In-flight break-up involving Robinson R44 Raven I, VH-HGU

31 km east of Goulburn Airport, New South Wales, on 2 December 2020

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Addendum

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Safety summary

What happened

On the afternoon of 2 December 2020, a Robinson Helicopter Company (RHC) R44 Raven I, registered VH-HGU, departed Goulburn Airport, New South Wales with a student pilot and instructor on board. The helicopter flew east, and the last recorded automatic dependent surveillance broadcast (ADS-B) detected it descending into a valley in the Bungonia State Conservation Area. A search commenced when the helicopter did not return as expected, and the wreckage of VH-HGU was found in a valley, approximately 4 km north-west of its last ADS-B transmission. Both pilots were fatally injured, and the helicopter was destroyed.

What the ATSB found

Wreckage examination indicated that while flying in the vicinity of the valley, the helicopter entered a low-G condition due to turbulence, inappropriate control inputs, or a combination of both. This condition, probably in combination with inappropriate recovery control inputs resulted in extreme teetering of the main rotor. A mast bump occurred as a result, and the helicopter subsequently broke up in flight.

An intense post-impact fire prevented a complete examination of the wreckage. However, the evidence available gave no indication that the helicopter was operating abnormally prior to the in-flight break-up.

The circumstances leading to in-flight break-ups from mast bumping and extreme teetering are usually not identified. While the fire would likely have prevented data recovery in this case, the inclusion of readily available cockpit video recorders on helicopters with semi-rigid rotor heads would provide valuable insights into low-G mast bumping events, which could help to prevent future occurrences.

What has been done as a result

The operator has introduced a limit of 6 consecutive training days. In addition, an online flight and duty monitoring system will be used to assess and adjust duty hours for instructors and students.

Since the occurrence, RHC has introduced cockpit video/audio recorders as standard equipment on new R44 helicopters, having previously been available on R66 models. The recorders are optional on R22 models, but will be standard equipment in 2023, with retrofit kits made available.

Safety message

Low-G conditions can be catastrophic for helicopters with semi-rigid rotor heads. A pilot's ability to recover from low-G remains uncertain, though all parties agree that it is dependent on airspeed and time available. Pilots must therefore avoid low-G situations, and take the following actions to mitigate risk:

- Make a careful study of the terrain, forecasts and observations applicable to the proposed flight to identify significant weather such as fronts or mechanical turbulence and avoid flying in those conditions.
- Reduce airspeed when encountering significant turbulence.
- Avoid flight downwind of hills, ridges or other potential sources of turbulence, particularly during changing or unpredictable weather conditions.
- Allow plenty of altitude so that there is enough time for recovery from unexpected flight conditions.
- Use slow and small control inputs.

Recording devices have long been recognised as an invaluable tool for investigators in identifying the factors behind an accident, and their contribution to aviation safety is irrefutable. While not required by regulations, operators should consider the benefits of installing such devices.

Contents

The occurrence

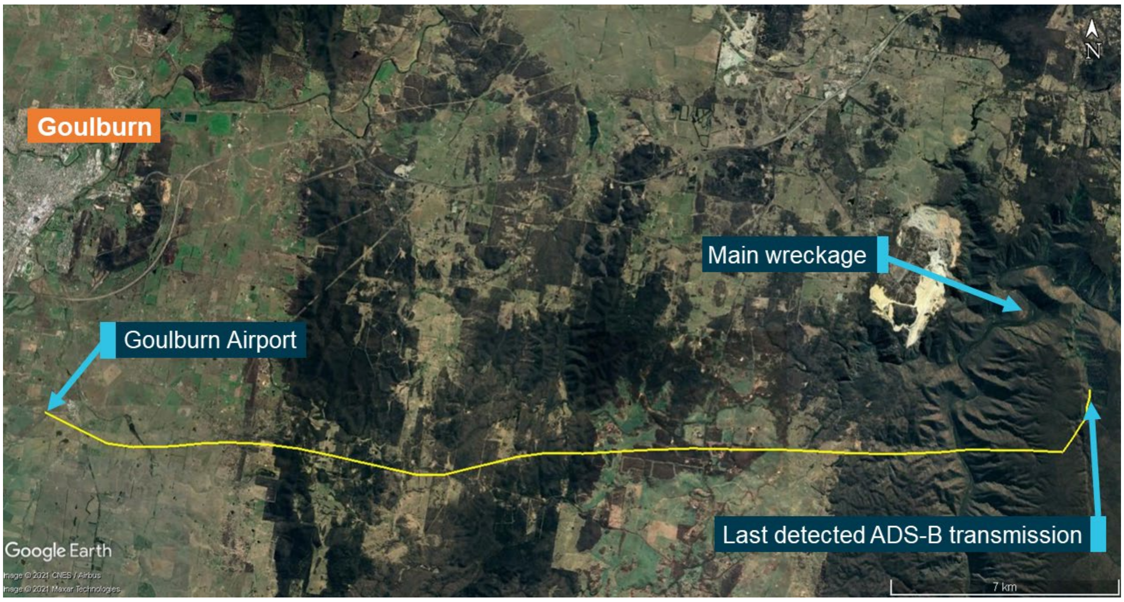
On the morning of 2 December 2020, an instructor and student pilot began a day of flight training operations in a Robinson R44 Raven I, registered VH-HGU. The pilots conducted a training area familiarisation from Goulburn Airport, New South Wales, after which the student pilot's first solo flight was conducted.

Over the course of the morning and early afternoon, the student completed two sets of solo circuits and a solo navigation flight around the edge of the training area. Immediately after the navigation flight, the instructor joined the student pilot on board VH-HGU, and at 1558 Eastern Daylight-saving Time,[1] they departed Goulburn Airport toward the east.

At 1846, when the helicopter had not returned to Goulburn as expected, the training operator's chief pilot contacted the Australian Maritime Safety Authority's Joint Rescue Coordination Centre (JRCC). The chief pilot then began an aerial search of the training area in another helicopter.

