Final Report AO-2015-002: Mast bump and in-flight break-up,
Robinson R44, ZK-IPY, Lochy River, near Queenstown, 19 February 2015

Final Report

Aviation inquiry AO-2015-002
Mast bump and in-flight break-up, Robinson R44, ZK-IPY
Lochy River, near Queenstown, 19 February 2015

Approved for publication: July 2016

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

The Transport Accident Investigation Commission (Commission) is a standing commission of inquiry and an independent Crown entity responsible for inquiring into maritime, aviation and rail accidents and incidents for New Zealand, and co-ordinating and co-operating with other accident investigation organisations overseas. The principal purpose of its inquiries is to determine the circumstances and causes of occurrences with a view to avoiding similar occurrences in the future. Its purpose is not to ascribe blame to any person or agency or to pursue (or to assist an agency to pursue) criminal, civil or regulatory action against a person or agency. The Commission carries out its purpose by informing members of the transport sector and the public, both domestically and internationally, of the lessons that can be learnt from transport accidents and incidents.

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Important notes

Nature of the final report

This final report has not been prepared for the purpose of supporting any criminal, civil or regulatory action against any person or agency. The Transport Accident Investigation Commission Act 1990 makes this final report inadmissible as evidence in any proceedings with the exception of a Coroner's inquest.

Ownership of report

Citations and referencing

Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1980 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publicly available are cited.

Photographs, diagrams, pictures

Unless otherwise specified, photographs, diagrams and pictures included in this final report are provided by, and owned by, the Commission.

Verbal probability expressions

The expressions listed in the following table are used in this report to describe the degree of probability (or likelihood) that an event happened or a condition existed in support of a hypothesis.

Terminology (adopted from the Intergovernmental Panel on Climate Change)	Likelihood of the occurrence/outcome	Equivalent terms
Virtually certain	> 99% probability of occurrence	Almost certain
Very likely	> 90% probability	Highly likely, very probable
Likely	> 66% probability	Probable
About as likely as not	33% to 66% probability	More or less likely
Unlikely	< 33% probability	Improbable
Very unlikely	< 10% probability	Highly unlikely
Exceptionally unlikely	< 1% probability	

R44 Raven II ZK-IPY

(Courtesy of Over The Top)

Source: mapsof.net

Location of accident

Contents

Abbreviations ii
Glossary iii
Data summary iv
1. Executive summary 1
2. Conduct of the inquiry 2
3. Factual information 4
3.1. Narrative 4
3.2. Site information 6
3.3. Aircraft information 9
Wreckage examination 9
3.4. Personnel information 12
3.5. Meteorological information 14
3.6. Operator information 14
3.7. Additional information 15
Robinson helicopters 15
Rotor head design 15
Mast bumping 17
4. Analysis 20
4.1. Introduction 20
4.2. What happened 21
Engine or transmission failure 22
Component failure 23
4.3. Mast bumping 23
Low rotor RPM 23
Turbulence 23
Pilot-induced low-G 24
Helicopter speed/power setting 25
Training and awareness 26
4.4. Emergency locator transmitter (ELT) 27
5. Findings 28
6. Safety actions 29
General 29
Safety actions addressing safety issues identified during an inquiry 29
Safety actions addressing other safety issues 30
7. Recommendations 31
General 31
Recommendation 31
8. Key lesson identified 33
9. Citations 34
Appendix 1: Review of mast bumping accidents in New Zealand 35
Appendix 2: *Robinson Helicopter Fleet Consultation Document* results 37

Appendix 3: Detailed summary of wreckage examination and testing 38
Appendix 4: Robinson Safety Notices... 42

Figures

Figure 1 Tracking data for R44 ZK-IPY 5
Figure 2 Accident site 6
Figure 3 Lochy River – looking downstream (north-east) 7
Figure 4 Main items of wreckage 8
Figure 5 Main rotor head showing broken components and extreme flapping of blades 11
Figure 6 Main rotor blade damage 12
Figure 7 R44 rotor head 17
Figure 8 Main rotor blade strike on rear of left skid 21
Figure 9 Track presentation and accident location 25
Figure 10 Main rotor head showing broken components and extreme flapping of blades 40
Figure 11 Main rotor blade damage 40

Abbreviations

ATSB	Australian Transport Safety Bureau
CAA	Civil Aviation Authority of New Zealand
Commission	Transport Accident Investigation Commission
ELT	emergency locator transmitter
FAA	Federal Aviation Administration (of the United States)
ICAO	International Civil Aviation Organization
km	kilometre(s)
m	metre(s)
NTSB	National Transportation Safety Board (of the United States)
Robinson	Robinson Helicopter Company
RPM	revolution(s) per minute
SFAR	Special Federal Aviation Regulation (United States)

