



Australian Government

Australian Transport Safety Bureau

In-flight tail rotor blade failure and tail assembly separation involving Robinson Helicopter R22, VH-THM

Gold Coast Airport, Queensland on 26 February 2022

ATSB Transport Safety Report

Aviation Occurrence Investigation (Defined)

AO-2022-010

Final – 9 August 2024

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

Publishing information

Published by: Australian Transport Safety Bureau
Postal address: GPO Box 321, Canberra, ACT 2601
Office: 12 Moore Street, Canberra, ACT 2601
Telephone: 1800 020 616, from overseas +61 2 6257 2463
Accident and incident notification: 1800 011 034 (24 hours)
Email: atsbinfo@atsb.gov.au
Website: www.atsb.gov.au

© Commonwealth of Australia 2024



Ownership of intellectual property rights in this publication

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

Creative Commons licence

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

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

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

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

Addendum

Page	Change	Date

Executive summary

What happened

On 26 February 2022, at around 1030 local time, a student pilot and instructor were conducting a low-level hover training exercise at Gold Coast Airport, Queensland, in a Robinson Helicopter R22, registered VH-THM, operated by Professional Helicopter Services.

After around 30 seconds of stable hover just above the ground, there was a ‘bang’ through the airframe. The helicopter then pitched nose up, developed a large vibration and then yawed to the right. The instructor took over immediately and landed. There were no injuries. Subsequent inspection found that the tail rotor gearbox and empennage assembly had separated from the tailcone (boom).

What the ATSB found

The tail rotor tip cap detached due to moisture-induced failure of the adhesive bond. Tap testing of the tail rotor blades during the most recent scheduled inspection, for the purpose of detecting adhesive failure, did not identify any disbonds that were very likely present at the time.

The tailcone aft casting then fractured due to the detachment of the tail rotor tip cap, which led to a tail rotor imbalance and severe abnormal loading event on the casting.

What has been done as a result

Robinson released updated service bulletins and service letters in response to seeing tail rotor blades that were allowed to corrode to an unserviceable condition and receiving reports of tail rotor blade tips coming loose in service due to corrosion. Notably, Robinson released Revision A of R22 service letter SL-93 in June 2022, which required blade replacement with any evidence of bond line corrosion. The updated service letter also included inspection criteria and a minimum 10x magnification inspection of the bond line to increase the likelihood of detection. Other recommended tail rotor blade maintenance practices were also updated.

Robinson has also identified certain part and serial number blades as being susceptible to corrosion. These blades required additional visual inspection prior to the first flight of the day, until replacement with blades that were less susceptible to corrosion. The United States Federal Aviation Administration released an airworthiness directive regarding this matter.

Safety message

In-service detachment of a tail rotor tip cap due to adhesive failure is an uncommon event, but still presents a significant hazard to the helicopter. The resultant destructive imbalance could result in a loss of tail rotor drive and/or tail assembly. Pilots and maintainers should recognise that tap testing alone may be insufficient to detect adhesive disbonds, and that detailed visual inspection, especially for signs of corrosion around the bond line, will assist in identifying blade degradation.

Meanwhile, pilots should ensure they are familiar with the immediate corrective actions required for the loss of tail rotor effectiveness, in accordance with the pilot operating handbook, to reduce the likelihood of a loss of helicopter control.

Contents

Executive summary	i
The occurrence	1
Context	3
Aircraft information	3
Component history	4
Component examinations	4
Empennage and gearbox	4
Tail rotor blades	7
Tailcone aft casting	11
Adhesive bond failures	12
Related occurrences	13
R44 in flight break-up	13
R22 tail rotor failure	13
Robinson tail rotor tip cap separations	14
Safety analysis	16
Failure sequence	16
Tail rotor tip cap adhesive failure	16
Maintenance inspections	17
Findings	18
Contributing factors	18
Safety issues and actions	19
General details	21
Glossary	22
Sources and submissions	23
Appendix A – Metallurgical examination and testing of the fractured tailcone aft casting	24
General fracture characteristics	24
Fracture surface striations	26
Fatigue testing of the casting alloy	28
Australian Transport Safety Bureau	31

The occurrence

On 26 February 2022, at around 1030 local time, a student pilot and instructor were conducting a low-level hover training exercise at Gold Coast Airport, Queensland, in a Robinson Helicopter R22 registered VH-THM, operated by Professional Helicopter Services.

Prior to commencement of the exercise, the instructor conducted a daily check of the helicopter, with no issues found. The instructor then taxied the helicopter from the helipad to the western grassed training area. The instructor reported having flown the helicopter frequently and that the helicopter felt normal, with no unusual sounds or vibrations.

After reaching the training area, the instructor handed control of the helicopter to the student to commence the hover exercise at a skid height of approximately 3–5 feet above the ground. This was the student's fourth hover exercise and the instructor was closely guarding the flight controls against any abrupt inputs from the student.

After around 30 seconds of stable hover, the instructor described feeling a significant jolt¹ through the airframe. The helicopter then pitched nose up, developed a large vibration and then yawed to the right. The instructor immediately took control of the helicopter, lowered the collective and closed the throttle to control the yaw. The helicopter was landed safely and there were no injuries.

Once on the ground, with the engine still running, the vibration ceased. The instructor shut down the helicopter and on inspection, identified that the tail rotor gearbox and empennage assembly had each separated from the tailcone (boom) and were reportedly located within 10 metres from the final position of the helicopter (Figure 1). The ATSB did not attend the site.

¹ Described as a 'bang' but the instructor did not recall hearing it.

Figure 1: Proximity of separated major tail components from the helicopter



Tail rotor blades (not shown) had separated from the gearbox assembly
Source: Helicopter operator, annotated by the ATSB

Context

Aircraft information

The accident helicopter was a Robinson R22 Beta, serial number 4057, manufactured in 2006 and registered with the current operator since November 2019. The airframe had 3,355 hours at the time of the occurrence. The helicopter's most recent maintenance was a scheduled 100-hour / annual airframe inspection that was conducted on 24 January 2022 at 3,334 airframe hours, which was 21 flight hours and 33 days prior to the occurrence.

The tail section of the R22 comprises a tailcone assembly, through which the tail rotor drive shaft and pitch control rod passes. An aluminium casting is riveted to the skin at the end of the tailcone, and supports the tail rotor gearbox and empennage assembly. An example of the tail arrangement on another R22 helicopter is shown in Figure 2.

Figure 2: Exemplar R22 tail arrangement



Source: Archangel12, via Wikimedia Commons, annotated by the ATSB

Component history

The tailcone assembly (part number A023-23, serial number 5986), including the tailcone aft casting, was removed from another helicopter in December 2016 due to it having been dented. A repair was completed by Robinson in April 2017 and fitted to VH-THM in November 2018. The assembly had accrued 1,155 hours since the repair and fitment to VH-THM, and 2,787 hours total time in service. The tailcone assembly had a 4,400-hour service life.

The tail rotor blades (part number A029-2 Rev R, serial numbers 5802 and 5803) fitted to the helicopter had a 2,200 hour operational, or 12 year calendar, life limit. The tail rotor blades were installed as a set in November 2018, having accrued 1,155 hours on another helicopter. At the time of the occurrence the blades had 2,147 hours since new (53 hours of life remaining), and had a calendar life expiry of April 2028. The tail rotor blades had most recently been repainted in November 2020.

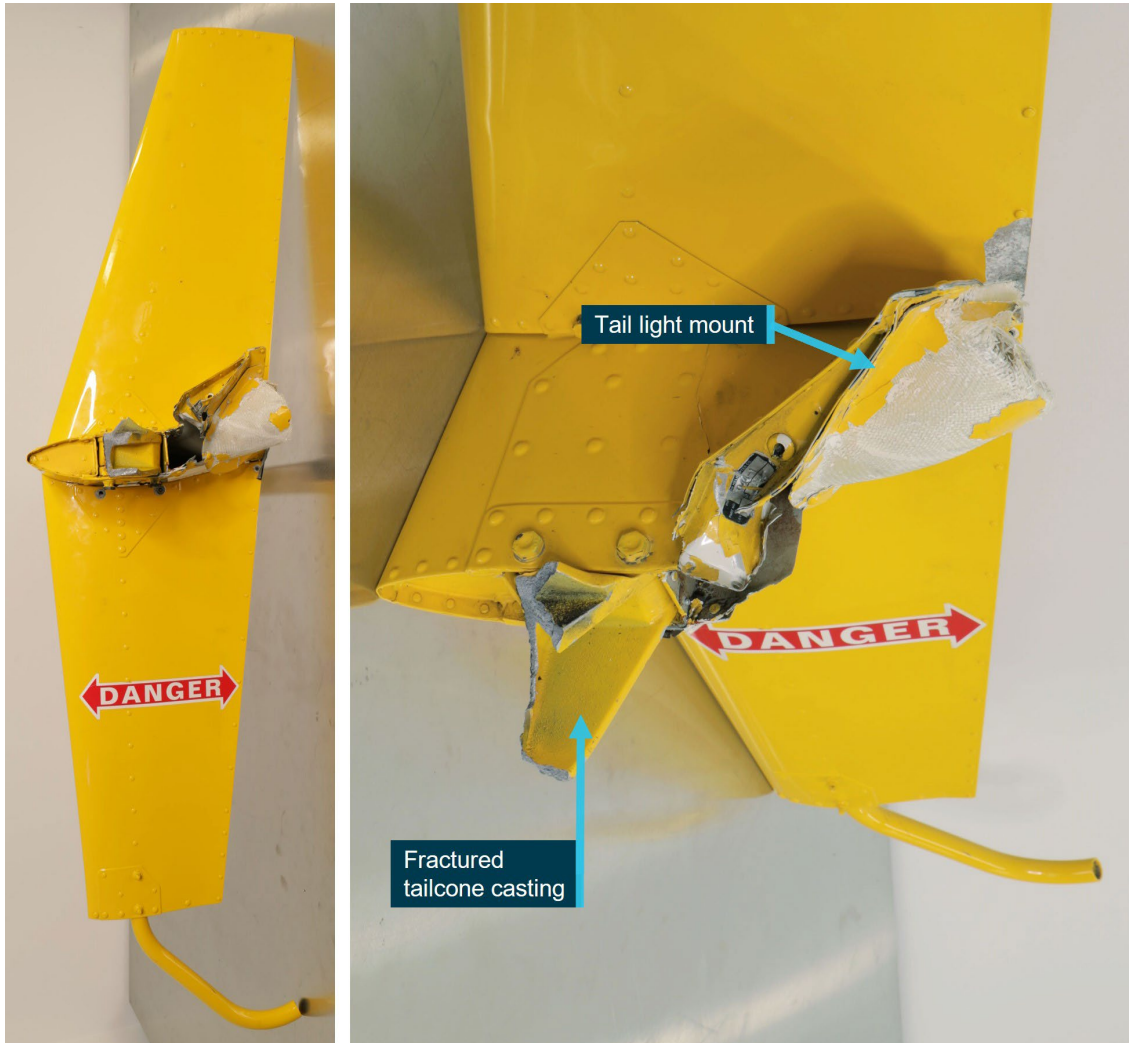
Component examinations

Empennage and gearbox

The separated tail rotor gearbox and empennage assembly, and tail rotor blades, were sent to the ATSB's technical facilities in Canberra for detailed examination.