During the search, JRCC provided the chief pilot with the helicopter's last known location—the last recorded automatic dependent surveillance broadcast (ADS-B)—which had detected it descending into a valley in the Bungonia State Conservation Area at 1611. At about 2000, the chief pilot located the helicopter's wreckage 4 km north-west of its last ADS-B transmission, which was in a valley approximately 31 km east of Goulburn Airport (Figure 1). The pilot then provided the wreckage location to emergency services. The helicopter's engine and fuselage had been exposed to a fire at the main wreckage site, which had self-extinguished before emergency services arrived. Both pilots had been fatally injured.

Figure 1: Flight path and wreckage location of VH-HGU



The aircraft track was calculated from ADS-B data.
Source: Google Earth, FlightAware, annotated by the ATSB

[1] Eastern Daylight-saving Time (EDT): Coordinated Universal Time (UTC) +11 hours

Context

Pilot information

Instructor

The instructor held a commercial helicopter pilot licence and a Grade 3 helicopter flight instructor rating. At the time of the occurrence, the instructor had accrued a total flying time of 690 hours. This included 684 hours in the Robinson R44, of which 103.1 hours had been in the past 90 days and 64.3 hours in the previous 30 days. The pilot held a Class 1 Aviation Medical Certificate valid until 7 December 2021.

Student

The student was 12 days into an intensive flight training course for the issue of a private helicopter pilot licence (PPL), having not flown previously. Over that time, the student had accrued a total of 37.9 hours of dual flying, all on VH-HGU. Prior to the accident, the student pilot had accrued 3 hours of solo flying. The student pilot held a Class 2 Aviation Medical Certificate valid to 23 September 2022.

Fatigue considerations

During the 12 days of flying training, the work patterns of the instructor and the student identified some factors that placed them both at risk of their performance being affected by fatigue. Some research (Powell and others, 2007) conducted on short-haul airline pilots indicated that the most important influences on fatigue were the number of sectors conducted and the duty period. This study indicated that fatigue increased with each additional sector studied, up to a maximum of 5 sectors studied. On 30 November, the pilots conducted four flights totalling 4.2 hours flying time. The instructor also conducted a fifth flight with another student, 1.5 hours long. On 1 December, the day before the accident, the pilots conducted five flights with 5.5 hours total flying time. On 2 December, prior to the accident flight, the student pilot had conducted three solo flights totalling 3 hours, and two dual flights totalling 1.3 hours.

The nature of the work also could have contributed to fatigue—the Civil Aviation Safety Authority has stated that from a workload perspective, training and monitoring another flight crew member is often more fatiguing than regular operations[2].

In the days prior to the accident, the student pilot was reportedly working into the night studying PPL theory. In conjunction with the flight operations and other training activities conducted during training days, this could have resulted in duty limits[3] being exceeded. However, it was not possible to obtain an accurate record of the amount of time either pilot spent on ground operations, including PPL study.

Helicopter information

The Robinson Helicopter Company (RHC) R44 Raven I is a four-seat, piston-engine helicopter, powered by a Lycoming O-540-F series six-cylinder carburetted engine. At the end of 2020, there were 566 R44 helicopters on the Australian civil aircraft register.

The R44 Raven I helicopter involved in the accident, serial number 2615, was built in May 2020 in the United States. The helicopter was first placed on the Australian register as VH-HGU on 10 July 2020.

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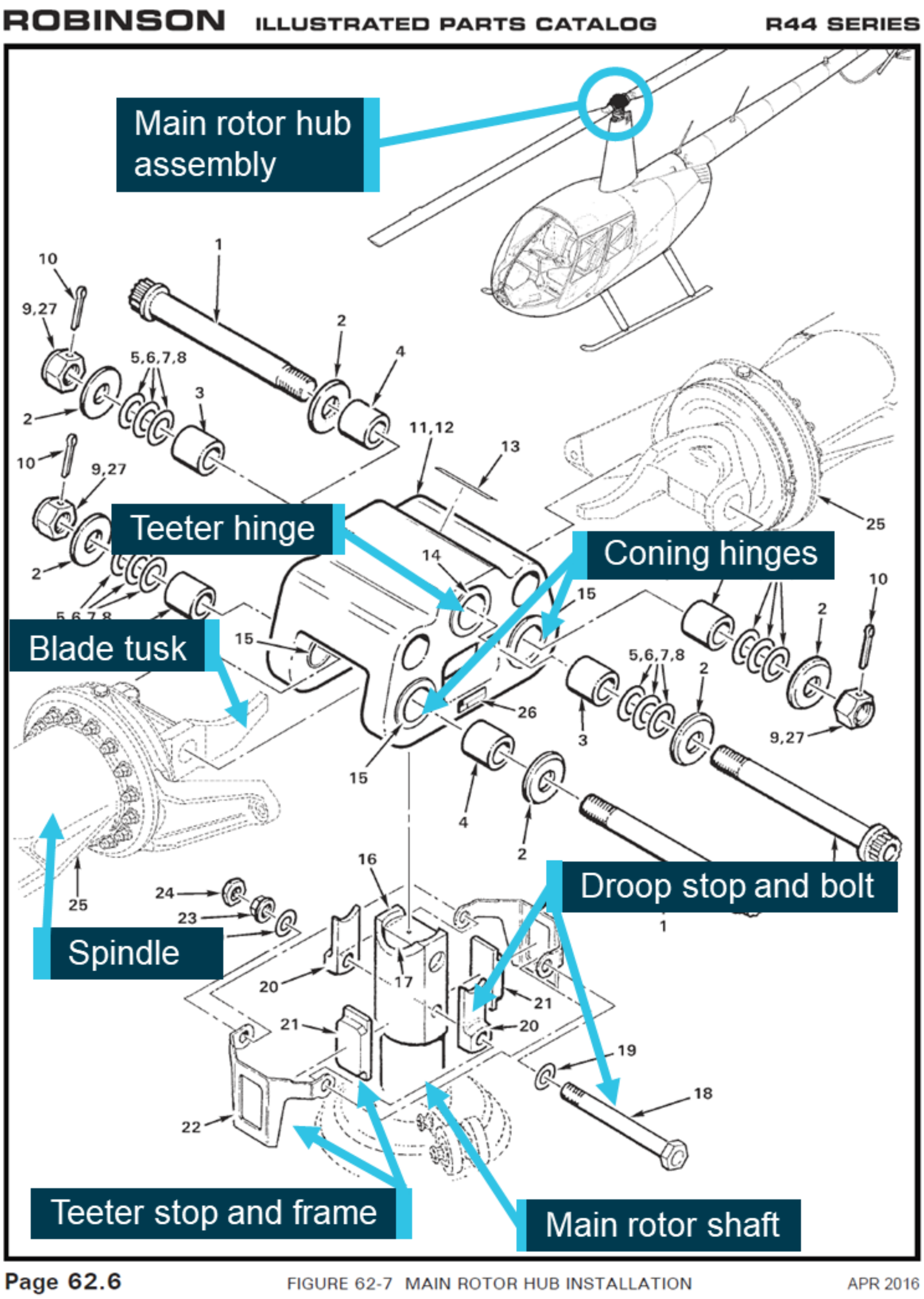
2 CAAP 48-01 (2020), paragraph 5.3.6.