Glossary

airworthiness directive	a mandatory instruction to ensure the continued airworthiness of an aircraft or component
autorotation	a condition of flight when the main rotor system is driven by the flow of air up through the main rotor blades, instead of by the engine
centre of gravity	the single point in the helicopter through which the weight (and force of gravity) acts
chord	the distance from the centre of radius of a leading edge to the centre of radius of a trailing edge of a wing or blade
collective lever	the control that changes the pitch angle of the main rotor blades by the same amount and at the same time, which changes the total rotor thrust, usually to effect a climb or descent
coning	the angle formed between the span-wise length of the main rotor blades and their tip path plane, the plane scribed by the tips of the rotors. The angle varies according to the resultant of the centrifugal force due to revolutions per minute and the lift that is demanded
cyclic control	sometimes called the cyclic stick, is the control that changes the pitch angle of the main rotor blades at the same point of their rotation cycle, which causes the rotor disc to tilt in the direction that the pilot has put the stick. The helicopter then moves in that direction
flapping	(in the case of the Robinson main rotor blades) the vertical movement of a blade about a hinge (coning bolt) perpendicular to the blade span
knot	a speed of one nautical mile per hour
low-G	or ‘reduced g’; an acceleration less than that due to the force of gravity
mast	the main rotor drive shaft
mast bump	contact between an inner part of a main rotor blade or a rotor hub and the main rotor drive shaft
rotor disc	the area swept by the rotor blades each revolution
swashplate	a device that translates cyclic and collective control inputs to the main rotor
teeter	the see-saw movement of a two-bladed rotor about the teeter bolt or centrally mounted rotor hub

Data summary

Aircraft particulars

Aircraft registration:	ZK-IPY
Type and serial number:	Robinson Helicopter Company R44 Raven II, 10555
Number and type of engines:	one IO-540-AE1A5 normally aspirated, reciprocating
Year of manufacture:	2004
Operator:	Over The Top Limited
Type of flight:	training
Persons on board:	two
Instructor's licence:	commercial pilot licence (helicopter)
Instructor's age:	42
Instructor's total flying experience:	4,703 hours, including 4,527 on helicopters and 950 hours on type
Student's total flying experience:	10 hours

Date and time	19 February 2015, 1342[1]
Location	Lochy River, near Queenstown
	latitude: 45° 11.15´ south
	longitude: 168° 35.7´ east
Injuries	two fatal
Damage	helicopter destroyed

[1] Times in this report are in New Zealand Daylight Time (co-ordinated universal time + 13 hours) and expressed in the 24-hour format.

1. Executive summary

1.1. On 19 February 2015, a Robinson R44 helicopter was returning to Queenstown from a training flight when it broke up in mid-air and crashed in bush near the Lochy River, killing the instructor and student.

1.2. The helicopter broke up in mid-air when one of the main rotor blades struck the cabin, which was caused by a phenomenon known as mast bumping, when the inner part of a main rotor blade or the rotor hub contacts the main rotor drive shaft.

1.3. Mast bumping is typically caused by one or a combination of the following factors:

- low main rotor revolutions per minute (RPM)
- the helicopter entering a low-Gravity (low-G) condition (where the occupants might get the feeling of lightness or weightlessness)
- turbulence
- the pilot making large and abrupt movements with the helicopter controls.

1.4. The Transport Accident Investigation Commission (Commission) could not conclusively determine what caused the mast bumping event. We found that it was unlikely to have been a low main rotor RPM event and could find no mechanical defect or failure that could have contributed to the accident.

1.5. The student was about as likely as not to have been flying the helicopter when the accident occurred and the speed of the helicopter was about as likely as not to have been 102 knots or greater as it flew down the valley, returning to Queenstown.

1.6. Although the weather was generally calm and suitable for the training flight, it was about as likely as not that there were pockets of light to moderate turbulence in the area. Light to moderate turbulence should not on its own cause mast bumping, but when combined with a relatively high speed and a pilot's control response to any turbulence, there is a high risk of the helicopter entering a low-G condition, rolling rapidly to the right and suffering a mast bump event before the pilot can react.

1.7. The Commission comments on the safety issue whereby the true causes of mast bumping and in-flight break-ups are often not able to be determined because the accidents are usually fatal and the consequent destructive nature of the accidents makes it difficult to either eliminate or confirm mechanical failure as a cause.

1.8. The Commission has made a recommendation to the Secretary for Transport and given notice to the Director of the New Zealand Civil Aviation Authority to promote, through the appropriate International Civil Aviation Organisation forum, 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.

1.9. The key lesson arising from this inquiry is that 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.

2. Conduct of the inquiry

2.1. At about 1600 on Thursday 19 February 2015, the Civil Aviation Authority (CAA) notified the Transport Accident Investigation Commission (Commission) of the accident. The Commission opened an inquiry under section 13(1)b of the Transport Accident Investigation Commission Act 1990, because it believed that the circumstances of the accident had or were likely to have implications for transport safety, and because the Commission was already inquiring into two other break-ups involving Robinson helicopters.

2.2. An investigation team travelled to Queenstown on the morning of Friday 20 February 2015. The team was given an initial briefing by the Police and arrived at the accident site by helicopter at about 1320. The Police assisted with the site examination and two CAA safety investigators were given approval to conduct a parallel site investigation.

2.3. The wreckage was removed from the accident site late on 21 February 2015 and transported to the Commission's examination and storage facility. Commission investigators remained in the Queenstown area for several days, interviewing witnesses, the operator (Over The Top Limited) and the families of the two victims. Records for the helicopter maintenance and for the pilots' training and experience were collected from the operator.