The empennage assembly was recovered in one piece and had separated from the tailcone and gearbox due to fracture of the aft casting, part of which remained attached to the horizontal stabiliser. The inboard end of the horizontal stabiliser had sustained impact damage (Figure 3). There was no damage to any of the stabiliser extremities.

Figure 3: Empennage overview and damage

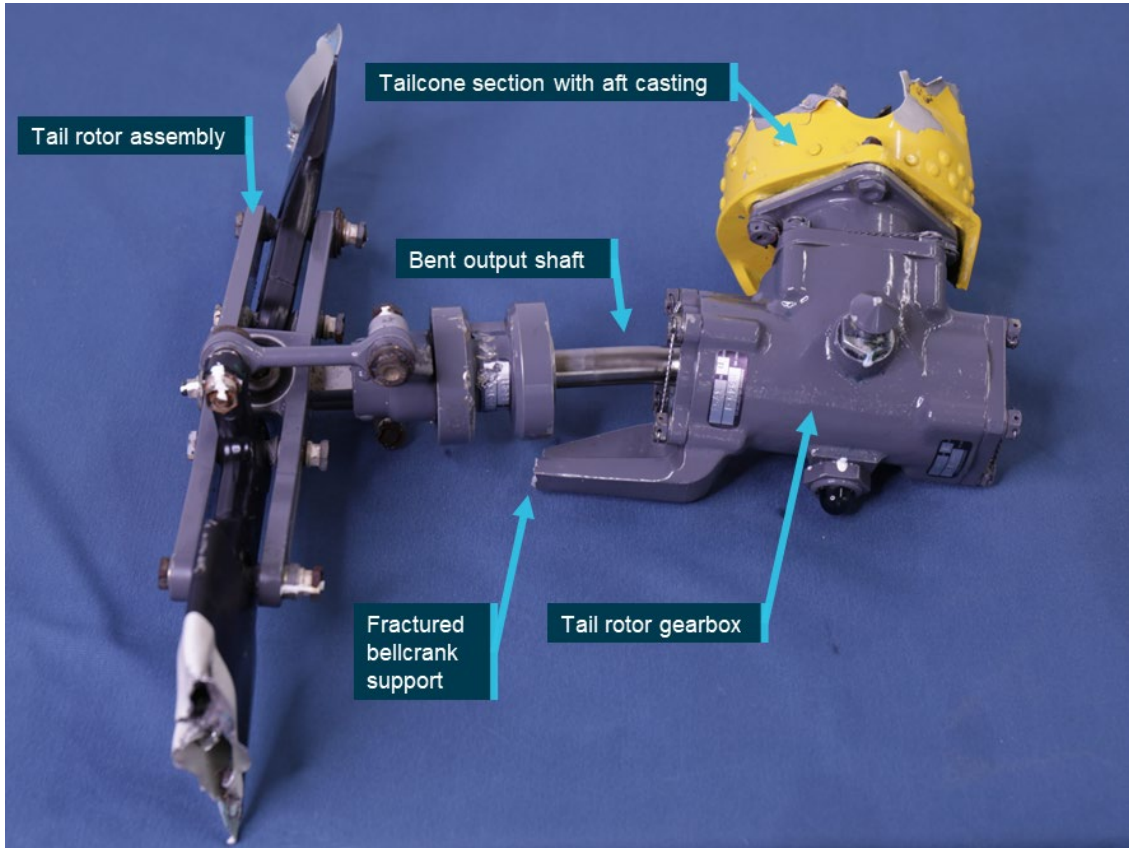


Source: ATSB

The tail rotor gearbox was firmly fastened to the remaining part of the fractured tailcone casting (Figure 4). On disassembly, there was no indication of movement or fretting² between the mating surfaces. The gearbox separated from the tailcone due to tearing of the skin immediately forward of the casting rivet line.

² Fretting refers to wear resulting from repeated, small, relative displacements in tight-fitting assemblies.

Figure 4: Tail rotor gearbox assembly as recovered

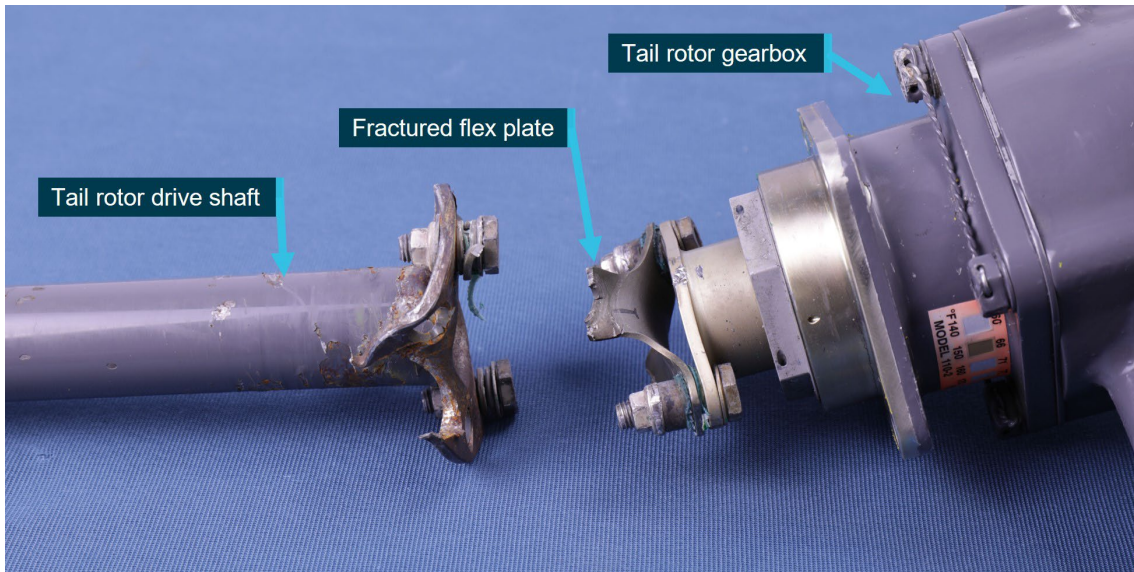


Source: ATSB

The gearbox output shaft was bent. Both tail rotor blades were fractured and separated close to the blade root. One of the tail rotor blades was missing the tip cap, which was not found. The pitch change bellcrank support arm was fractured due to rotation of the bent output shaft.

The tail rotor drive shaft was fractured at the aft flex coupling and the tailcone push-pull tube was fractured and twisted around the driveshaft. The aft flex coupling was determined to have been assembled correctly and the flex plate had deformed and fractured due to overstress. The driveshaft flange had deformation consistent with resistance on the tail rotor side of the drive system.

Figure 5: Fractured tail rotor aft flex coupling



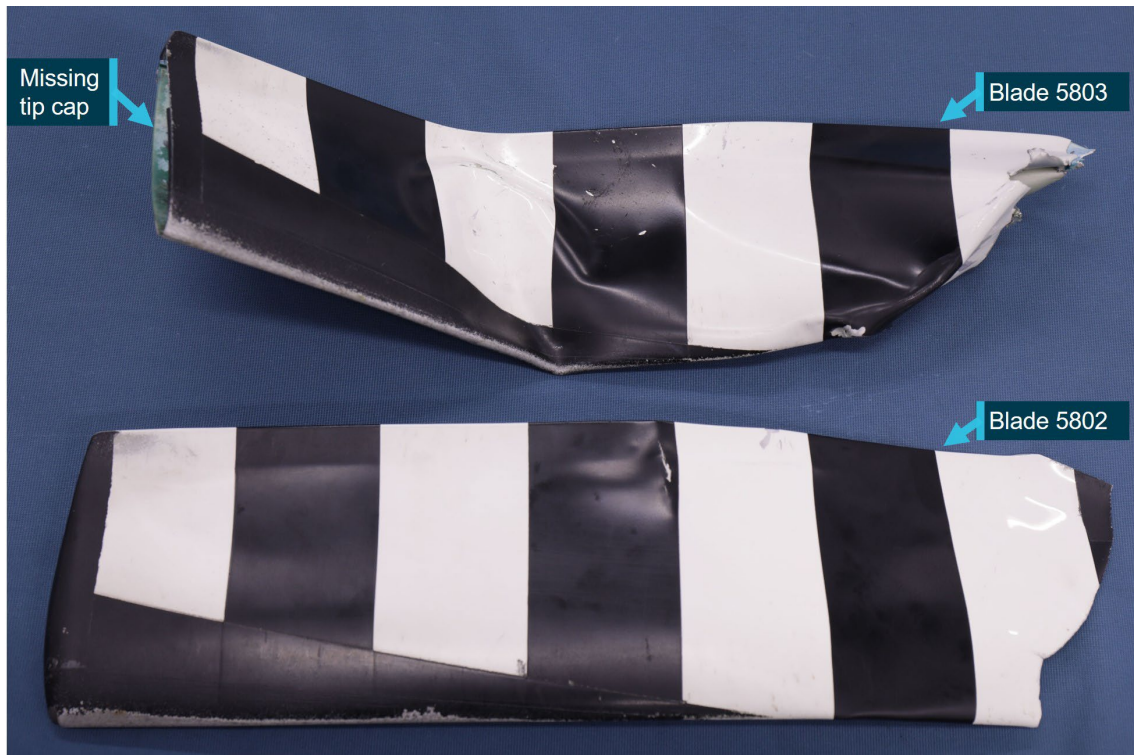
Source: ATSB

Tail rotor blades

Description and examination

The tail rotor blades were Robinson part number A029-2 Rev R with serial numbers (SN) 5802 and 5803 (Figure 6). After ATSB examination, the blades were forwarded to Robinson for examination under the supervision of the United States National Transportation Safety Board (NTSB).