3 Regulatory duty limits manage the effects of fatigue on a pilot, such as Civil Aviation Order 48.1.

Rotor system

The Robinson R44 main rotor hub assembly design is a semi-rigid rotor head, otherwise known as a teetering rotor head (Figure 2). Bolts secure the blades to the hub at the coning hinges. During stopping and starting of the main rotor, when rpm is low, the blade tusks rest against the droop stops, restricting teetering and preventing the blades from drooping. As the main rotor rpm increases, the blades become rigid and straighten due to rotational forces, and the tusks shift off the droop stop as the blades lift. During normal flight, the rotor is free to teeter and flap around its designed flight axis via the teeter hinge, while polyurethane teeter stops limit the degree of teetering.

Figure 2: R44 main rotor hub assembly



Source: Robinson Helicopters, annotated by the ATSB

Under certain specific flight conditions, semi-rigid rotor systems are susceptible to extreme teetering where the blades teeter beyond their normal operational range, resulting in a what is commonly known as 'mast bumping'. Mast bumping is the act of the inboard end of the blade (the spindle) contacting the main rotor shaft. In R44 helicopters, this can generally be identified by extensive damage to the teeter stops and varying degrees of damage to the main rotor shaft. Extreme teetering will also result in failure of one or both pitch links,[4] allowing uncontrolled pitching of the blade(s). This allows the blade(s) to deviate from their normal path of rotation.

Maintenance

The operator was using the RHC R44 manual suite to maintain VH-HGU. The most recent maintenance release was not recovered from the wreckage, but the helicopter had an estimated 150 hours total time in service.

According to RHC, it had received reports of burned intake valves on engines with serial numbers ending in '40E' and less than 500 hours' time-in-service, which included VH-HGU. It noted that a burned valve can result in partial or complete loss of power. On 14 October 2020, RHC issued a safety alert for engine intake valves installed on O-540-F1B5 engines. The alert stated:

> Pilots should observe the following precautions:
>
> 1. Perform a complete run up and stabilized hover check prior to every flight. Do not initiate flight if there is any indication of engine roughness or sudden yaw.
>
> 2. If engine roughness or a sudden yaw occurs in flight, land as soon as practical and be prepared to land immediately.

The intake valves were inspected and a compression check was conducted at a recent periodic inspection (about 101 hours total time in service), with no issues identified.

Meteorological information

Weather forecast

The Goulburn aerodrome forecast (TAF)[5] for the day of the accident predicted clear conditions up until a change at about 1600, which was expected to bring 13 kt easterly winds and broken cloud with a base 2,000 ft above ground level (AGL). The cloud was expected to descend to 1,000 ft AGL over the next few hours following the change.

The flight took place on the borders of several Graphical Area Forecasts[6] (GAF) with different predicted conditions. Forecast conditions issued at 1515 and valid from 1600 indicated some areas of:

- greater than 10 km visibility
- isolated drizzle, rain and thunderstorms reducing visibility, with associated broken cumulous and stratocumulus clouds as low as 2,000 ft above mean sea level (AMSL)
- isolated drizzle with broken stratus clouds between 1,000 and 2,000 ft AMSL.

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[4] Pitch links are rods that adjust main rotor blade angles based on pilot control inputs.

[5] 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. The heights referenced in TAFs are heights above the aerodrome reference point (ground)

[6] Graphical Area Forecast (GAF) provides information on weather, cloud, visibility, icing, turbulence and freezing level in a graphical layout with supporting text. These are produced for 10 areas across Australia, broadly State-based.

Reported weather conditions

The Bureau of Meteorology (BoM) provided METAR[7] and SPECI[8] data from Goulburn and Moss Vale aerodromes, located 31 km west and 43 km north-east of the accident site, respectively. These were the two automatic weather stations closest to the accident site, but indicated significantly different weather conditions—at the time of the accident and 1 hour prior.

Between 1530 and 1630, the METARs for Goulburn aerodrome recorded the wind varying in direction from 290° to 340°, up to 9 kt. The visibility remained greater than 10 km, and the temperature was 25 °C. There was no other significant weather observed. The 1530 METAR at Moss Vale recorded the wind from 080° at 14 kt, and a layer of overcast[9] cloud at 1,800 ft AGL and 2,600 ft AGL.

Based on the Moss Vale observations, a SPECI was first issued at 1538, due to a significant deterioration of cloud conditions in the area. Conditions at this time included a layer of broken cloud at 1,300 ft AGL and overcast layer at 2,000 ft AGL. The SPECI issued at 1600 included a layer of broken cloud at 1,100 ft AGL an overcast layer at 1,800 ft AGL. These conditions continued to deteriorate for several hours.

Bureau of Meteorology analysis

The BoM provided an analysis of the likely weather conditions based on nearby observations and the geographical features of the accident location, such as the valley. It estimated that the weather change would have arrived at the accident site between 1540 and 1610. It would then have taken 30 minutes or more for the change to pass.

Before the change, the BoM determined that conditions would probably have been fine and clear with light to moderate winds. Low cloud and turbulence would not have been expected. Similarly, after the change, conditions would likely have been clear, with cloud probably not developing until approximately 1630.