2.4. On 21 February 2015 the National Transportation Safety Board of the United States (NTSB) appointed an Accredited Representative to the inquiry in accordance with the provisions of Annex 13 to the Convention on International Civil Aviation.[2] The Accredited Representative appointed two senior air safety investigators from Robinson Helicopter Company (Robinson) as technical advisors, one of whom travelled to New Zealand to assist with the examination of the wreckage.

2.5. One of the main rotor blades had fractured near the change in chord[3] – the point where the blade dimensions changed. The CAA investigators identified that this fracture was in a similar location to that of a suspected fatigue failure in another R44 that the CAA was investigating at the time. On 22 February 2015 the CAA issued an airworthiness directive[4] that grounded R44s fitted with the C016-7 model of main rotor blades in New Zealand. On 23 February sections of the fractured blade from ZK-IPY were taken to a laboratory, where a metallurgist determined that the failure was impact related and not due to fatigue. The CAA then cancelled the airworthiness directive.

2.6. On 26 and 27 February 2015 the investigation team and a Robinson technical advisor examined the wreckage of the helicopter more closely at the Commission's storage facility. On 5 March 2015 the engine was taken to a maintenance facility where a complete teardown examination was performed in the presence of a Commission investigator. The examination included the testing of engine accessories.

2.7. The clutch was subsequently examined by a licensed engineer familiar with the R44 and clutch assembly.

2.8. On 11 March 2015 a representative of the operator was permitted to inspect and photograph the wreckage, under supervision, at the Commission's examination and storage facility.

2.9. On 25 March 2015 the CAA files on the operator, helicopter and instructor were reviewed. A meeting was also held on the same day with CAA staff to discuss this accident and other related Robinson helicopter accidents.

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[2] International Civil Aviation Organisation Annex 13 Aircraft Accident and Incident Investigation, Participation in the Investigation, *Rights*, paragraph 5.18.

[3] The chord is the distance from the centre of radius of a leading edge to the centre of radius of a trailing edge of a wing or blade.

[4] An airworthiness directive is a mandatory instruction to ensure the continued airworthiness of an aircraft or component.

2.10. On 8 June 2015 the Commission requested specialist assistance from the Australian Transport Safety Bureau (ATSB), which opened an investigation and appointed an Accredited Representative and a technical advisor. Both personnel were experienced in accidents involving Robinson helicopters. The technical advisor, a senior investigator, held a licensed aircraft maintenance engineer qualification and a Diploma of Transport Safety Investigation, had completed the Robinson helicopter maintenance course and was trained in fracture analysis.

2.11. On 16-18 June 2015 the ATSB technical advisor examined the wreckage with the investigation team. In the period 8-10 July 2015 the Chief Investigator of Accidents, the investigator in charge, the ATSB Accredited Representative and his technical advisor analysed the available evidence and examined various hypotheses for the accident. Further enquiries were initiated as a result.

2.12. On 31 July 2015 the fractured surfaces of the main rotor blades were sectioned off and sent to the ATSB for examination. On 14 September 2015 the ATSB provided a report to the Commission on that examination.

2.13. On 9 November 2015, on behalf of the operator, a licensed aircraft maintenance engineer with air accident investigation experience examined the wreckage. This took place under the supervision of Commission investigators at the Commission's examination and storage facility.

2.14. The helicopter had been fitted with a TracPlus[5] satellite tracking system. Recorded information from this system was used to help determine the flight path of the helicopter.

2.15. On 27 April 2016 the Commission approved this report for circulation to interested persons for comment. Eight submissions were received and considered by the Commission. Any changes as a result of those submissions have been included in this final report.

2.16. On 4 July 2016 the emergency locator transmitter (ELT) installed in the helicopter was examined by the New Zealand agent for the manufacturer (Kannad) to establish whether it performed as designed.

2.17. The Commission approved this final report for publication on 27 July 2016.

[5] TracPlus Global Limited.

3. Factual information

3.1. Narrative

3.1.1. The Robinson R44 helicopter registered ZK-IPY (the helicopter) was owned and operated by Over The Top Limited (the operator), based in Queenstown. The helicopter was typically used for local scenic flights for two or three passengers, and for familiarisation flights. On Thursday 19 February 2015 the helicopter was not being used and was available for training.

3.1.2. One of the operator's pilots, who was also an instructor, approached the son of the company owner during the morning and asked if he would like to go flying. They had flown together the day before as part of *ad hoc* training for the son (referred to hereafter as the student). The student accepted the offer as this was likely to be the last opportunity for a flight before he headed overseas to university.

3.1.3. At about 1225 the helicopter was started and hover-taxied to a nearby refuelling pump, where it was shut down and 94.2 litres of fuel were added. At about 1240 the student called Queenstown tower requesting a take-off clearance.[6] The helicopter was cleared for take-off and instructed to vacate the control zone to Collins Bay not above 6,500 feet.

3.1.4. The air traffic service's surveillance system showed that the helicopter departed the aerodrome at 1243, flying initially to the south before turning right to cross Lake Wakatipu to the north end of Collins Bay. The helicopter steadily climbed to an altitude[7] of 3,050 feet – about 2,000 feet above the lake.