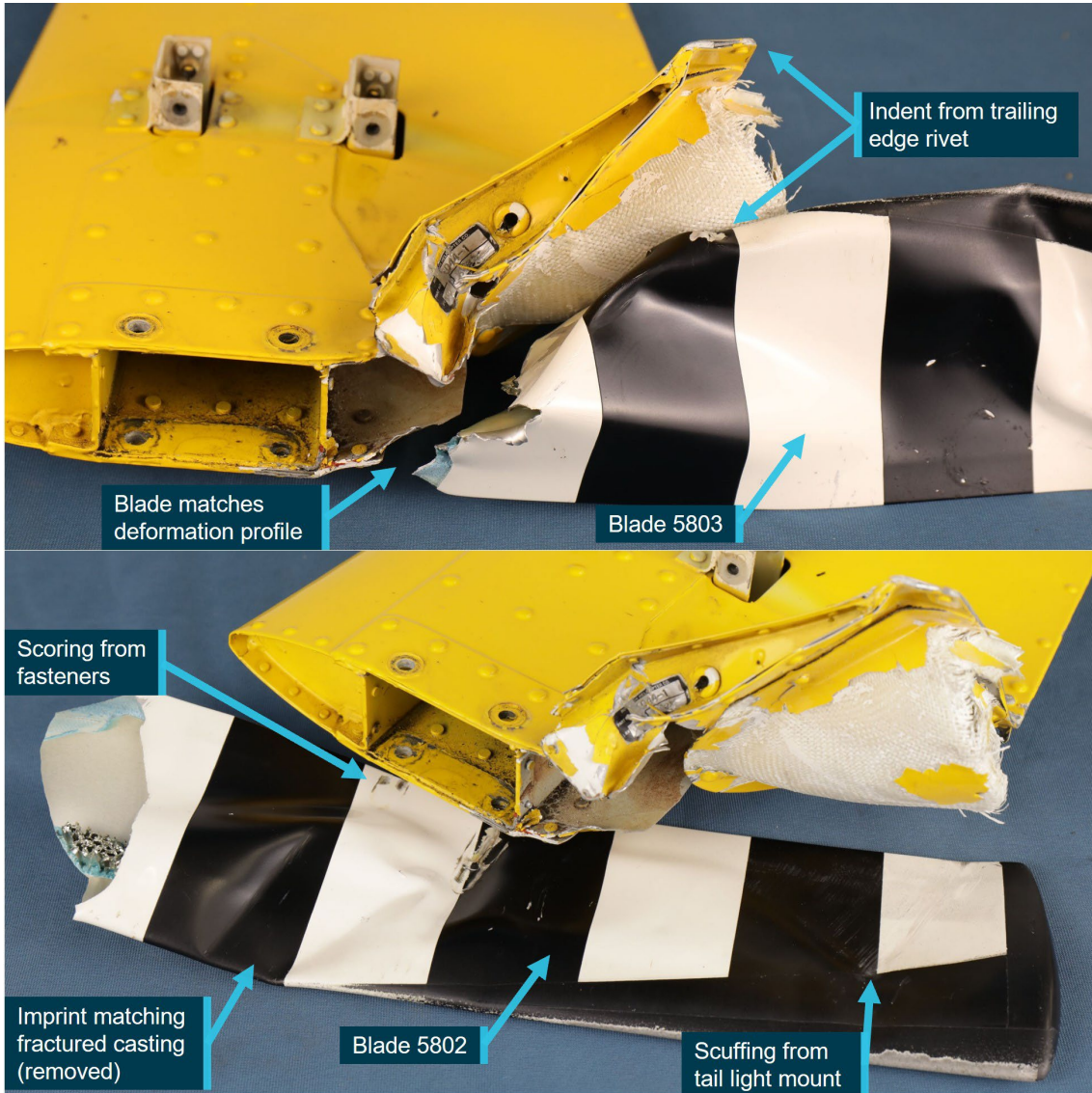
Figure 6: Tail rotor blades SN 5802 and SN 5803



Source: ATSB

Deformation and scoring of the tail rotor blades matched the damage sustained to the inboard end of the horizontal stabiliser, indicating they had come into contact during the occurrence sequence (Figure 7).

Figure 7: Rotor blade contact with horizontal stabiliser



Source: ATSB

The aluminium tip cap was bonded to the internal skin surface of the blade using an epoxy film adhesive (Solvay FM 94K) described in the datasheet as follows:

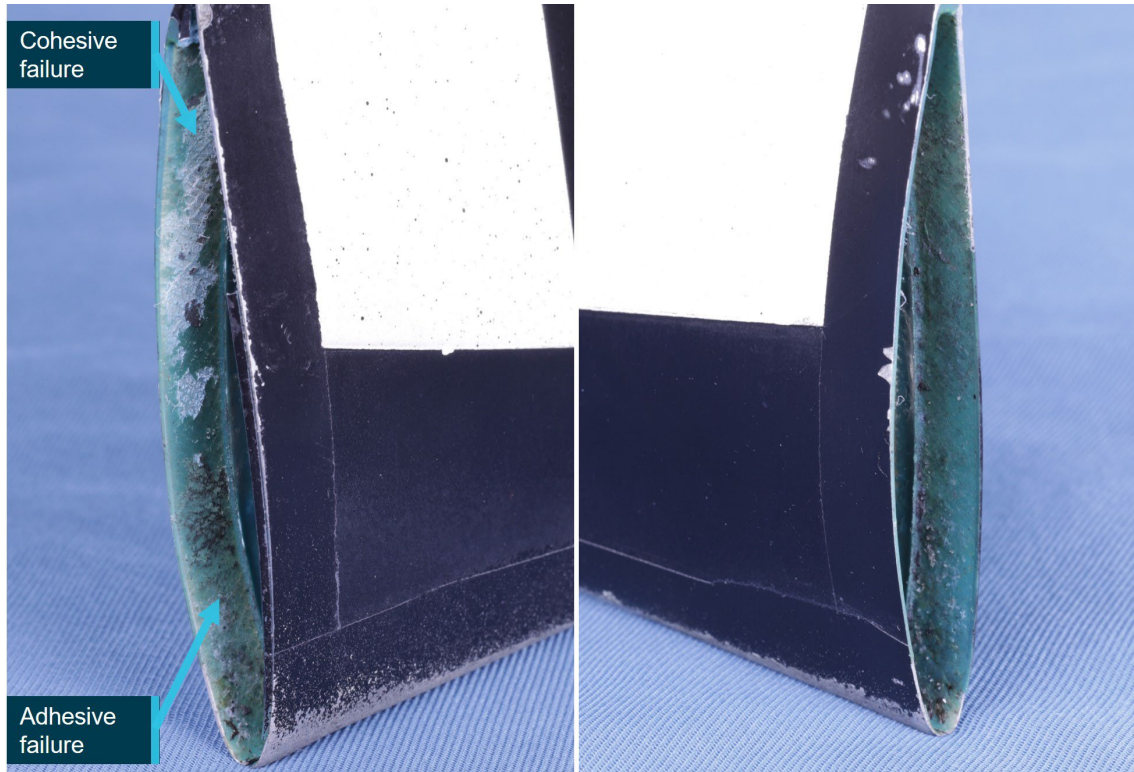
FM® 94 adhesive offers a unique combination of high temperature performance, toughness and moisture resistance as demonstrated by its ability to bond to wet Nomex® honeycomb and retention of shear properties after pre- and post-bond humidity exposure.

The tip cap of blade SN 5803 had separated. Examination and measurements of the original bonded area identified that approximately 85% was smooth, consistent with adhesive failure,³ with some discolouration and material transfer from the missing tip cap (Figure 8). The remaining 15%

³ See *Adhesive bond failures* for a description of adhesive and cohesive failures.

exhibited a rough fracture surface indicative of cohesive failure. The NTSB reported ‘traces of yellow patches were observed across the entire surface ... and under microscopic examination, when pressed, the patches expressed fluid.’ Robinson and the NTSB concluded that the tip cap detached from the blade as a result of moisture-induced adhesive failure.

Figure 8: Blade SN 5803 post-occurrence tip cap adhesive condition



Source: ATSB

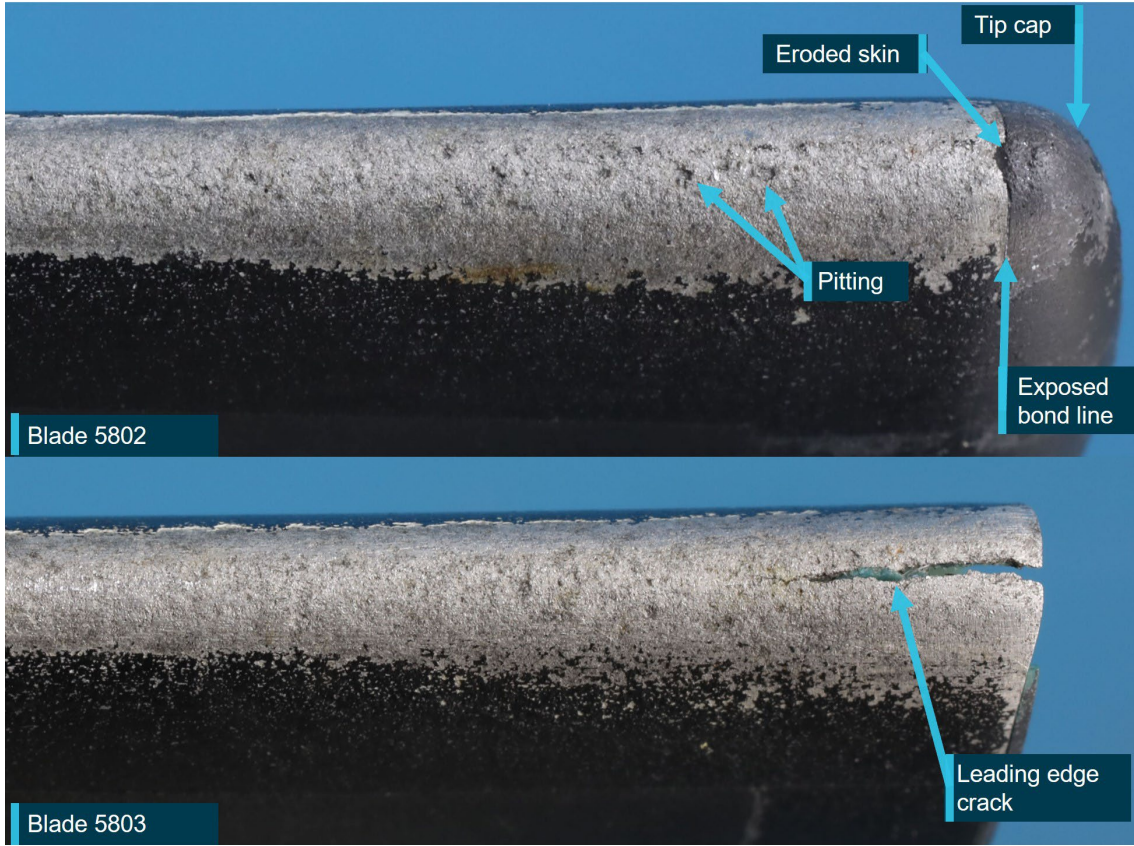
Both blades had significant erosion and thinning of the leading edge skin, particularly at the tip (Figure 9). The erosion wore completely through the skin on a small section of the leading edge on Blade SN 5802. Blade SN 5803 had a crack in the leading edge, across the tip cap bond. The heavily oxidised condition of the crack surface indicated that it was not a recent fracture and therefore pre-dated the tip cap separation. Both blades had small areas of corrosion, indicated by paint bubbles, on the blade skin adjacent to the tip cap.

During the examination, Robinson tap-tested⁴ SN 5802 with the tip cap in situ and identified likely indications of voids or disbonding ‘mid-span’ along the tip cap bond line.⁵ Disassembly of the blade revealed some regions of adhesive failure, appearing to be predominantly progressing towards the blade root from around the circumference of the bond line, amounting to about 30% of the original bond area (Figure 10).

⁴ See *Maintenance requirements* for a description of tap testing.