At the time of the change, however, the BoM predicted the possibility of a short period of moderate or greater low-level windshear and turbulence. As the change moved across the area, it noted that low-level vertical windshear of 20 kt or more would be expected, with possible turbulence and rotor winds[10] induced by the local terrain.

Recorded information

The ADS-B transmissions detected during the accident flight provided the helicopter's track after departing Goulburn towards the Bungonia State Conservation Area. The last recorded transmission at 1611 indicated that the helicopter was descending into a system of valleys, approximately 4 km southeast of where it later impacted terrain.

The training operation regularly used OzRunways[11] for flight planning and tracking, however there was no data recorded for the accident flight. There were no other recording devices fitted to the

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7 METAR: A meteorological report for an aerodrome at a routine time (half hourly) when conditions are better than specified thresholds

8 SPECI: A weather report for an aerodrome or significant location issued whenever weather conditions fluctuate below specified criteria.

9 Cloud cover: in aviation, cloud cover is reported using words that denote the extent of the cover— 'scattered' indicates that 3 to 4 eights of the sky in covered by cloud, 'broken' indicates that more than half to almost all the sky is covered, and 'overcast' indicates that all the sky is covered.

10 Rotor winds are a type of turbulence associated with mountain waves—a weather phenomenon involving winds flowing over mountain ranges.

11 The OzRunways application is a portable information system for flight deck crew members which allows storing, updating, delivering, displaying and/or computing digital data to support flight operations or duties. It provides the option for live flight tracking by transmitting the device's position and altitude.

aircraft, and data from personal electronic devices found at the accident site could not be recovered.

In early 2021, RHC introduced cockpit video cameras, standard on the R66 and optional for the R22 and R44. The forward-facing camera records video (encompassing view through the windshield, pilot controls and the instrument panel), intercom audio, radio transmission and GPS data. RHC advised the recordings (up to 10 hours) can be used as a training tool, maintenance aid, or aerial-tour souvenir. VH-HGU did not have a cockpit video camera installed.

Purpose of the flight

There was nothing in either pilot's logbook or the training syllabus to indicate the purpose of the accident flight. The chief pilot—who was also the owner of the training operation—reported that the flight was likely to provide the student with area familiarisation. Previous students of the instructor were asked about any similar flights during their training—none had any recollection of such a flight. However, these students trained in regions without any substantial mountain ranges or valley systems nearby.

Without any documentation or recorded information to indicate the purpose of the flight, it could not be determined which pilot might have been flying the helicopter at the time of the accident.

Wreckage and impact information

Accident site and distribution of wreckage

The accident site was located about 31 km east of Goulburn Airport, near the bottom of a valley in the Bungonia State Conservation Area. The valley was about 1 km wide and 500 m deep.

The wreckage trail was approximately 275 m long on a south-easterly heading, parallel to the river. Figure 3 shows the location of the wreckage and calculated direction of flight prior to impact, as well as the helicopter's last detected ADS-B transmission.

Figure 3: Wreckage trail and final ADS-B transmission from VH-HGU

Orange arrows show the aircraft heading at its last transmission point and prior to the break-up. Heading at its last transmission point was determined using ADS-B data, while the heading prior to the break-up was estimated based on the direction of wreckage and damage to trees around the accident site.
Source: Google earth, annotated by the ATSB

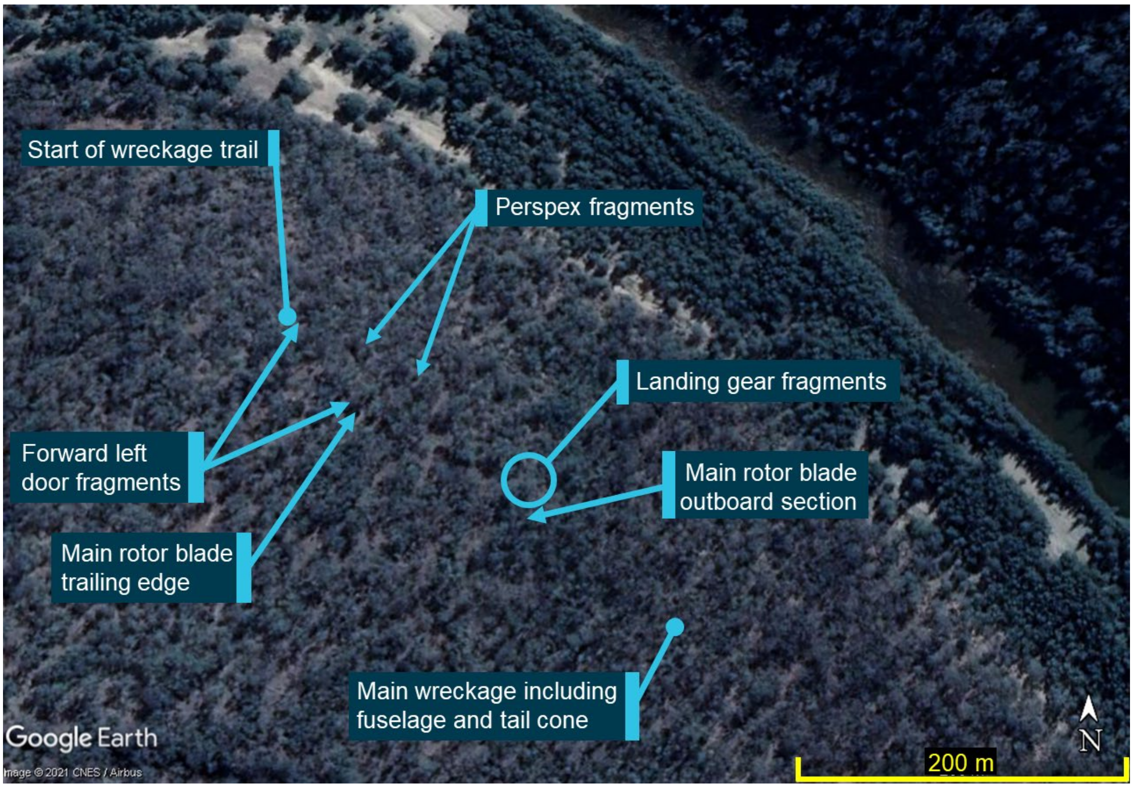
The start of the wreckage trail consisted of:

- multiple pieces of windshield Perspex
- fragments of the forward left door
- a small piece of main rotor blade trailing edge skin
- left landing gear skid toe cap
- covers for the left and forward sections of the landing gear.