3.1.5. Approaching the far shore, the helicopter descended to about 500 feet above the lake and turned right to fly along the shoreline. The helicopter flew northwest for about one kilometre (km) before reversing direction to fly in a southeast direction just inland of the shore.

3.1.6. A witness, who was herding some sheep close to the shoreline, saw the helicopter approaching after it had crossed the lake. He recognised the helicopter's paint scheme because the operator regularly conducted training at locations around the farm and adjoining properties. The helicopter flew above the witness before returning back towards the southeast. As the helicopter approached the second time the instructor called the witness by mobile phone. They talked briefly, including commenting on the good weather. As the helicopter continued along the shoreline, it climbed steadily before turning inland.

3.1.7. The last surveillance record of the helicopter was at 1252, when the helicopter was flying up Collins Creek, behind Collins Bay, heading towards the Lochy River valley about 3 km away. The helicopter was maintaining about 2,350 feet above mean sea level (about 1,000 feet or 300 metres [m] above the floor of the valley at this point), flying at a groundspeed of about 100 knots.[8]

3.1.8. The helicopter was fitted with a satellite tracking system that every two minutes provided a report of the helicopter's position, altitude and groundspeed. (See paragraph 4.3.19 and on for more information on the tracking system and data.) The tracking data was sent automatically to the operator's base where it could be displayed on a monitor. The data showed that the helicopter entered the Lochy River valley and flew approximately 15 km up the river before conducting various manoeuvres (see Figure 1).

[6] Before departure the student was observed sitting in the right seat and the instructor in the left seat. These were the normal seating positions for an instructional flight.
[7] Altitudes in this report are referenced to mean sea level, while heights are above the terrain.
[8] A knot is a speed of one nautical mile per hour.

Figure 1
Tracking data for R44 ZK-IPY

3.1.9. A farmer and farmhand, who were working several kilometres further up the Lochy River from where the helicopter was operating, observed it flying in what were described as 'circuit-like' manoeuvres. The helicopter would descend and slow, coming to a hover in an open area for a period before taking off and flying around again. These manoeuvres continued for about 35 minutes.

3.1.10. At 1338 the helicopter started flying down the river towards Queenstown, climbing as it followed the valley. The last tracking report was made at 1340:30, when the helicopter was at an altitude of about 2,900 feet, or about 1,200 feet above the ground, and near the centre of the valley. The helicopter groundspeed was 102 knots on a track of 032° True at this time.

3.1.11. The instructor needed to be back in Queenstown by 1400 to meet a potential buyer for one of the operator's other helicopters. The potential buyer was to arrive at this time and after inspecting the helicopter go for a flight with the instructor. At 1347 a staff member called the instructor on the radio to advise that the flight had been cancelled. The staff member was unable to raise a response, so checked the tracking display. She saw that the tracking had stopped some six minutes earlier when the helicopter was still in the Lochy River valley. The staff member talked to management, who had also become concerned about the flight. The staff member then sent a text message to the instructor and student, and phoned the aerodrome tower controller to see if they had contact with the helicopter. The staff member also started an 'Overdue Aircraft Checklist' during this time.

3.1.12. At 1411 three of the operator's staff took off in a second helicopter and headed to the last recorded position of the helicopter. The Police were informed and, in conjunction with the Rescue Coordination Centre, started organising a search. At 1416 the operator's search helicopter entered the Lochy River valley, and shortly afterwards started a search of the area. After finding nothing the operator's search helicopter proceeded up the Lochy River valley where the pilot and passengers located the farmer and farmhand who were returning down the valley along a track. The operator's search helicopter landed near the pair, who advised that the helicopter was last seen heading down the valley.

3.1.13. The farmer was familiar with helicopters and boarded the operator's search helicopter to assist with the search. The farmhand continued down the track and remained in contact using a hand-held radio. The operator's search helicopter spent the next 70 minutes searching the valley and side gullies. The pilot and passengers on the operator's search helicopter heard a faint ELT signal over the radio, but were unable to obtain a bearing on the weak and intermittent signal. At about 1540 the operator's search helicopter was joined by a second helicopter organised by the Rescue Coordination Centre. At about this time the farmhand radioed that he had found some wreckage near the track. The main wreckage was found soon afterwards (see Figure 2). The bodies of the two pilots were found close to the main wreckage. They had died from severe traumatic injuries.

