	‘M’ on base
Nut and washer found 15-5-2018	0.213 (5.4mm)	0.311 (7.9mm)	‘M’ on base
Various fasteners, 2 of, small nuts	0.258 – 0.275 (6.57 – 6.7mm)	0.375 – 0.379 (9.52 – 9.62mm)	No markings
Various fasteners, 2 of, large nuts	0.280 (7.1mm)	0.440 (11.17mm)	No markings
Exemplar nut (from maintenance stock)	0.207	0.308	‘c’ and ‘k’ on base vertical line on opposite flats

The forward support assembly (A014-6) was part of the landing gear, and the IPC showed that it should contain two NAS6604-15 bolts.[46] Due to fire damage, the markings on the heads of the two bolts from the forward support assembly were illegible. However, the bolts were measured and the results consistent with the requirements for a NAS6604-15 bolt Table A5.

Table A5: Results from bolt examinations

	Width (flats) (in)	Shank diameter (in)	Thread length (in)	Grip length (in)	Length +/- 0.015 (in)	Height (head) (in)
NAS6604-15 bolt	0.429-0.439	0.2485-0.2495	0.425	0.938	1.363	0.125
A014-6 bolts	11.16mm (0.439in)	0.249	0.429	0.935	34.74mm (1.368in)	0.126

Jackshaft

Maintenance records showed that the jackshaft had undergone maintenance, including non-destructive testing, on or around 25 May 2017 during the 2,200-hour overhaul. The testing involved the removal of the fasteners, and as per the R22 service letter SL-64, updated IPC and maintenance manual, the nuts on the jackshaft should have been changed to the new D210-series nuts at this time.

Examination of the four nuts showed them to be similar to those remaining in the bellcrank. Specifically, they were of a similar size, and three of them exhibited the same markings 'R' on the flats (Figure A14). Due to heat damage, no markings were able to be resolved on the fourth self-locking nut. Analysis of the four nuts from the jackshaft assembly was performed using the EDS, and showed that all four nuts were consistent with a carbon/alloy steel, not stainless steel. The geometry, markings and chemistry indicated they were MS21042-L4/NAS1291-series nuts.

Figure A14: Jackshaft assembly (left) and magnified view of one of the nuts (right)

Source: ATSB

Discussion

Separation of the fastener from the bellcrank

The investigation considered when separation of the fastener from its installed position within the bellcrank was likely to have occurred. A number of observations indicated that the fastener was not in position at the time of the impact with the ground:

- There was an absence of significant physical damage to the bolt holes where the bolt was missing and surrounds. That is, no gross deformation or elongation of the holes to indicate that the fastener assembly had been forcibly removed during the accident sequence.

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46 RHC indicated there were six NAS6604-15 bolts on the R22; three in the cyclic control bellcrank, two in the forward support assembly, and one (of variable length, but possibly a -15 bolt) within the main rotor swashplate. The swashplate bolt was not normally accessible, but was observed in position by ATSB investigators.

- The bellcrank and torque tube fork assembly had been subject to significant mechanical damage such that the rod ends had fractured in overstress and the left side of the yoke assembly and bellcrank plate had significantly distorted. While the distortion of the plates was similar where the fasteners remained in position, the plates had been pushed together where the fastener was missing.
- Rippling was observed on the internal surfaces of the bolt hole, considered to be evidence of heat damage, and the bellcrank was twisted/distorted such that a new bolt was unable to be inserted into the hole. The two remaining bolts could be easily reinserted into their respective holes following removal.
- Yellow colouration was present on the inside of the bellcrank around the two fasteners that had remained in position. This was likely from the oxidised cadmium plating from the installed hardware including nuts, bolts and washers. No such colouration was observed around the internal surfaces of the bellcrank holes where the fastener was missing. This indicated that the bolt and associated hardware was not in position at the time of the post-impact fire. A minimal amount of residue was observed around the hole on the nut side of the bellcrank, likely from material transfer from the lock washer. This suggested the fastener had been previously installed.