Extensive examination of surrounding vegetation identified no evidence of a tree strike at the start of the wreckage trail.

Figure 4 shows the locations of some of the components identified in the wreckage trail. An outboard section of one main rotor blade was located about halfway along the debris trail, along with liberated pieces of landing gear skids and struts. Damage to vegetation commenced about 20 m prior to the impact zone and was consistent with a relatively shallow descent profile. Impact forces likely ruptured the crash-resistant fuel tanks and an intense fire ensued, destroying the fuselage, engine and main gearbox. The fire zone was about 10 m in diameter. The tail cone assembly was situated a few metres to the west of the fire zone, and was unaffected by the fire. All extremities of the helicopter were identified.

Figure 4: Location of aircraft components following in-flight break-up



Source: Google earth, annotated by the ATSB

Wreckage examination

Fuselage

The fuselage was upright, but almost entirely destroyed by the fire. The few flight instruments that were identifiable did not exhibit any witness marks that could assist the investigation. All of the seat belt buckles were found in the secure (closed) configuration, but the belt webbing had perished in the fire.

Main rotor drive and hydraulics

The main rotor drive assembly was primarily intact, however, the intense heat of the post-impact fire had reduced the integrity of the mounts, and the assembly had collapsed. Examination of the main gearbox did not identify any pre-existing condition that could have affected its operation.

Damage due to impact forces and fire also prevented a complete examination of the hydraulic system. However, a hydraulic system failure should not result in a loss of control or in-flight break-up.

Engine

Examination of the severely fire damaged engine and clutch assembly identified no pre-existing issues that might have affected operations. The cooling fan exhibited some rotational scoring, consistent with the engine operating up to the point of impact. Based on the presence of fire and a fuel odour present during the on-site examination, there was a considerable amount of fuel on board at the time of the break-up

Various engine components—including the throttle and magnetos—were identified, however, the fire damage prevented complete examination. The engine was retained for further examination (see section titled *Engine inspection*).

Flight controls

Most of the flight control tubes had melted in the fire. Those that were recovered showed fractures consistent with overstress due to the impact. Without all flight control tubes, examination of the bellcranks was used to confirm flight control continuity from the main rotor hub through to the tail rotor—The steel rod ends were securely attached despite the control rod having melted. Damage to the pilot dual flight controls did not provide any indication as to whether the left or right seat pilot was in control.

Main rotor assembly

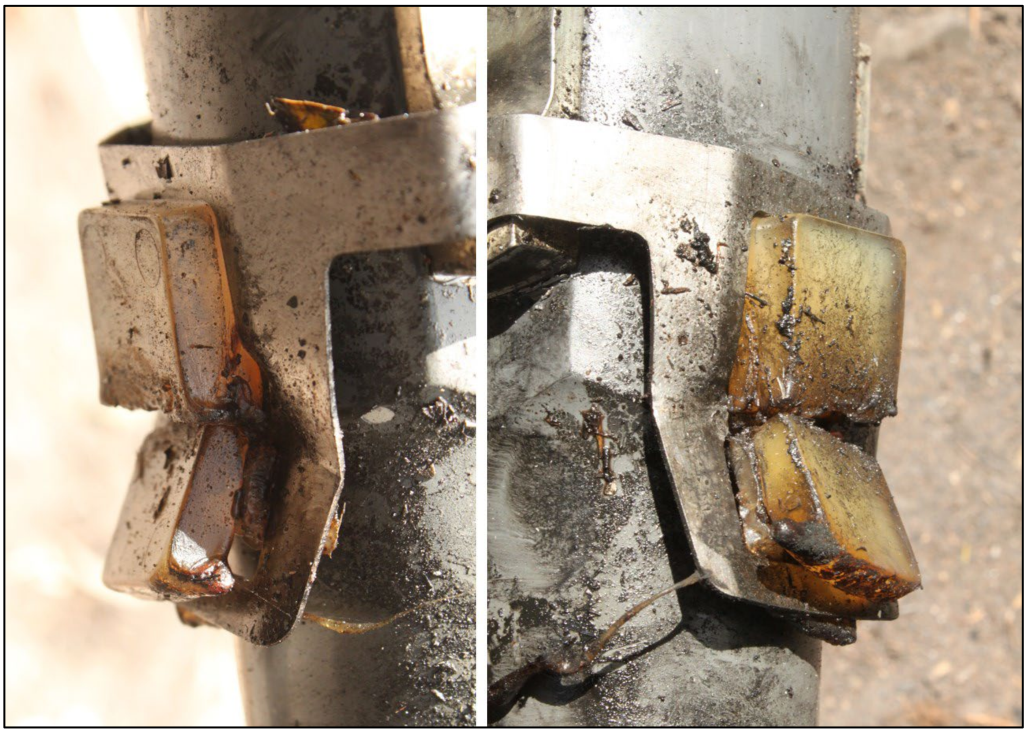
The main rotor hub was secured to the mast, and both spindles—including an inboard portion of each main rotor blade—were attached. Both main rotor pitch links had failed in overstress at the upper rod end thread, probably as a result of extreme teetering. The pitch link rod ends were secured to their respective pitch horns. The remainder of the pitch links were secured to the swashplate. Both spindles could be rotated freely about their axis of operation.

The coning hinge bolts were removed to allow removal of the spindles and remains of the main rotor blades (designated red and blue) from the main rotor hub (MRH). While the MRH attachment point on the red rotor blade was undamaged, the blue rotor blade tusk had been severely deformed (bent downwards nearly 90°), and the coning hinge bolt bore was split open as a result. This damage is shown in Figure 5, with the undamaged tusk from the red rotor blade for comparison. Following removal of the MRH, the teeter stops were seen to exhibit damage consistent with severe impact from the blade spindles, shown in Figure 6.