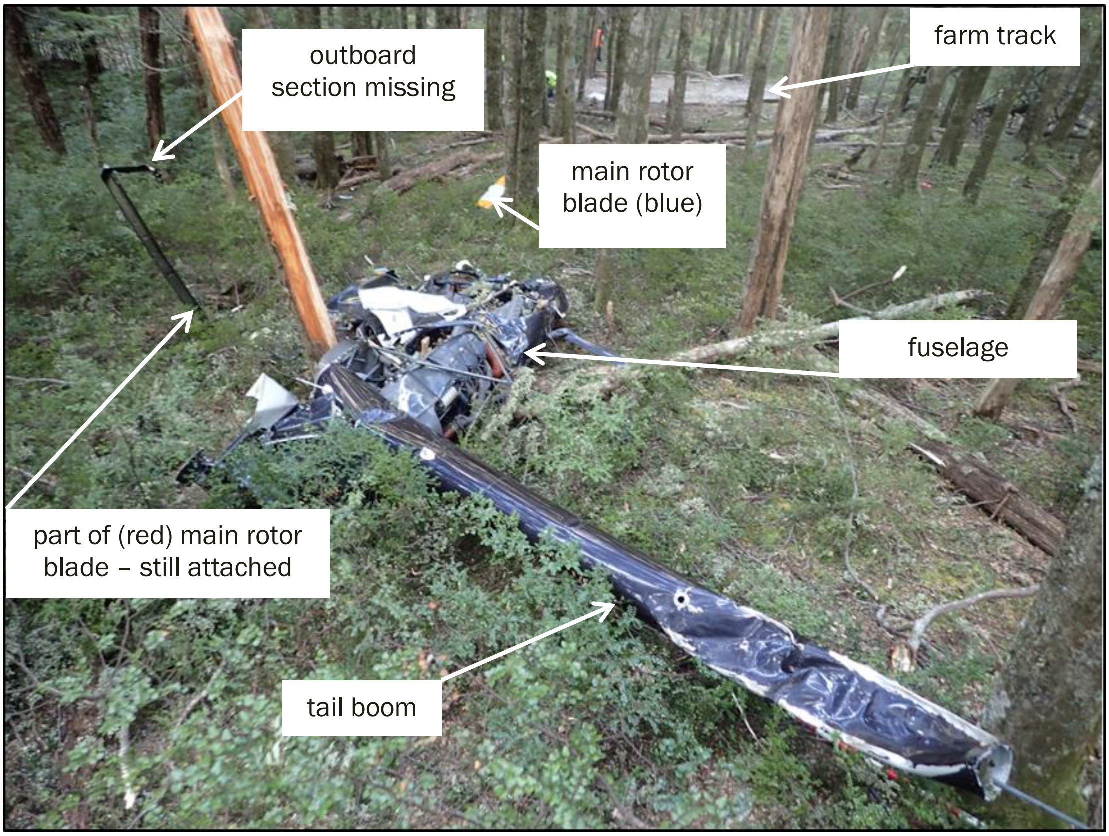

Figure 2
Accident site

3.2. Site information

3.2.1. The accident site was 12 nautical miles (21 km) southwest of Queenstown airport (see Figure 3). The site was on the western side (true left) of the Lochy River, in a narrow section of the valley at an altitude of approximately 1,450 feet (440 m). The immediate area was covered in beech trees approximately 80 feet (25 m) high. The wreckage was spread over an area approximately 200 m by 200 m (see Figure 4). A farm track ran through the centre of the accident site.

3.2.2. From the last known position of the helicopter to the accident site, the first item in the wreckage trail was a rear section of the left skid. To the right of this on the river bed was a radio controller box that had been installed at the base of the instrument panel at the front of the helicopter. The main wreckage, consisting of the fuselage, tail boom, engine, transmission and most of the main rotor, was 110 m further on, approximately 30 m north of the farm track.

3.2.3. Between the start of the wreckage trail and the main wreckage was a range of helicopter components and personal items. These included individual instruments, the upper instrument console, the left cyclic control handle, a tail rotor pedal and footwear. Approximately 100 m to the east of the main wreckage and near the river were the main fuel tank and the outboard

2.3 m of the red main rotor blade.[9] Pieces of Perspex and cabin structure were found throughout the accident site.

3.2.4. Several items were seen suspended in the tree canopy. The largest was a section of fuselage panel from above the engine and behind the main rotor mast.[10] This was recovered by using the rotor downwash from a helicopter to blow the panel free.

3.2.5. The main fuselage was resting nearly upright on the forest floor. It lay against a tree that had significant gouging down one side, consistent with the fuselage having slid down the side of the tree. The tail boom remained partially attached but bent at nearly 90° to the fuselage. The tail rotor assembly and empennage from just forward of the tail rotor gear box had separated and lay 2-3 m from the end of the boom.