Bellcrank – the missing fastener

A solitary bolt excavated from the accident site and submitted by the next-of-kin exhibited the markings of a NAS6604-15 bolt. It also exhibited the same manufacturing mark as that on the other bolts fitted to the bellcrank. As all the other NAS6604-15 bolts were accounted for—on the bellcrank, forward support assembly, main rotor head yoke assembly and inside main rotor blades—it was very likely that this was the missing bolt from the bellcrank. The bolt was in relatively good condition, and except for thermal effects from the post-accident fire, it showed no damage on the head, shank or threads. One small groove was observed on the second to third thread flank, which was potentially from engagement with a self-locking nut during assembly. There did not appear to have been any galling or thinning of the threads, which is damage that would be expected from multiple installations of a MS21042-L4 nut.

Jackshaft

Examination of the jackshaft assembly recovered from the wreckage of VH-HGU showed that three of the four nuts had the same manufacturer markings to the nuts in position on the bellcrank. There were no discernible markings on the fourth nut. The same manufacturer's mark was also observed on the forward support assembly, and it was considered very likely that the nuts were original from manufacture.

The ATSB's chemical analysis of the nuts confirmed that all four were consistent with a carbon/alloy steel. Though the analysis was semi-quantitative, the spectrographs of the four nuts were inconsistent with the CRES (corrosion resistant – stainless steel) D210-4 nuts specified in the Robinson R22 IPC. The nickel, chromium and molybdenum additions, where detected, were not of sufficient quantity to designate the nuts as stainless steel. The nuts fitted to the jackshaft were therefore likely MS21042-L4/NAS1291-series nuts.

Conclusion

The following is a summary of the main findings made during examination of the bellcrank and associated components, other recovered items and the jackshaft from VH-HGU:

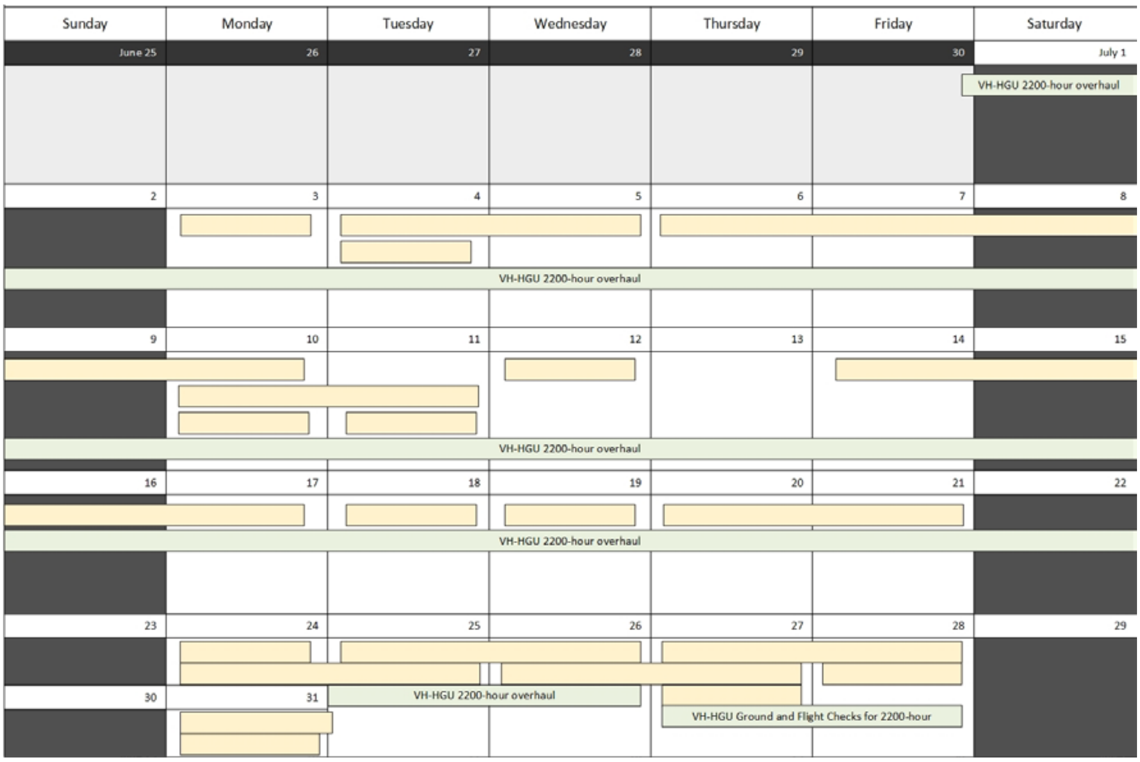
- Due to the observed damage on the bellcrank and torque tube fork assembly, the horizontal push-pull tube fastener assembly was not in position at the time of the impact with terrain.
- The remaining bolts from the bellcrank were consistent with a NAS6604-15 bolt and the nuts were consistent with an MS21042L4/NAS1291-series nut.
- The solitary bolt found on 16 May 2018 was consistent with an NAS6604-15 bolt, and had the same manufacturer mark as the bolts that had remained in position. As the other NAS6604-15 bolts were accounted for, it was very likely that this was the missing bolt from the bellcrank.