Figure 5: Blue blade tusk and coning hinge bolt bore

Source: ATSB

Figure 6: Teeter stop damage



Source: ATSB

The underside of the blue main rotor blade exhibited impact damage and a witness mark consistent with the dimensions of a landing gear strut. In addition, the forward left landing strut showed some scrapes and scuff marks. The location of the damage on the blade was consistent with the measured distance of the left forward strut from the main rotor hub. Some yellow paint transfer was noted on the forward section of the left skid, consistent with a main rotor strike.

Figure 7: Damage to the blue main rotor blade and the forward left landing strut

Source: ATSB

Tail cone

On-site examination of the separated tail cone assembly, including tail rotor drive components and flight control surfaces identified no pre-existing anomalies that could have contributed to a loss of control. In addition, black paint transfer was noted on the tail cone, just aft of where it had separated from the fuselage. The red main rotor blade had impact marks consistent with the rivet pattern at that location, including comparative distance from the main rotor hub. The paint transfer and rivet marks were indicative of tail cone separation due to a main rotor blade strike, likely just prior to the collision with terrain. The black paint was from the underside of the main rotor blade, indicating that it was inverted due to the fractured pitch link.

Engine inspection

The engine examination was carried out at a maintenance facility under ATSB supervision. Extensive impact and fire damage prevented the inspection and testing of electrical and fuel system components. In addition, heat distortion of cylinders and pistons limited the teardown to the removal of two cylinders. Borescope inspection was utilised to examine the remainder of engine internals.

There was no evidence found to indicate:

- catastrophic mechanical failure
- oil starvation to the crankshaft journals and conrod bearings
- damage to the valves, valve faces or cylinder bore.

While a transient engine condition such as a partial or complete power loss could not be ruled out, no evidence was found to indicate that the engine was not capable of operating normally.

Summary

Distribution of the wreckage, damage to the main rotor system, and damage to the fuselage and skids are all consistent with a main rotor blade striking the left forward fuselage at the commencement of an in-flight break-up.

Examination of the wreckage did not identify any pre-existing issues with the helicopter that could have contributed to:

- loss of control
- engine power loss
- in-flight break-up.

Comments from the manufacturer

According to RHC, the damage observed was consistent with an extreme teetering event leading to mast bumping. It described the two different scenarios below to explain further:

Low rotor rpm mast bumping

In a low rotor rpm situation, the main rotor disc can start to cone, and subsequent mast bumping events tend to result in the main rotor striking the tail cone, often leading to separation of the tail.

Low-G mast bumping

RHC stated that extreme teetering and subsequent mast bumping can result from the pilot attempting to recover from an uncommanded right roll while in a low-G condition. This condition is expanded in the section below (see the section titled *The low-G condition*). RHC stated that inappropriate recovery control inputs often resulted in the main rotor blade impacting the forward left side of the fuselage.

In the case of VH-HGU, RHC concluded from the available evidence that mast bumping was the result of an extreme cyclic input while in a low-G condition. However, there was insufficient evidence to determine whether low-G was induced by a pilot input, turbulence or a combination of both.

The low-G condition

'G' or 'g' is an abbreviation for the acceleration due to the earth's gravity. Positive G is necessary for helicopters to respond to pilot control inputs. In a low-G condition (that is, approaching the feeling of weightlessness), the pilot's ability to control the attitude of the helicopter is greatly reduced. A low-G condition could be induced by an unusual attitude (for example, if the helicopter was inverted due to spatial disorientation). However, during normal flight, low-G is typically induced either by a cyclic pushover, or by turbulence.

Low-G due to cyclic pushover

The FAA Helicopter Flying Handbook[12] provided a description of how cyclic pushover can induce low-G and ultimately result in a mast bump:

> During a pushover from moderate or high airspeed, as the helicopter noses over, it enters a low-G condition. Thrust is reduced, and the pilot has lost control of fuselage attitude but may not immediately realize it. Tail rotor thrust or other aerodynamic factors will often induce a roll. The pilot still has control of the rotor disk, and may instinctively try to correct the roll, but the fuselage does not respond due to the lack of thrust. If the fuselage is rolling right, and the pilot puts in left cyclic to correct, the combination of fuselage angle to the right and rotor disk angle to the left becomes quite large and may exceed the clearances built into the rotor hub. This results in the hub contacting the rotor mast, which is known as mast bumping.

RHC Safety Notice SN-11[13] provided a descriptive warning about the cyclic pushover manoeuvre described above. It also stated that severe in-flight mast bumping usually results in main rotor shaft separation and/or rotor blade contact with the fuselage. The following warning was included:

> Never attempt to demonstrate or experiment with low-G manoeuvres, regardless of your skill or experience level. Even highly experienced test pilots have been killed investigating the low-G flight condition. Always use great care to avoid any manoeuvre which could result in a low-G condition. Low-G mast bumping accidents are almost always fatal.

Low-G due to turbulence

The FAA Helicopter Flying Handbook stated that 'Turbulence, especially severe downdrafts, can also cause a low-G condition and, when combined with high airspeed, may lead to mast bumping.' RHC Safety Notice SN-32[14] referred to flying in high winds or turbulence, firstly stating that it should be avoided. It continued:

> A pilot's improper application of control inputs in response to turbulence can increase the likelihood of a mast bumping accident.

The following were among RHC's recommendations when encountering turbulence:

- Reduce power and use a slower than normal cruise speed. Mast bumping is less likely at lower airspeeds.
- Avoid flying on the downwind side of hills, ridges, or tall buildings where turbulence will likely be most severe.

In November 2016, RHC released a safety alert[15] reiterating the dangers of cyclic pushovers and the low-G condition, warning against over-reacting or flying too fast when in turbulence. If pilots

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12 FAA Helicopter Flying Handbook, Chapter 11: Helicopter Emergencies and Hazards
13 RHC Safety Notice SN-11: Low-G Pushovers – Extremely Dangerous
14 RHC Safety Notice SN-32: High Winds or Turbulence
15 RHC Safety Alert: Low-G Mast Bumping Accidents

found themselves flying in the low-G condition, RHC recommended the application of gentle aft cyclic in order to reload the rotor.