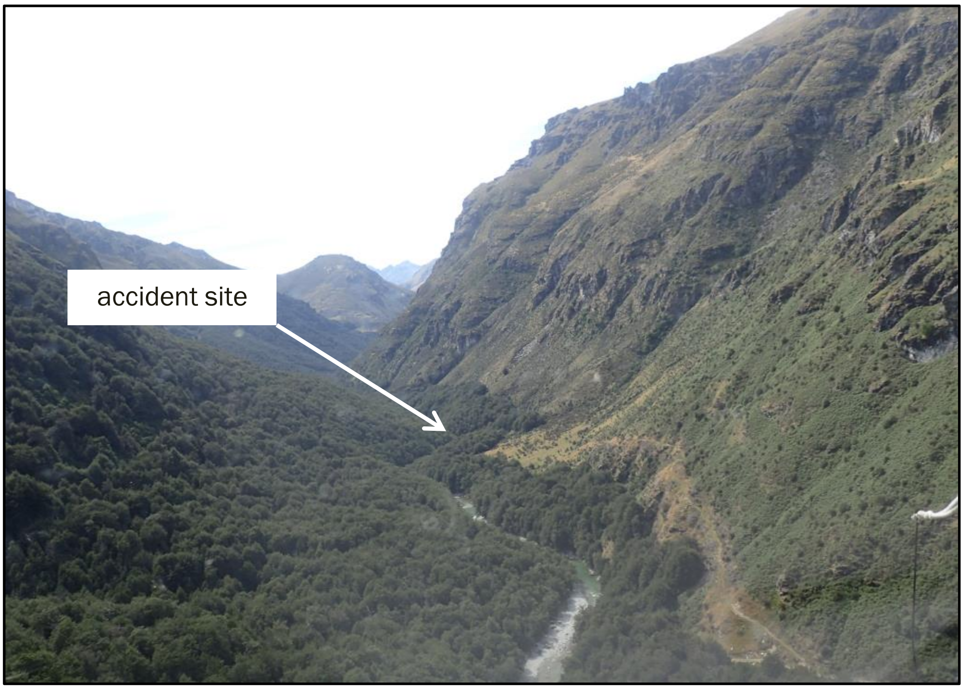

Figure 3
Lochy River – looking downstream (northeast)

[9] The two main rotor blades were identified in the logbook as the blue blade (serial # 3761) and the red blade (serial # 3709).
[10] The mast is the main rotor drive shaft.

Figure 4
Main items of wreckage

3.2.6. The engine, transmission, mast and main rotor hub assembly were still connected but had twisted to the left. The blue main rotor blade had broken off 1.4 m out from the hub. The outboard section, approximately 3.5 m long, lay about 5 m from the fuselage. The red main rotor blade had two 90° downward bends at 0.6 m and 2.5 m from the hub. The blade had separated 0.4 m outboard of the second bend. The separated tip end was found near the river.

3.2.7. The student and instructor had been flung forward from their seats during impact. When the fuselage was lifted, the right handle for the cyclic control was found under where the fuselage had been. Both of the pilots' lap-diagonal seatbelts were found buckled but had failed where the straps that held the release levers were anchored to the airframe between the two seats. The inertia reels functioned normally.

3.2.8. The damage to the trees, the ground markings and the wreckage damage and its spread were consistent with the wreckage having fallen nearly vertically through the forest canopy in a near level or flat attitude.

3.2.9. Several pieces of broken instruments and a section of the front canopy bow were found after the helicopter wreckage had been removed from the accident site.

3.3. Aircraft information

3.3.1. ZK-IPY was a Robinson R44 Raven II helicopter, serial number 10555, manufactured in November 2004. It was powered by a single Textron Lycoming IO-540-AE1A5 normally aspirated engine, serial number L-29707-48A. The helicopter was imported into New Zealand and registered by the operator in January 2005.

3.3.2. At the time of the accident the helicopter had accrued a total of 1,529 hours. Records showed that the helicopter was being maintained in accordance with the approved maintenance manual and Robinson instructions. The last maintenance inspection had been a scheduled 50-hour check carried out on 9 February 2015, 10 days before the accident. An annual review of airworthiness had been completed at the same time. The helicopter had since flown 19 hours without any reported defects.

3.3.3. Maintenance requirements for the helicopter included a daily inspection of the tail rotor blades and main rotor blades for potential fatigue cracking. Aircraft documentation and interviews with other pilots who had flown the helicopter showed that these requirements had been complied with.

3.3.4. The weight and centre of gravity[11] of the helicopter when it departed Queenstown were calculated using the recorded basic weight of the helicopter, the reported weights of the two pilots, and the weight of fuel and additional survival items carried on board. It was determined that the helicopter had departed with full fuel tanks. The take-off weight was calculated to be 987 kilograms – the maximum allowable weight was 1,134 kilograms. The centre of gravity was calculated to be 245.36 centimetres aft of the datum; within the allowable range of between 234 and 257.8 centimetres. The lateral centre of gravity was within limits, close to the centreline of the helicopter.

3.3.5. The helicopter centre of gravity continued to be within the limits for the duration of the flight. The weight at the time of the accident was calculated to be about 940 kilograms.

Wreckage examination

3.3.6. Appendix 3 gives a more detailed account of the wreckage examination. All major components of the helicopter, including flight and engine controls, main rotor and tail rotor assemblies, landing skids and fuselage were accounted for at the site and removed for further examination.

[11] The centre of gravity is the single point in the helicopter through which the weight (and force of gravity) acts.

Flight controls

3.3.7. Dual flight controls had been installed.[12] The cyclic control or stick had broken off near the floor. Both the left and the right cyclic extension handles had been broken off, with the left extension handle having an impact mark that matched the curve of the leading edge of a main rotor blade.

3.3.8. The connectivity of the flight controls through to the main rotor and tail rotor was established. No evidence of pre-impact failure or problems was found.

Engine and controls

3.3.9. The engine cooling fan displayed scoring around its perimeter and on the inlet cone surfaces, indicating that it was turning at the time of the accident sequence.

3.3.10. The drive belts were intact, although one had a partial longitudinal split. There was no evidence that the belts had rolled off. The clutch was found to lock and free-wheel normally. The clutch was subsequently examined by a licensed engineer familiar with the R44 and clutch assembly. The clutch assembly showed "virtually no sign of in-service wear". Tear damage was found on the inner race, which matched marks on the same end of each pall. The damage was in the direction of drive.