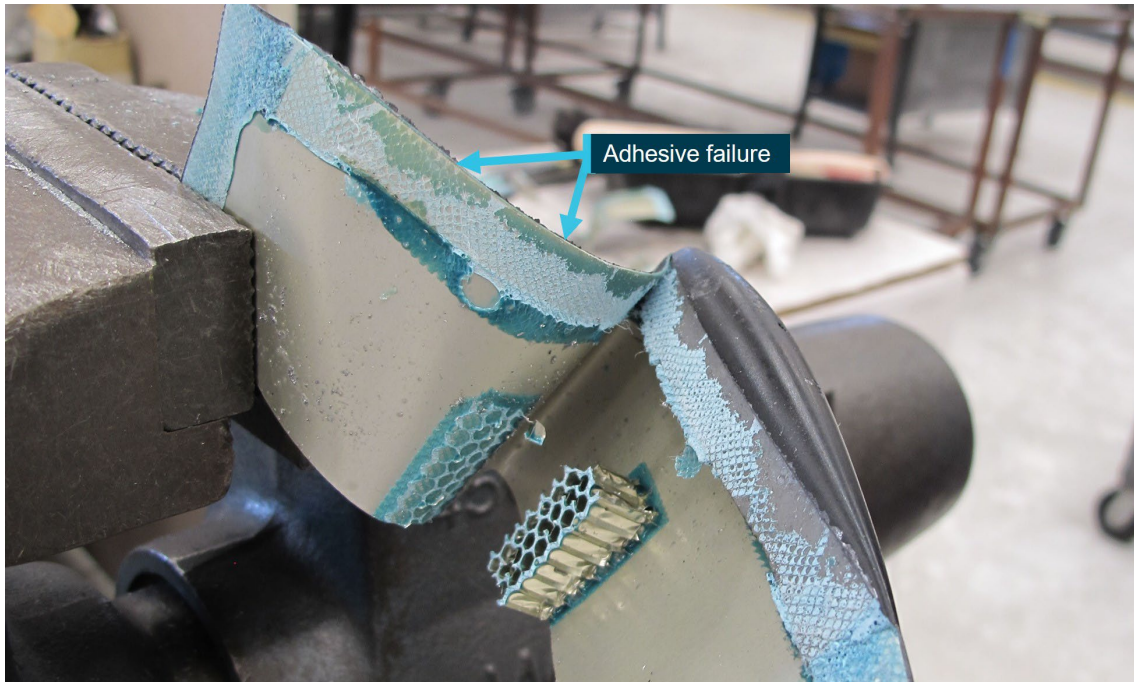
⁵ Robinson advised that once the tap test identified an adhesive void that exceeded limitations, the size and location of further voids were not noted. Robinson did not attempt to determine the full extent of the disbonded area using tap testing.

Figure 9: Tail rotor blade leading edges, showing paint loss, erosion and skin cracking



Source: ATSB

Figure 10: Blade SN 5802 adhesive failure



The other side of the bond exhibited similar visual characteristics.
Source: Robinson Helicopter Company, annotated by the ATSB

Maintenance requirements

Chapter 2 of the R22 maintenance manual contained a 100-hourly inspection procedure and checklist, which stated:

Tail Rotor Blades: Inspect condition. Refer to § 9.220 for damage limitations...Verify blade tip drain holes (2 per A029-1 blade, 1 per A029-2 blade) are unobstructed. Verify no corrosion. Tap test bonded areas per § 26-44.

Tap testing structures involves lightly tapping an item of specific size, weight and material (often a coin or washer) along the length of a bonded structure and listening for changes in the acoustic response. Areas of delamination or disbond will sound hollow in comparison to a solid structure. A video illustrating a tap test was published by Robinson, at <https://shop.robinsonheli.com/robinson-safety-videos/>.

The 100-hourly inspection procedure and checklist was completed at the 24 January 2022 inspection, with no defects recorded.

Chapter 9, section 9.220 of the helicopter's maintenance manual detailed inspection and repair limits for tail rotor dents, nicks, scratches and corrosion. Blades were required to be replaced where erosion caused deformation or ripples in the leading edge. The section contained a procedure for re-painting the blades, but not a specific limit or requirement for repainting due to general wear. The tail rotor blade description under section 9.000 stated that 'Maintaining the paint finish will reduce corrosion and erosion.' The service letter, SL-93, similarly stated: 'Paint offers the best protection against leading edge corrosion' and the 'preferred blade condition is with a fully painted leading edge'.

Section 26-44 of the maintenance manual detailed void limits during detection by tap testing of main rotor blades and referenced 'critical', 'semi-critical' and 'non-critical' blade bond areas. There were no tail rotor blade void limits given. The maintainer of the occurrence tail rotor blades indicated they had extensive experience in tap testing and had previously identified disbonds in other manufacturer's rotor blades.

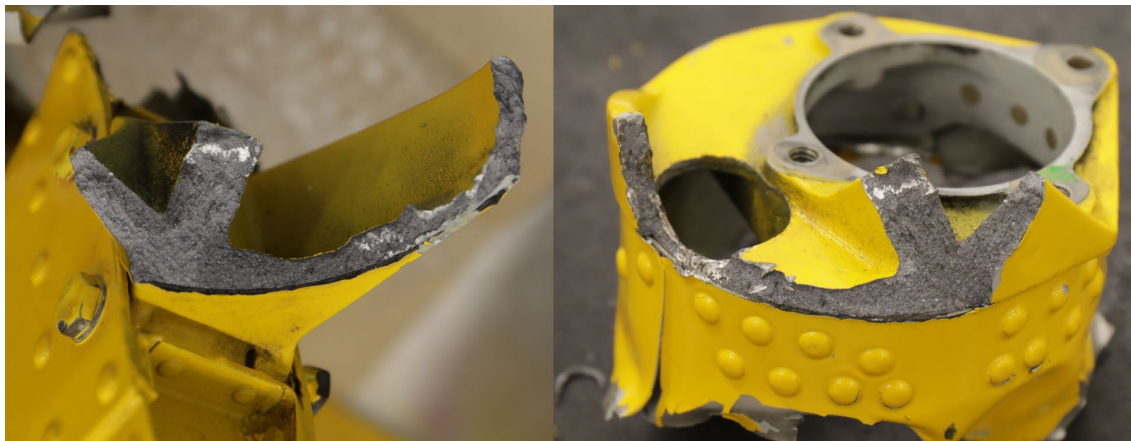
Robinson also published R22 service letter SL-93 in June 2021, the background for which stated:

RHC [Robinson] has recently seen tail rotor blades that were allowed to corrode to an unserviceable condition including severe leading edge pitting and degradation of the bond at the tip cap. Regular preventive maintenance is imperative for continued safe operation and additional care may be required in corrosive environments such as coastal or shipboard operations.

The service letter recommended practices included removal of any corrosion by hand sanding and instructed to 'remove only material necessary to eliminate corrosion; any hole that completely penetrates blade skin requires blade replacement.' The service letter also reinforced the maintenance manual requirement for tap testing of the blades to 'verify bond integrity'.

Tailcone aft casting

The two separated pieces of the fractured tailcone casting remained secured to the horizontal stabiliser and tailcone skin/gearbox respectively (Figure 11). There were no visible part or serial numbers.

Figure 11: Aft tailcone casting fracture, empennage side (left) and tailcone side (right)

Darkened regions on the fracture surface were considered to be due to gearbox oil migration.
Source: ATSB

The casting was manufactured from A356.0-T6⁶ aluminium alloy. Chemical analysis and hardness of the occurrence casting material found these characteristics to be in accordance with the alloy standard.

Visually and under low magnification optical microscopy, the casting fracture surface had irregular and faceted, brittle fracture features. There was evidence of localised deformation from contact between the two halves of the fractured bulkhead and as a result of impact with the adjacent pitch-change push-pull tube. Microstructural analysis showed that the casting was unmodified,⁷ and the faceted fracture surface was the result of the presence of coarse, plate-like silicon eutectic constituents in the alloy. Unmodified A356 crack growth studies have found that, at higher stress intensities, crack progression tends to follow the silicon particle orientation, which therefore dominates the fracture surface, producing the faceted fracture features observed in the occurrence sample.

At high magnification using a scanning electron microscope (SEM), there were several areas of minor shrinkage porosity and non-metallic inclusions that were generally to be expected for this type of casting. There were also some very minor striated areas that appeared consistent with high-cycle cracking. However, none of the defects observed were considered significant enough to have meaningfully contributed to the casting fracture.

To more fully characterise the fracture surface of this type of unmodified cast aluminium alloy, the ATSB conducted some laboratory fractures and the Defence Science and Technology Group (DSTG) conducted fatigue testing on the casting alloy for comparison (Appendix A).

Adhesive bond failures

Failure types comprise adhesive, cohesive, and mixed failures (Petrie 2000):

Adhesive failure is an interfacial bond failure between the adhesive and the adherend [bonded surface]. Cohesive failure could exist within either the adhesive material or the adherend. Cohesive failure of the adhesive occurs when stress fracture within the adhesive material allows a layer of adhesive to remain on both substrates (i.e., the attachment of the adhesive to the substrate is stronger than the internal strength of the adhesive itself, and the adhesive fails within its bulk). When the

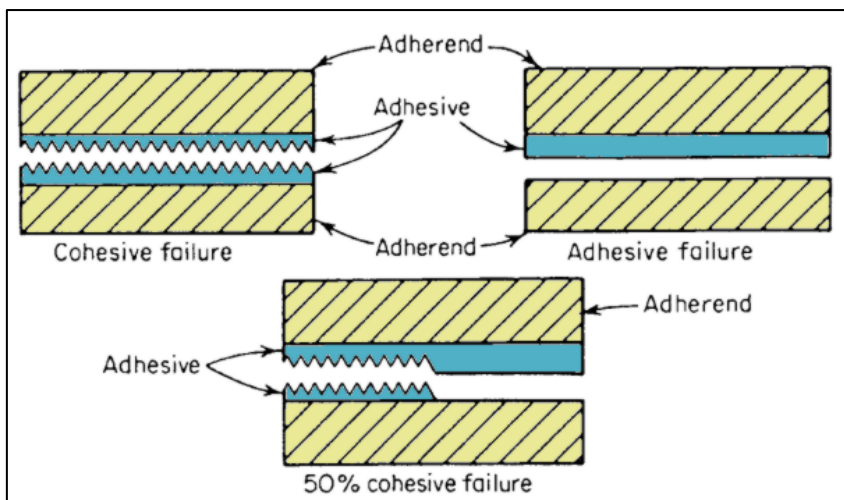
⁶ A356 is a widely used aluminium-silicon-magnesium casting alloy. The alloy is normally used in the heat-treated condition and 'T6' is the temper designation for a high strength, solution heat-treated and artificially aged part.

⁷ Small additions of alloying elements can be added to modify the microstructure during the casting and solidification process. Silicon eutectic modifiers refine the coarse, plate-like phase to a smaller, spheroidal morphology. This result is a significant increase in the alloy ductility.

adherend fails before the adhesive and the joint area remains intact, it is known as a cohesive failure of the adherend.

An illustration of cohesive, adhesive, and mixed failure types is provided in Figure 12.

Figure 12: Cohesive and adhesive failures



Source: Petrie (2000), modified by the ATSB

Moisture can affect the strength of an adhesive bond. This failure mechanism involves water diffusing through the adhesive, through the interface between the adhesive and adherend and/or through cracks or defects in the adhesive or adherend layers. The absorbed water molecules degrade the interface by deteriorating secondary bonds between the adhesive and adherend, or by weakening the oxide layer of the aluminium substrate.

Related occurrences

R44 in flight break-up

On 4 July 2020 a Robinson R44 Raven I helicopter, VH-NBY, experienced an in-flight break-up shortly after takeoff, 3 km north of Broome Airport, Western Australia. As with VH-THM, the tailcone aft casting failed, but there was no tail rotor blade failure (ATSB investigation [AO-2020-033](#)).

R22 tail rotor failure

The US National Transportation Safety Board investigated ([ERA22LA340](#)) a July 2022 accident involving an instructional flight in a Robinson R22 helicopter that collided with terrain. The instructor reported hearing a popping and banging sound, followed by an uncommanded right yaw, and subsequent collision with terrain.

The investigation report stated:

Postaccident examination of the helicopter revealed that the tail rotor gearbox had fractured and that the tail rotor assembly had separated from the helicopter. Additional examination of the tail rotor blades, which had remained attached to the tail rotor drive shaft and gearbox, revealed corrosion and interior delamination of the blades. There was also erosion present on the blade leading edges, which likely provided a path for moisture to ingress, thereby resulting in the observed corrosion as well the failure of the bonding adhesive within the blade. It is likely that this condition resulted in an imbalance of the blades that imparted a vibratory loading onto the tail rotor gearbox that ultimately resulted in its failure during the accident flight. Review of partial maintenance records provided by the operator revealed that the tail rotor blades installed on the accident helicopter were not the blades that were noted in the maintenance logbooks, and the service history of the installed blades could not be determined.