Previous occurrences

There have been a number of fatal mast bumping accidents involving helicopters with semi-rigid rotor heads worldwide. A review of occurrences in Australia, New Zealand and the United States identified the following accidents, dating back to 1983:

- In New Zealand, there have been 12 fatal mast bumping accidents, all involving RHC helicopters, 6 of which have been deemed low-G accidents.
- In the United States, there have been 18 fatal accidents where mast bumping was the primary occurrence. Eleven of those accidents involved RHC helicopters.
- In Australia, there has been one other known fatal mast bumping accident.[16] It was determined to be induced by low rpm rather than low-G.

Many of the low-G fatal mast bumping accidents in New Zealand and the United States share other similarities with the in-flight break-up of VH-HGU. Two such accident investigations by the New Zealand Transport Accident Investigation Commission (TAIC) are summarised below:

Loss of control, R44 helicopter ZK-HTB, New Zealand (AO-2018-006)

The helicopter was travelling to Upper Estuary Burn Valley when it departed controlled fight and crashed into Lake Wanaka, fatally injuring the pilot who was the sole occupant. Wreckage examination found signs of mast bumping, including teeter stop damage and evidence of the main rotor striking the canopy, however it was not conclusively determined to be an initiator of the occurrence. With regard to turbulence, the report stated:

> Turbulence is a known contributor to mast bumping. Large, sudden upward or downward gusts can upset a helicopter and cause the blades to flap up or down excessively, or cause a low-G situation. Inappropriate or inadvertent pilot inputs or over-controlling by the pilot can further exacerbate the effects of the turbulence.

The investigation found that the helicopter probably encountered turbulence that was strong enough to have resulted in the in-flight break-up of the helicopter. The report also made note of the lack of available data regarding mast bumping accidents in RHC helicopters

In-flight break-up, R44 helicopter ZK-IPY, New Zealand (AO-2015-002)

The helicopter was returning to Queenstown from a training flight when it broke up in mid-air and crashed near the Lochy River, fatally injuring the instructor and student. The break-up occurred after a main rotor blade struck the cabin due to mast bumping. The investigation report stated that mast bumping was typically caused by one or a combination of the following factors:

- low main rotor rpm
- the helicopter entering a low-G condition
- turbulence
- the pilot making large and abrupt movements with the helicopter controls.

The report noted that a low-G scenario could have been induced by a combination of airspeed and the pilot's response to turbulence. In a safety recommendation, TAIC stated:

> The uncertainty around the circumstances of this accident are not unique. The nature of mast bump accidents is that they are usually fatal, leaving no one to explain what was happening at the time. In-

[16] AO-2016-156: In-flight break-up involving Robinson R44, VH-ZNZ, 41 km NW Mossman, Queensland, on 18 November 2016

> flight break-ups are destructive, making it difficult to determine with certainty whether mechanical failures of some kind could have initiated the mast bumps.

The report included a recommendation emphasising '…the need for cockpit video recorders and/or other forms of data capture in the cockpits of certain classes of helicopter to address this safety issue [mast bumping]'. The report identified the following key lesson:

> Helicopter pilots must be fully aware that a condition of low-G (feeling of lightness or weightlessness) can result in: a rapid right roll; mast bumping; and in-flight break-up before even the most experienced pilot can react and recover the situation. Pilots need to fly in a manner that avoids low-G conditions rather than allow them to develop and then expect that they can recover from them.

Safety analysis

Introduction

While flying in the vicinity of a valley in the Bungonia State Conservation Area on the afternoon of 2 December 2020, the R44 helicopter, VH-HGU, experienced an in-flight break-up. As a result, both pilots were fatally injured, and the helicopter was destroyed.

Although fire and impact damage had destroyed some parts of the helicopter, the ATSB was able to use available evidence to make certain important findings. Components recovered near the beginning of the wreckage trail indicated that a main rotor blade had struck the left side of the fuselage at the beginning of the break-up sequence. No evidence was found to indicate pre-existing mechanical defects or issues that could have prevented normal engine operation. While a transient condition such as a partial or complete power loss could not be ruled out, such an event should not have resulted in an in-flight break-up.

The investigation considered the possibility of clouds or reduced visibility forcing a descent. However, a Bureau of Meteorology (BoM) analysis of the weather conditions indicated that low cloud would not have created difficulties until after the time of the accident. Further, any unfavourable weather coming with the easterly change would not have prevented the pilots from safely returning to Goulburn at any point.

As there were no survivors and no available records, the purpose of the flight could not be determined, nor which pilot had been flying the helicopter. For the same reason, their working hours that day and in the preceding days could not be ascertained. While the nature of their work and work patterns in terms of overall duty hours and time spent on ground operations suggested that both pilots could have been at risk of fatigue, there was insufficient evidence to determine whether or not fatigue was a factor in this accident.

The following analysis focuses on factors that probably contributed to the in-flight break-up, which include the low-G condition in helicopters with semi-rigid rotor heads, the effects of turbulence, and the influence of control inputs (pilot actions) in such conditions.

Helicopter entered low-G

The broken teeter stops, failed pitch links, bent tusk and blade impact damage were consistent with the low-G mast bumping scenario described by the Robinson Helicopter Company (RHC). The damage was also similar to many other in-flight break-up incidents that were the result of extreme teetering after entering a low-G condition.

There have been several fatal mast bumping accidents where turbulence has probably contributed to inducing a low-G scenario. While not a necessary condition to enter low-G, the Federal Aviation Administration has stated that turbulence can induce a low-G condition. RHC has also stated that turbulence can contribute to a low-G mast bumping event and encourages pilots to avoid the severe turbulence associated with flying on downwind side of hills and ridges.

Based on the weather and the geographical conditions at the accident location, the BoM analysis noted the potential for windshear and moderate or greater turbulence at the time of the accident, dependent on the arrival of a weather change. It is likely but not certain that turbulence was present in the area at the time of the break-up. The various weather forecasts showed differing conditions, but it could not be determined which, if any, the pilots checked before departure nor the conditions that they were expecting.