- The self-locking nut from the missing bellcrank fastener assembly was not recovered in the wreckage, including in the pieces of metallic debris when dissolved.
- The nuts on the jackshaft assembly were not changed to D210-4-series nuts as per the Robinson instructions for continued airworthiness when they were removed to perform non-destructive testing on the jackshaft (part number A337-1) during the 2,200-hour overhaul.

Appendix B – Maintenance workload

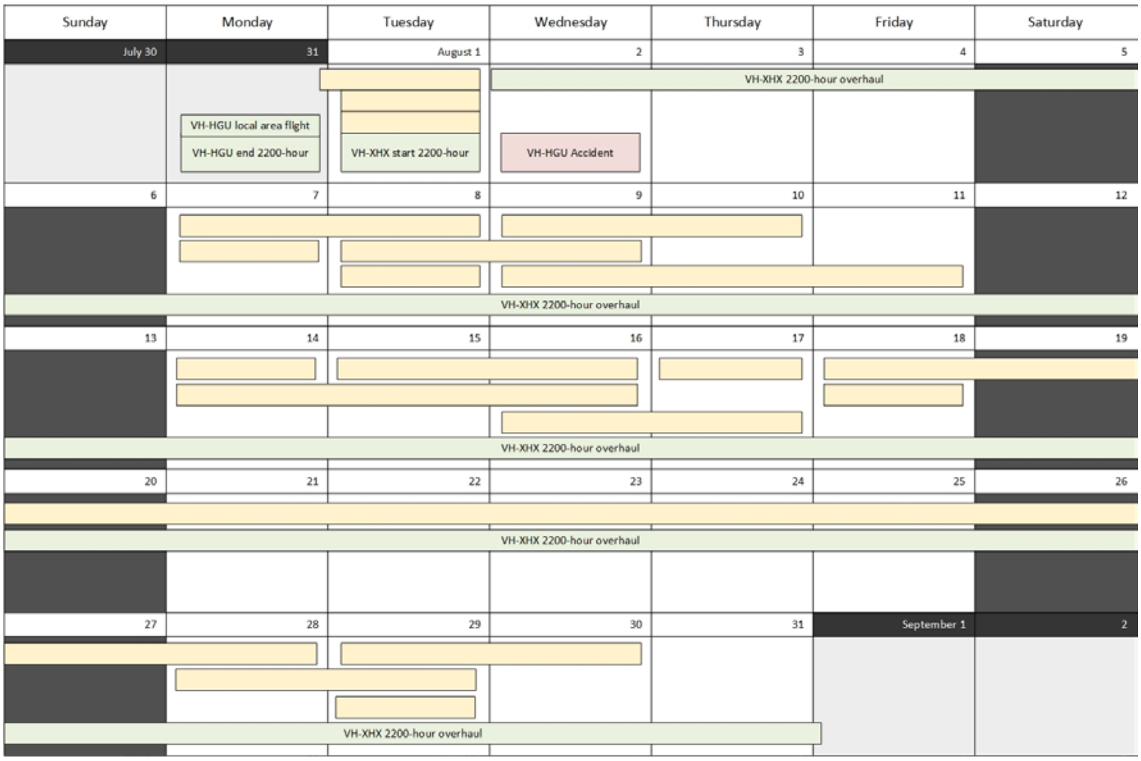
Figure B1 and Figure B2 depict the progression of the 100-hour inspections (yellow) and 2,200-hour overhauls (green) by Cloncurry Air Maintenance for the Cloncurry Mustering Company in the month prior to and following the accident (red).

Figure B1: CAM maintenance jobs for CMC in July 2017



Source: ATSB

Figure B2: CAM maintenance jobs for CMC in August 2017



Source: ATSB

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 the 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.