Robinson tail rotor tip cap separations

R44 tail rotor tip cap separation

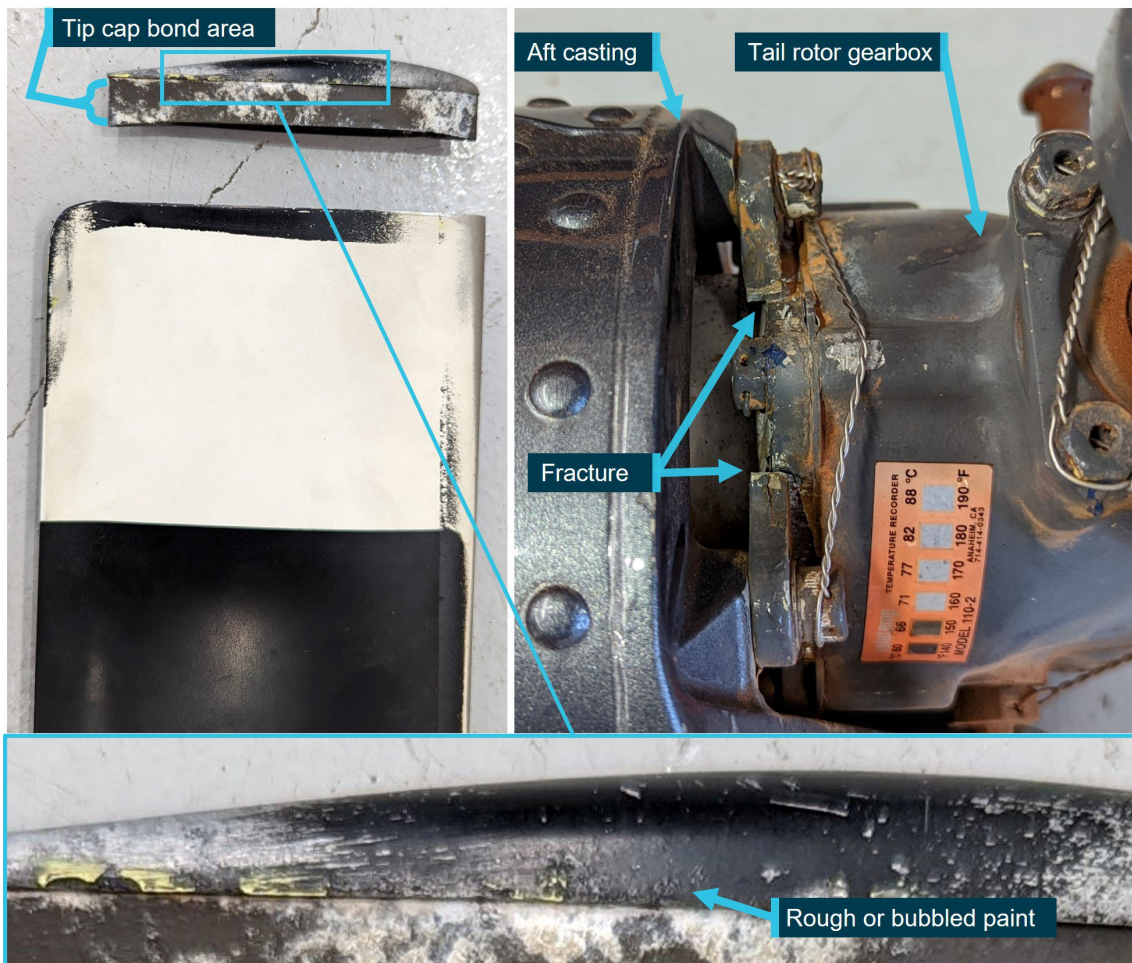
A March 2022 occurrence involving an R44 tail rotor tip cap separation was reported through the Civil Aviation Safety Authority's (CASA's) defect reporting system (the location was not provided).

The tip cap separated from rotating tail rotor blade shortly after landing and the resulting vibration fractured the tail rotor gearbox input cartridge mounting flange, as shown in Figure 13. Internal corrosion at the tip bond area was attributed to a disbond (per the mechanism described in R22 SB-120 and the R44 equivalent, SB-112). The R44 part number C029-3 tail rotor blades were similar in construction to the R22 A029-2 blades, and these reportedly had 1,806 hours since new.

The submitted report advised that tap testing of the bonded area at the most recent inspection gave no indication of disbonding. During subsequent experiments the separated tip was loosely re-fitted to the blade and another tap test carried out. The reporter stated that there was no discernible difference between the sound response of the blade with the refitted, but not bonded, tip and that of a new blade. Additionally, while there was evidence of leading-edge erosion on the blade, the reporter indicated there was no corrosion discernible under external visual examination.

The ATSB did not examine the subject blade or tip cap. The supplied images indicated minor rough or bubbled paint on the exterior surface, mid-span, adjacent to the bond line, which may have been indicative of underlying corrosion.

Figure 13: R44 tip cap separation and resultant gearbox mount fracture



Source: Civil Aviation Safety Authority, modified by the ATSB

Other tail rotor tip cap separation occurrences

A 2024 United States Federal Aviation Administration airworthiness directive ([AD 2024-04-02](#)) was prompted by 3 reports⁸ of tail rotor blade tip caps coming loose due to corrosion at the bond in R44 helicopters (which have similar tip caps). A search of the Civil Aviation Safety Authority and Federal Aviation Administration defect reporting systems did not identify any other reports of tip caps separating on Robinson R22 or R44 helicopters.

⁸ It is not clear whether these are the same 3 occurrences discussed in this report.

Safety analysis

Failure sequence

The normal proximity of the tail rotor blades to the point of impact with the horizontal stabiliser meant that contact was only possible if the empennage assembly separated. The remaining damage to the tail rotor drive system was the result of the tail rotor strike on the stabiliser. Separation of the empennage assembly in this manner was due to fracture of the tailcone casting.

Detailed fractographic analysis of the tailcone casting found that the fracture was the result of a high applied stress intensity, and identified no significant defects that would have resulted in fracture during normal operation. As such, the casting was most likely subjected to abnormal loading conditions around the time of the occurrence.

Aside from the tail rotor tip cap detachment, there was no evidence of an operational event or issue with the helicopter tail or tail rotor drive system that might have resulted in abnormal loading of the tail assembly. Consistent with Robinson service bulletin advice, in-flight detachment of the tip cap would have caused severe vibration. This would have been in the form of immediate, and relatively high frequency and high amplitude loading leading to rapid fracture of the low-ductility casting. That is, the tip cap detachment and resulting imbalance led to the empennage separation.

The failures occurred with the helicopter in a low hover. Nevertheless, the instructor's quick and appropriate actions were effective in preventing a more serious outcome.

Tail rotor tip cap adhesive failure

The condition of the residual adhesive at the tail rotor tip cap was consistent with adhesive failure over approximately 85% of the original bonded area. With normal forces acting on it at the time of the occurrence, reduced bond effectiveness is the only reasonable explanation for the tip cap to separate in this case.

Given the nature of the failure and the presence of the fluid patches (likely water) in the bond of blade 5803 it is likely that this adhesive failure was associated with the presence of moisture. While both blades exhibited adhesive failure, there was a marked difference in the residual cohesive failure area, indicating a more rapid degradation in blade 5803. The tail rotor blades were installed as a set and, to the extent that could be determined, had experienced the same operational life and environmental conditions. This was consistent with the blades exhibiting a similar degree of erosion and pitting of the leading edge.

The leading-edge skin crack was almost certainly related to the significant erosion and pitting, and the condition of the crack showed that it existed prior to the tip cap separation. As such, it would have provided a moisture pathway to the adhesive bond, in addition to attack around the circumference of the bond line. This probably contributed to the differing extent of disbonding between the cracked blade and the opposing blade. However, it is noted that the reported tip cap separation involving an R44 had no evidence of blade skin cracking, showing that cracking was not necessarily a prerequisite for adhesive failure of the tip cap bond.

The resistance of adhesive bonds to moisture attack relies primarily on appropriate preparation of the substrate. While there were no identified manufacturing anomalies, it was possible that there were small differences in the bonding preparation between the two blades. However, given the very low incidence of this type of occurrence, it is unlikely that the manufacturing process was problematic or that the life limit was inappropriate.

Maintenance inspections

Defence against detachment of the tail rotor tip cap involved visual inspections of external blade condition and tap testing of the bond area. The extent of adhesive failure at the detached blade tip indicated that a significant disbond likely existed at the time of the most recent maintenance inspection, 21 flight hours prior to the occurrence. However, there were no recorded defects or indications of disbond from tap testing that, per the R22 service letter SL-93, was for the purpose of verifying bond integrity.

Tap testing is perhaps the simplest and most inexpensive method for non-destructive inspection of adhesive bond integrity. However, the test has limitations. Tap testing relies on operator judgement in identifying differences in acoustic responses while consistently tapping along a bond area. To produce a change in pitch, there needs to be an underlying structural difference associated with the bond. Unbonded substrates maintaining good contact with the adhesive, or as in this case, bonds with extensive adhesive failure may not produce a clear acoustic difference.

The reason disbond indications were not detected by tap testing in this occurrence was not explored in detail, however the limited examples in this report highlight some of the variability and limitations of tap testing to accurately assess adhesive bond integrity:

- The maintainer of the occurrence blade indicated they had extensive experience in tap testing and had previously identified disbands in other manufacturer's rotor blades. This indicates a degree of success with the test method, but not necessarily with the subject blades.
- Tap testing of the opposite blade by Robinson, under ideal conditions during their blade inspection, identified some likely disbands 'mid-span' (although Robinson did not attempt to determine the extent of the disbands that were later found to be present around most of the tip circumference).
- The reporter of an R44 tip cap detachment occurrence stated that their tap testing during the most recent maintenance inspection did not produce indications of disbonding. They could not subsequently identify an acoustic difference between the blade with the detached tip (after refitment) and a new blade.

Visual examination of the external blade condition for damage and corrosion cannot provide a direct indication of adhesive bond integrity, but may provide an indication of potential underlying conditions that could lead to in-service failure. For example, the occurrence blades, the blade from the NTSB tail rotor failure investigation, and potentially the R44 occurrence mentioned above had indications of corrosion adjacent to the tip cap bond line. The visible bond line corrosion could extend to the adjacent bond or be indicative of exposure to conditions that increase the risk of adhesive failure.

At the time of the occurrence, detection of blade corrosion did not require blade replacement, unless it exceeded the depth limits in the R22 maintenance manual, or per SL93, for 'any hole that completely penetrates blade skin'. Had the corrosion been identified and removed in accordance with this procedure, the tip cap separation would likely still have occurred. In contrast, identification of the leading-edge crack would have necessitated blade replacement. However, the blade skin had deformed and the crack opened up during the tip separation. As such, it wasn't possible to establish how the crack would have initially presented and whether it would have been readily identifiable under unaided visual inspection.

Findings

ATSB investigation report findings focus on safety factors (that is, events and conditions that increase risk). Safety factors include ‘contributing factors’ and ‘other factors that increased risk’ (that is, factors that did not meet the definition of a contributing factor for this occurrence but were still considered important to include in the report for the purpose of increasing awareness and enhancing safety). In addition ‘other findings’ may be included to provide important information about topics other than safety factors.