While the evidence shows that VH-HGU entered a low-G condition, it was not possible to determine the contribution that turbulence or incorrect/inappropriate pilot control inputs (for example, initiating a cyclic pushover) had in triggering the condition. However, one or both of these factors must have been present.

In-flight break-up following low-G

While it has been well established that a low-G condition can result in mast bumping and an in-flight break-up, there remains some uncertainty regarding a pilot's ability to recover from a low-G situation, and whether inappropriate recovery control inputs are necessary for an accident to occur.

Both RHC and New Zealand's Transport Accident Investigation Commission (TAIC) have acknowledged that turbulence and airspeed can contribute to a low-G mast bump and subsequent in-flight break-up. The latter has identified turbulence as a sufficient condition for low-G mast bumping to occur and stated that certain low-G situations can lead to mast bumping and in-flight break-up before a pilot can reasonably react. Conversely, RHC has stated that turbulence only results in mast bumping when pilots react with inappropriate control inputs. However, it should be noted that according to RHC, even highly experienced test pilots have sometimes failed to recover from a low-G condition.

In this accident, once the helicopter entered a low-G condition, inappropriate recovery control inputs probably contributed to the mast bumping and subsequent in-flight break-up. Following the right roll that can be induced by low-G, either pilot could have reacted by instinctively applying left cyclic, rather than the gentle aft cyclic recommended by RHC. Extreme teetering, potentially in combination with broken pitch links resulted in the main rotor striking the fuselage and the helicopter breaking up in flight.

Video recorders

Throughout the accident sequence, the relative contribution of turbulence and pilot actions could not be determined due to the lack of available evidence. This lack of evidence is common to many previous low-G mast bumping accidents. While the post-impact fire in this accident would probably have destroyed recorded data, including readily available cockpit video recorders on helicopters with semi-rigid rotor heads would provide valuable insights into low-G mast bumping events, and help to prevent future occurrences.

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 break-up of Robinson R44 VH-HGU on 2 December 2020.

Contributing factors

- While flying in the vicinity of the valley, the helicopter entered a low-G condition due to turbulence, inappropriate control inputs, or a combination of both.
- The low-G condition, probably in combination with inappropriate recovery control inputs resulted in extreme teetering of the main rotor and subsequent in-flight break-up.

Other findings

- No evidence was found to indicate that the helicopter was not capable of normal operation prior to the in-flight break-up.
- In helicopters with semi-rigid rotor heads, the circumstances leading to in-flight break-ups from mast bumping and extreme teetering are not well understood. Recorded cockpit imagery could provide valuable insight for understanding the effect that weather conditions and pilot input has in these occurrences.

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.

Safety action by Hughes Helicopters

Following this accident, Hughes Helicopters placed a limit of 6 consecutive training days on the intensive flight training course. An online flight and duty system has been introduced so that the head of operations can monitor and adjust the duty periods and hours flown by students and instructors. Instructors will be continuously monitoring student fatigue levels and adjusting the training program accordingly.

Safety action by the Robinson Helicopter Company

In 2022, video and audio recorders that were already equipped on R66 models became standard equipment on all new production R44 models and optional on R22 models. In 2023, the recorders will be standard on all three models and retrofit kits will be available.

General details

Occurrence details

Date and time:	02 December 2020 16:30 EDT	
Occurrence class:	Accident	
Occurrence categories:	In-flight break-up	
Location:	31 km east of Goulburn Airport	
	Latitude: 34°46'42.0"S	Longitude: 150°03'45.9"E

Aircraft details

Manufacturer and model:	Robinson Helicopter Company R44	
Registration:	VH-HGU	
Operator:	Hughes Helicopters	
Serial number:	2615	
Type of operation:	Flying Training	
Activity:	General aviation – Instructional Flying	
Departure:	Goulburn Airport, New South Wales	
Destination:	Goulburn Airport, New South Wales	
Persons on board:	Crew – 2	Passengers – Nil
Injuries:	Crew – 2 (fatal)	Passengers – Nil
Aircraft damage:	Destroyed	

Glossary

ADS-B	Automatic dependent surveillance broadcast
AGL	Above ground level
BoM	Bureau of Meteorology
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulations
FAA	Federal Aviation Administration
GAF	Graphical area forecast. Provides information on weather, cloud, visibility, icing, turbulence and freezing level in a graphical layout with supporting text. These are produced for 10 areas across Australia, broadly State-based.
ICAO	International Civil Aviation Organisation
JRCC	Joint Rescue Coordination Centre
METAR	A meteorological report for an aerodrome at a routine time (half hourly) when conditions are better than specified thresholds.
MRH	Main rotor hub
NTSB	National Transportation Safety Board
PPL	Private pilot licence
RHC	Robinson Helicopter Company
RPM	Revolutions per minute
SPECI	A weather report for an aerodrome or significant location issued whenever weather conditions fluctuate below specified criteria.
TAF	Aerodrome forecast. 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.
TAIC	Transport Accident Investigation Commission

Sources and submissions

Sources of information

The sources of information during the investigation included the:

- chief pilot
- Bureau of Meteorology
- Robinson Helicopter Company
- OzRunways
- maintenance organisation for VH-HGU
- former trainee pilots
- Civil Aviation Safety Authority
- New South Wales Police Force
- New Zealand Transport Accident Investigation Commission
- United States National Transportation Safety Board
- United States Federal Aviation Administration.

References

Civil Aviation Safety Authority (2020); *CAAP 48-01 v3.2 Fatigue management for flight crew members*. D20/103350. Civil Aviation Safety Authority, Canberra, Australia. https://www.casa.gov.au/sites/default/files/2021-08/caap-48-01-fatigue-management-for-flight-crew-members.pdf . Accessed on 16 December 2020

Powell, DMC; Spencer, MB; Holland, D; Broadbent, E and Petrie KJ (2007) Pilot fatigue in short-haul operations; effects of number of sectors, duty length and time of day. *Aviation Space and Environmental Medicine 2007; 78:698-701*.

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 operator
- the Robinson Helicopter Company
- the Civil Aviation Safety Authority
- the United States National Transportation Safety Board.

Submissions were received from:

- the operator
- Robinson Helicopter Company
- Civil Aviation Safety Authority.

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

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.