3.3.11. The engine was removed and taken to an approved aircraft engine overhaul facility and subjected to a bulk strip inspection[13] under the supervision of a Commission investigator. Maintenance records matched the engine and all applicable airworthiness directives were found to have been embodied.

3.3.12. Engine accessories, including the magnetos, fuel control unit and fuel pump were all removed and tested, with no defects found. The fuel control unit was free of any contamination. The testing of the fuel flow divider did identify a "slightly restricted flow due to tiny metallic particle contamination" for the #5 nozzle.

3.3.13. In summary, the engineering company determined that "no evidence was found of any pre impact defect that would have affected the engine's ability to run. The restriction in the #5 nozzle may have caused the engine to run slightly rough with minor power loss".

3.3.14. Both fuel tanks had separated from the fuselage and had significant deformation. Both tanks had bladders installed and their caps were in place. The tanks were found empty. However, the smell of fuel about the wreckage and the heavy ground indent where the main tank had landed indicated that both tanks had contained some fuel on impact. The main fuel filter ('gascolator') was intact and found to contain fuel that was consistent with the correct fuel for the helicopter. The filter screen was clean and vent lines free of obstruction.

Main and tail rotors

3.3.15. Both of the pitch change links, which connect the swashplate to the main rotor blades and control the pitch angle of the blades, had failed in overload[14], likely after a reverse bending motion (see Figure 5). Both teeter stops were split horizontally through the middle, and their retention brackets were bent.

3.3.16. Both main rotor blades had fractured (see Figure 6). Because the fracture of the red blade was near the point where another R44 blade had failed, which the CAA suspected had been due to fatigue, the Commission had this blade examined by a metallurgist at the earliest opportunity. The metallurgist's initial assessment was that the blade had failed in overload. Subsequent detailed examination by the same laboratory and a further examination by an

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[12] A second set of flight controls to permit instruction from the left seat.
[13] The disassembly of the engine to its individual components.
[14] Overload is the common term used to describe the mode of failure where the force sustained exceeds the material's physical strength or design load.

ATSB metallurgist confirmed this. The ATSB also determined that the failure of the blue blade was the result of overload and not fatigue, with the blue blade exhibiting "significant plastic deformation in the region of the fracture surface consistent with an overstress failure". Both blades were examined for signs of any pre-existing delamination or dis-bonding, and none was found.[15]

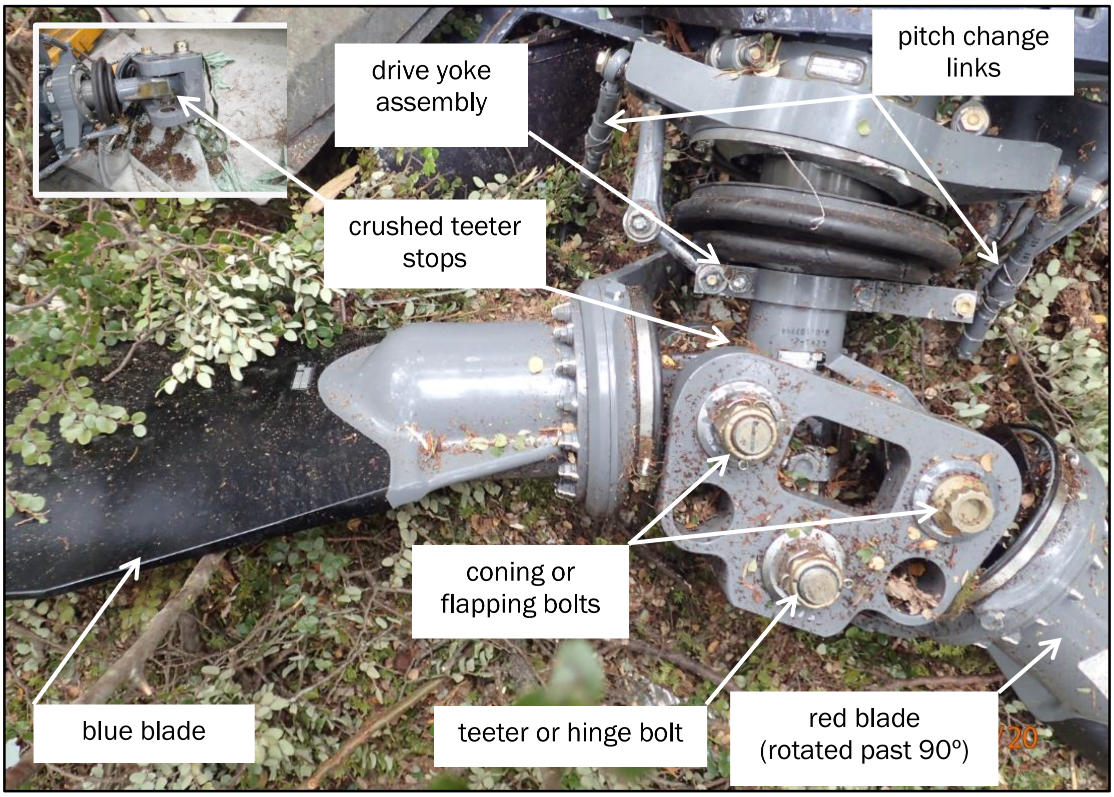

Figure 5
Main rotor head showing broken components and extreme flapping of blades

[15] The earlier R44 'Dash 2' and 'Dash 5' blades were subject to a Continuing Airworthiness Notice following several cases of dis-bonding near the blade tip. The Dash 7 blades fitted to ZK-IPY were not subject to the same inspection requirement.