These findings should not be read as apportioning blame or liability to any particular organisation or individual.

From the evidence available, the following findings are made with respect to the in-flight tail rotor blade failure and tail assembly separation involving Robinson R22, VH-THM, at Gold Coast Airport, Queensland on 26 February 2022.

Contributing factors

- In-flight detachment of a tail rotor blade tip cap led to abnormal dynamic loading within the tail rotor assembly, fracture of the aft tailcone bulkhead and separation of the empennage.
- The tail rotor blade tip cap bond had a significant proportion of moisture-induced adhesive failure that reduced the bond strength resulting in the in-flight detachment from the tail rotor blade.
- The scheduled maintenance inspection, including tap testing of the tail rotor blades, 21 flight hours prior to the occurrence, did not identify adhesive disbonding that was very likely present at the tip cap bond line of both blades.

Safety issues and actions

Safety action not associated with an identified safety issue

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. All of the directly involved parties are invited to provide submissions to this draft report. As part of that process, each organisation is asked to communicate what safety actions, if any, they have carried out to reduce the risk associated with this type of occurrences in the future. The ATSB has so far been advised of the following proactive safety action in response to this occurrence.

Safety action by Robinson Helicopter Company

On 3 June 2022, RHC published revision 'A' of R22 Service Letter SL-93, R44 Service Letter SL-82, and R66 Service Letter SL-40, on the subject of tail rotor blade condition and care. The original service letter was published on 30 June 2021. The background to the service letter stated:

RHC has recently seen tail rotor blades that were allowed to corrode to an unserviceable condition including severe leading edge pitting and degradation of the bond at the tip cap. Regular preventive maintenance is imperative for continued safe operation and additional care may be required in corrosive environments such as coastal or shipboard operations. Recommended practices to prevent and mitigate the effects of corrosion are provided below. Revision A adds inspection criteria.

Revision A corrosion inspection criteria included using 10x magnification to inspect adjacent to the tip cap bond line for the presence of adhesive and absence of corrosion. Blades were required to be replaced if there was any corrosion at the bond line or if there were any gaps in the bond line adhesive.

On 22 December 2022 RHC published revision A of R22 Service Bulletin SB-120, R44 Service bulletin SB-112, and R66 Service Bulletin SB-41. The background to the service bulletin stated:

RHC has received reports of tail rotor blade tips coming loose due to corrosion at the bond. Helicopters operating near saltwater are particularly susceptible to corrosion, especially if stored outdoors. A debonded tip can cause severe vibration and possible failure of the tail rotor gearbox housing.

The service bulletin listed the affected blade part and serial numbers that have been deemed susceptible to corrosion and provided a recurrent visual inspection to be inserted into the pilot's operating handbook and carried out before the first flight of the day. Any indications of corrosion or exposure at or adjacent to the tip cap bond line required compliance with SL-93 before further flight. The susceptible blades were required to be replaced no later than 31 December 2024, noting that:

Helicopters operated and/or stored outdoors in corrosive environments such as salt water coastlines should replace affected blades as soon as practical.

The bulletin indicated that newer revision blades had tip caps manufactured from an alternate alloy to reduce the likelihood of corrosion.

Safety action by United States Federal Aviation Administration

The United States Federal Aviation Administration (FAA) issued airworthiness directive [AD 2024-04-02](#), effective from 2 April 2024, relating to tail rotor blades on Robinson helicopters, due to 3 reports of tip caps coming loose due to corrosion at the bond in R44 helicopters (which have similar tail rotor blade tip caps). The summary statement stated:

The FAA is adopting a new airworthiness directive (AD) for certain Robinson Helicopter Company Model R22, R22 Alpha, R22 Beta, R22 Mariner, R44, R44 II, and R66 helicopters. This AD was

prompted by reports of helicopters losing a tail rotor blade (TRB) tip cap. This AD requires visually checking and inspecting certain part-numbered and serial-numbered TRB tip caps for evidence of corrosion and, depending on the results, removing the corrosion. This AD also requires removing all affected TRBs from service and prohibits installing them on any helicopter. The FAA is issuing this AD to address the unsafe condition on these products.

General details

Occurrence details

Date and time:	26 February 2022 – 1025 Eastern Australian Standard Time	
Occurrence class:	Accident	
Occurrence categories:	Fuselage / Wings / Empennage, Transmission and gearboxes	
Location:	Gold Coast Aerodrome	
	Latitude: 28.1644° S	Longitude: 153.5047° E

Aircraft details

Manufacturer and model:	Robinson Helicopter Company R22 Beta	
Registration:	VH-THM	
Operator:	Professional Helicopter Services	
Serial number:	4057	
Type of operation:	Part 91 General operating and flight rules-Part 141 - training	
Activity:	General Aviation / Recreational-Instructional flying-dual	
Departure:	Gold Coast Aerodrome	
Destination:	Gold Coast Aerodrome	
Persons on board:	Crew – 2	Passengers – 0
Injuries:	Crew – 0	Passengers – 0
Aircraft damage:	Substantial	

Glossary

CASA	Civil Aviation Safety Authority
DSTG	Defence Science and Technology Group
FAA	Federal Aviation Administration
NTSB	National Transportation Safety Board
RHC	Robinson Helicopter Company
SEM	Scanning electron microscope
SN	Serial number

Sources and submissions

Sources of information

The sources of information during the investigation included:

- the instructor for the occurrence flight
- Professional Helicopter Services
- Robinson Helicopter Company and
- the maintenance organisation for VH-THM.

References

Petrie, Edward M. (2000). *Handbook of Adhesives and Sealants*. McGraw-Hill, New York.

Submissions

Under section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. That section 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 following directly involved parties:

- the instructor for the occurrence flight
- Professional Helicopter Services
- Robinson Helicopter Company
- the maintenance organisation for VH-THM
- the Civil Aviation Safety Authority

Submissions were received from the Robinson Helicopter Company.

The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Appendix A – Metallurgical examination and testing of the fractured tailcone aft casting

Casting material

The as-cast A356 microstructure primarily consists of a hard, brittle, plate-like silicon eutectic⁹ constituent in an aluminium matrix. In the unmodified¹⁰, as-cast state, the silicon phase is brittle and has a coarse, plate-like morphology, leading to a low ductility material. Alloy modification and heat treatment is often employed to improve the ductility and toughness of the material.

Fractography

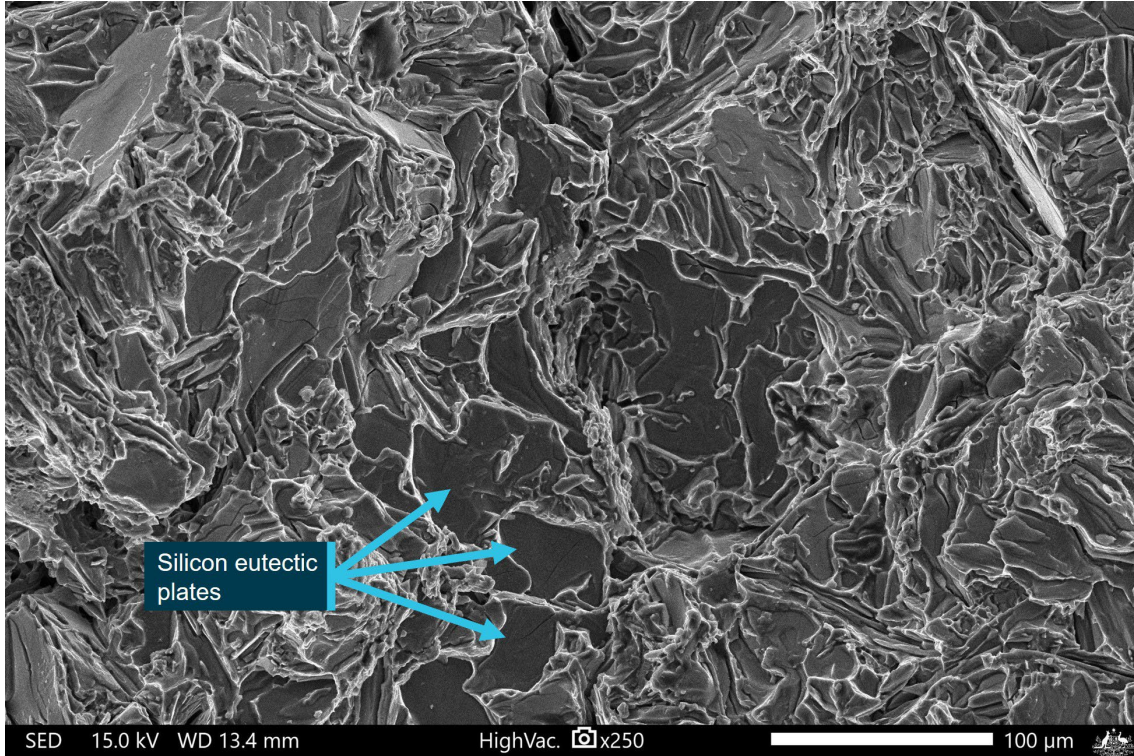
General fracture characteristics

The scanning electron microscope (SEM) examination of the tailcone aft casting fracture identified a general brittle fracture surface dominated by irregularly shaped silicon plates within an aluminium matrix (Figure 14). The brittle fracture features were consistent with a metallographic section perpendicular that showed the jagged fracture path preferentially followed the line of silicon plates in the alloy microstructure. A metallurgical examination identified that the microstructure of the aft bulkhead was consistent with unmodified A356 (Figure 15).

⁹ Eutectic refers to the mixture of components in a ratio that has the lowest melting/freezing point possible. In the aluminium-silicon alloy system, that point is 12.6% silicon.

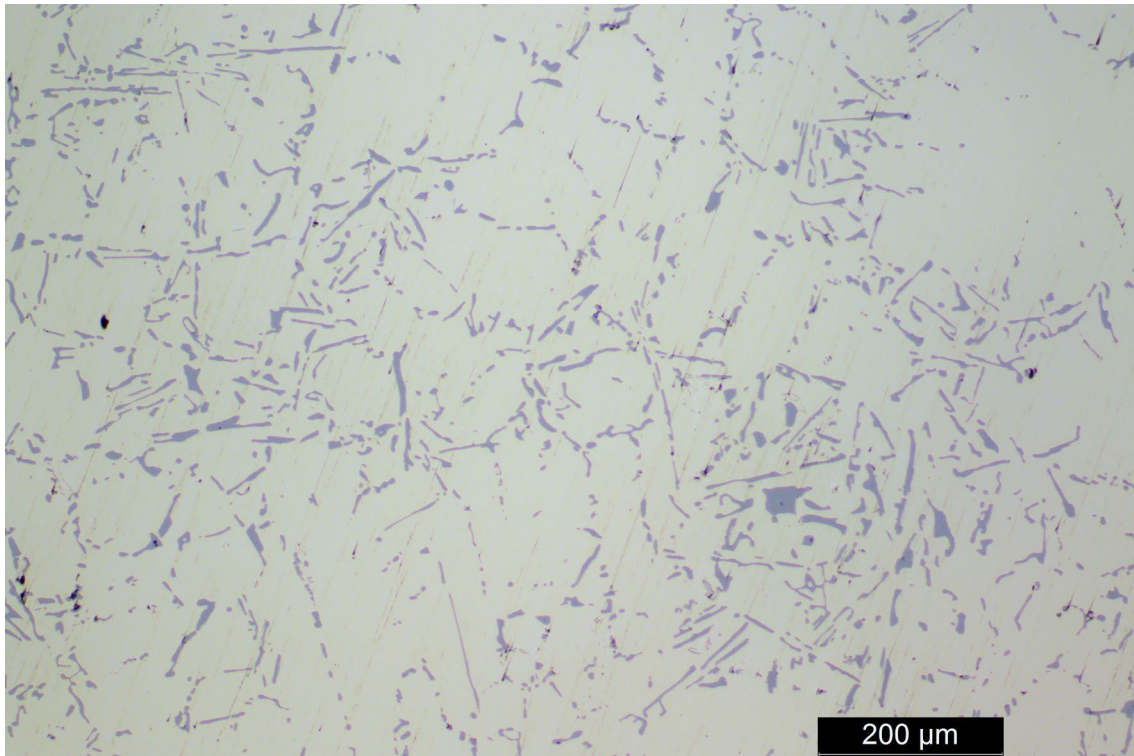
¹⁰ Small additions of grain refining alloying elements can be added to modify the microstructure during the casting and solidification process.

Figure 14: SEM micrograph showing the general casting fracture surface morphology



Source: ATSB

Figure 15: Microstructural cross section of unmodified A356, showing silicon eutectic (grey) in an aluminium matrix (white)



Source: ATSB

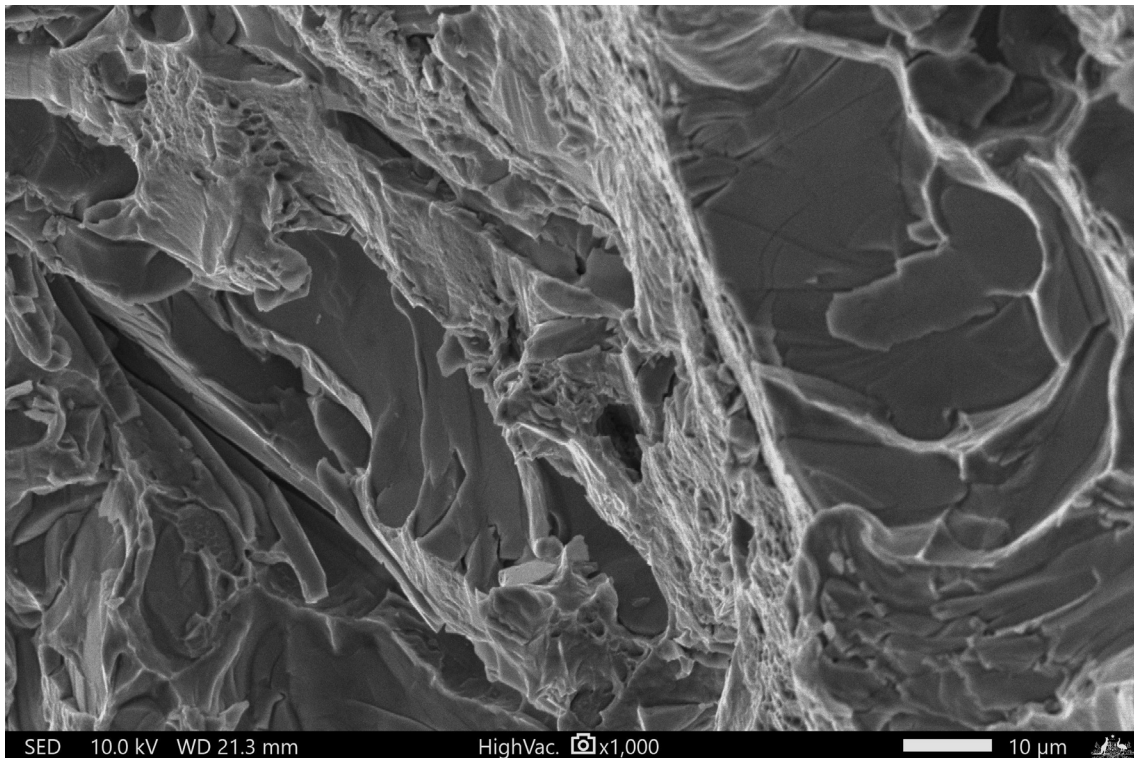
Fracture surface striations

Isolated areas of aluminium matrix with vague parallel features, or striations, were present across the fracture surface (Figure 16). Some of the features were determined to be mechanical damage due to local contact between the crack or fracture halves and/or related to fracture or decohesion¹¹ of the silicon eutectic particles.

For comparison, a section of the casting was subjected to a monotonic (single impact) fracture. At low magnification, the fracture surface appeared similar in appearance to that of the occurrence fracture. However, at high magnification there were areas of well-defined, micro-dimpled rupture in the matrix (Figure 17) that were not observed on the occurrence fracture. The dimples were determined to be characteristic of unstable crack growth or ‘fast fracture’ under tensile loading.

Further examination of the occurrence casting identified localised areas of very fine striations near the part surface or an area of shrinkage porosity, that were more representative of high cycle fatigue crack progression (Figure 18). There were no gross material or manufacturing defects observed on the fracture surface and the total combined defect area was relatively low in comparison to similar castings examined (from other Robinson helicopters). The larger of these defects were located immediately below the part surface and were in the order of 1 mm across the principal axis on the fracture surface (Figure 19). The fracture surface immediately surrounding some of these defects was noticeably flatter and also exhibited similar striation-like features in area of aluminium matrix. The reason for the striations or cracking was not determined, however, the areas affected were too small to have had any meaningful influence on the casting fracture.

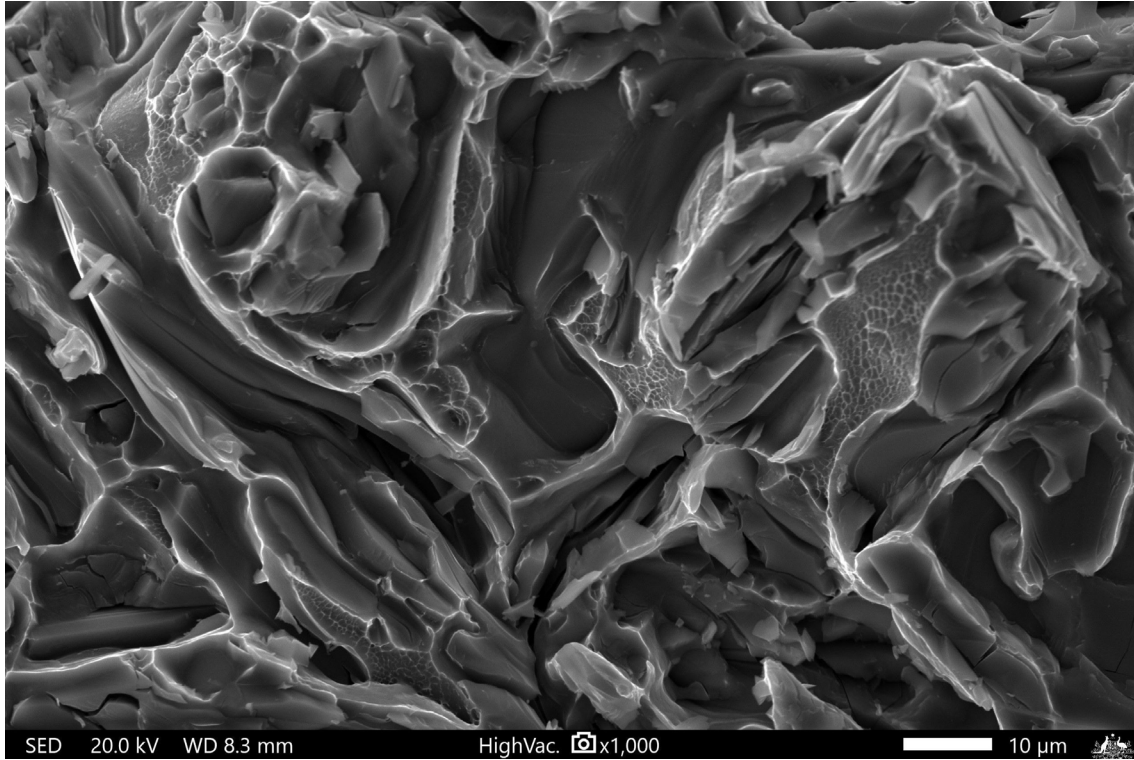
Figure 16: Occurrence fracture surface ‘striated’ matrix



Source: ATSB

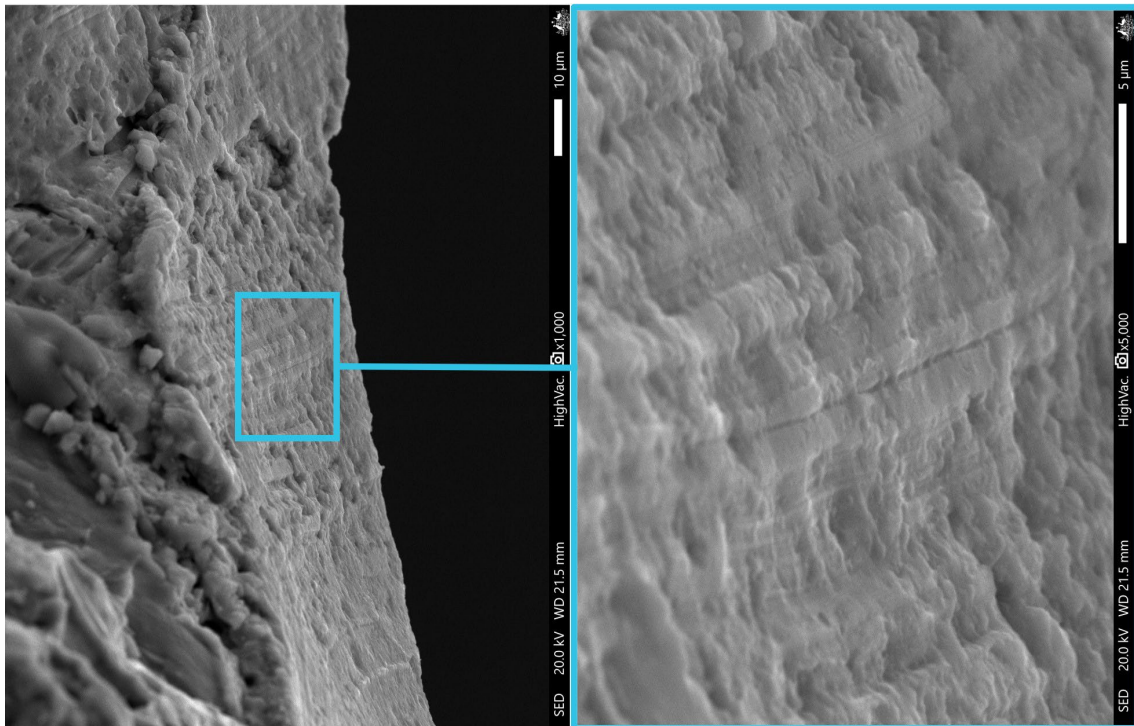
¹¹ Interfacial separation of the particle from the matrix.

Figure 17: Monotonic fracture surface showing micro-dimpled rupture



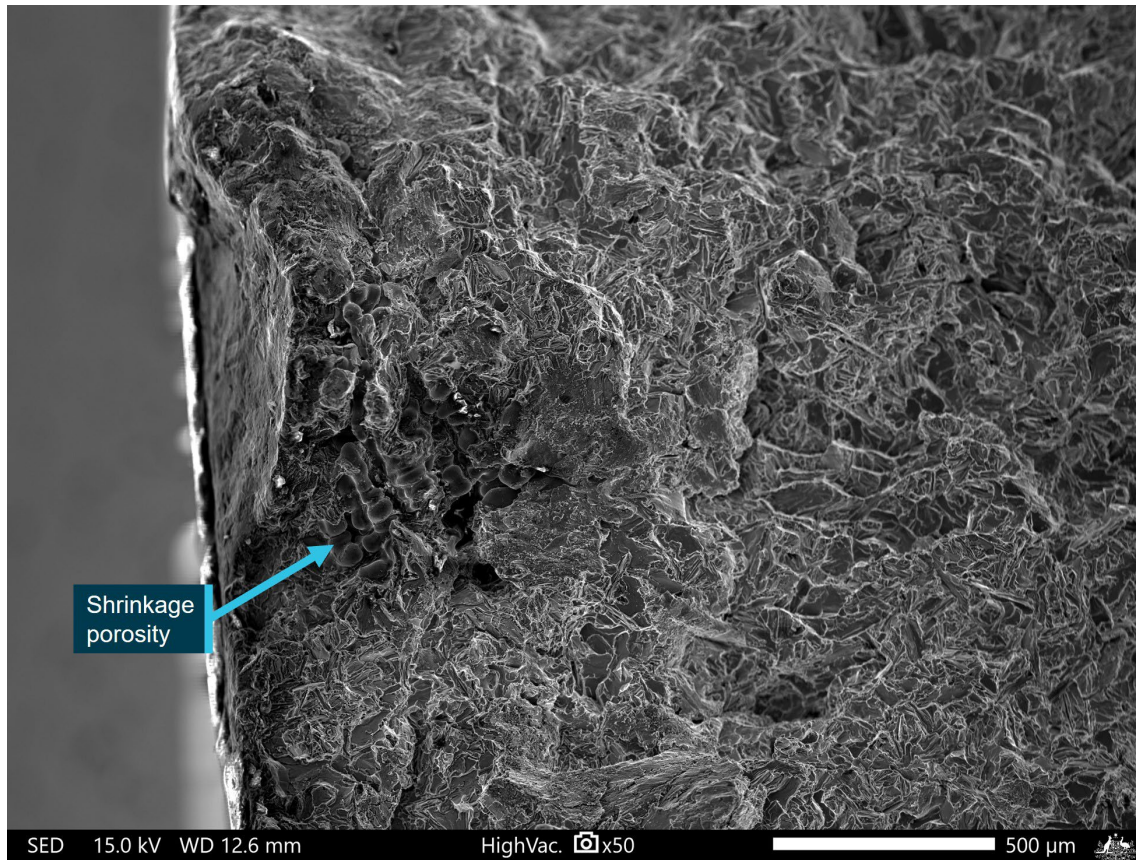
Source: ATSB

Figure 18: Discrete area of striations identified on the fracture surface



Source: ATSB

Figure 19: SEM micrograph of an example defect in the aft bulkhead fracture surface where subsurface shrinkage porosity was identified



Source: ATSB

Fatigue testing of the casting alloy

High-cycle and low-cycle fatigue tests were conducted on a representative sample¹² of A356 material by the Defence Science and Technology Group (DSTG) at the request of the ATSB to allow further fractographic characterisation and comparison with the occurrence casting. The specimens were tested to failure in a tension-tension test regime (Table 1, Table 2, Table 3, and Table 4).

Table 1: High cycle fatigue testing specimen geometry

H	30 mm	width
r	10 mm	notch radius
d	10.05 mm	width at reduced section
h	5.05 mm	thickness
Area	50.75 mm ²	
K_t	1.348777778	

¹² Machined from a Robinson R44 tailcone casting, manufactured from the same alloy.

Table 2: High cycle fatigue testing parameters

Load profile					Results		
Run #	σ max MPa	σ nom MPa	P max (target) kN	P min (target) kN	Cycles applied	P max (applied) kN	P min (applied) kN
1	50	37	1.88	0.19	20 x 10 ⁶	2.04	-
2	60	44	2.26	0.23	20 x 10 ⁷	2.42	0.09
3	80	59	3.01	0.30	20 x 10 ⁹	3.17	0.19
4	100	74	3.76	0.38	1,114,639	3.93	-0.76

Table 3: Low cycle fatigue testing specimen geometry

H	30 mm	width
r	10 mm	notch radius
d	10.05 mm	width at reduced section
h	6.48 mm	thickness
Area	51.12 mm ²	
K _t	1.348777778	

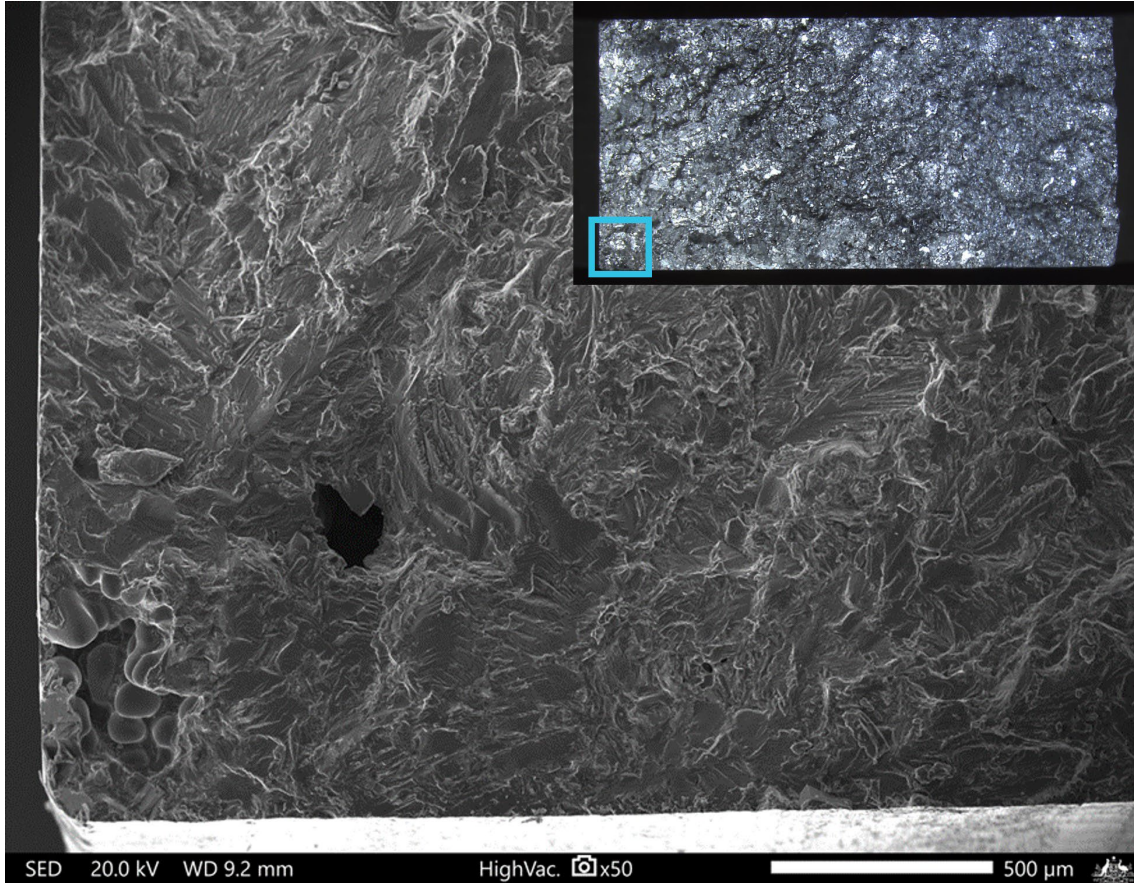
Table 4: Low cycle fatigue testing parameters

Load profile					Results		
Run #	σ max MPa	σ nom MPa	P max (target) kN	P min (target) kN	Cycles applied	P max (applied) kN	P min (applied) kN
1	130	96	6.28	0.63	1000	6.46	-0.04
2	140	104	6.76	0.68	1000	6.99	0.54
3	150	111	7.24	0.72	1000	7.43	0.62
4	160	119	7.73	0.77	1000	7.91	0.67
5	170	126	8.21	0.82	1000	8.4	0.74
6	180	133	8.69	0.87	1000	8.88	0.74
7	190	141	9.17	0.92	1000	9.41	0.84
8	200	148	9.66	0.97	1000	9.88	0.86
9	210	156	10.14	1.01	1000	10.63	0.5
10	220	163	10.62	1.06	1000	10.85	0.95
11	230	171	11.11	1.11	1000	11.34	0.99
12	240	178	11.59	1.16	1000	11.86	1.01
13	250	185	12.07	1.21	1000	12.29	1.03
14	260	193	12.55	1.26	1000	12.84	1.01
15	270	200	13.04	1.30	1000	13.4	1.01
16	280	208	13.52	1.35	1000	13.87	1
17	290	215	14.00	1.40	784	14.42	-1.55
18	300	222	14.49	1.45	-	-	-

Cracks initiated in both specimens at subsurface porosity at one corner of the specimen. Both specimens showed a defined, relatively flat, cleavage-type crack origin and initial crack progression region, with clear chevrons, river lines and striation features, clearest in the high-cycle

fatigue specimen (Figure 20). This transitioned to an increased prevalence of the faceted, silicon particle-dominated, fracture surface and micro-dimpled rupture through the unstable crack growth and overstress regions. There was no similar significant area of cleavage fracture on the occurrence fracture surface.

Figure 20: High-cycle fatigue specimen fracture origin



Source: ATSB

Discussion

A review of fatigue crack growth studies showed that the mechanism of crack progression through unmodified A356 alloy was dependent on the particle morphology and orientation, as well as the applied stress intensity. At low stress intensities, the plate-like silicon particles debond from the matrix unless their principal axis was oriented perpendicular to the crack plane. The result was a flatter, cleavage-type fracture, such as that exhibited by the initiation region of the high cycle fatigue test specimen. At higher stress intensities, particle fracture was found to dominate and the fracture surface produced was more faceted, with the crack path following the orientation of the silicon particles. Based on this, while there were discrete areas representative of the former mechanism, the dominant appearance of the occurrence fracture was consistent with a higher applied stress intensity.

While there were some minor casting defects in this occurrence, there were no significant material, manufacturing or operational anomalies identified that would have abnormally predisposed the part to fracture, beyond other similar castings.

Australian Transport Safety Bureau

About the ATSB

The ATSB is an independent Commonwealth Government statutory agency. It is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's purpose is to improve the safety of, and public confidence in, aviation, rail and marine transport through:

- 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, as well as participating in overseas investigations involving Australian-registered aircraft and ships. It prioritises investigations that have the potential to deliver the greatest public benefit through improvements to transport safety.

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

Purpose of safety investigations

The objective of a safety investigation is to enhance transport safety. This is done through:

- identifying safety issues and facilitating safety action to address those issues
- providing information about occurrences and their associated safety factors to facilitate learning within the transport industry.

It is not a function of the ATSB to apportion blame or provide a means for determining 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. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Terminology

An explanation of terminology used in ATSB investigation reports is available on the ATSB website. This includes terms such as occurrence, contributing factor, other factor that increased risk, and safety issue.