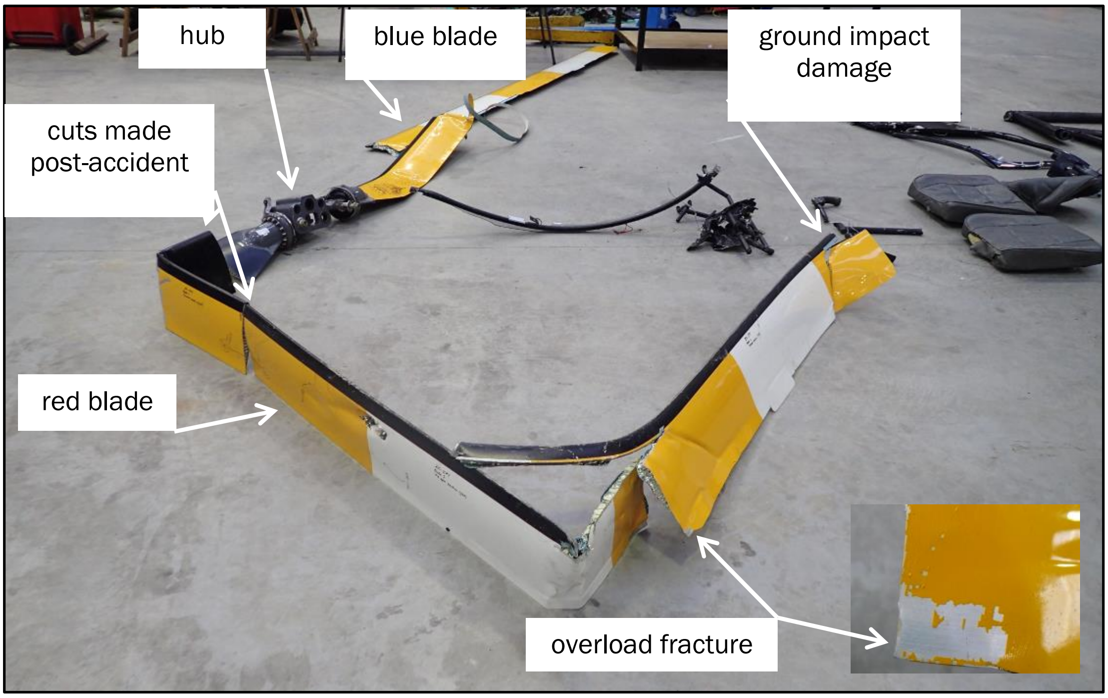

Figure 6
Main rotor blade damage

3.3.17. The intermediate and aft flexible couplings were bent and separated. The gearbox and tail rotor assembly had separated. The gearbox was able to be rotated freely.

Instruments and readings

3.3.18. The upper instrument console, found near the start of the wreckage trail, had a deformation consistent with having been struck by a main rotor blade. The instruments normally held by the upper console had been dislodged, with the exception of the vertical speed indicator. Most of the warning lights at the top of the console were either broken or missing. The only light showing evidence of 'hot stretch'[16] was the clutch light. None of the temperature indication stickers on gear boxes and the hydraulic pump showed any evidence of excessive heat having been generated in these components.

3.4. Personnel information

3.4.1. The instructor was aged 42 years. He had begun his piloting career with the British Royal Marines in March 1998. In September 2003 he migrated to New Zealand, obtaining his New Zealand commercial pilot licence on helicopters in November 2003. The instructor flew the Robinson R22 in preparation for his commercial flight test. During this time he also completed the required Robinson safety awareness training.[17]

3.4.2. The instructor joined the operator in August 2004 and obtained his R44 and AS350 Squirrel helicopter ratings shortly afterwards. He occasionally flew the R44, but predominantly flew the AS350 on local area scenic flights. On 23 August 2005 the instructor completed further Robinson safety awareness training as part of his annual competency check, which was flown on the R44.

3.4.3. In June 2007 the instructor left the operator and joined another helicopter company that performed flight training. As part of the instructor's R22 re-familiarisation and instructor training, he again completed Robinson safety awareness refresher training. He obtained his C-category instructor qualification on 9 July 2007. He then instructed on both the R22 and

[16] When a bulb is illuminated, the filament is heated and therefore ductile. When subjected to a sudden and large load, the filament will stretch before breaking. The result is 'hot stretch', sometimes termed a bird's nest. The opposite is a cold, brittle failure with no filament stretch.
[17] Comprising ground and flight training.

R44 helicopters. On 13 November 2008 the instructor obtained his B-category instructor qualification.

3.4.4. In July 2010 the instructor returned to fly with the operator for two years. During this time he completed further Robinson safety awareness refresher training, which included a flight in an R22. He also presented safety awareness training on several occasions. He then flew helicopters in Papua New Guinea for 20 months before returning to New Zealand and re-joining the operator in August 2014.

3.4.5. At the time of the accident the instructor had accrued a total of 4,703 flying hours, including 4,527 hours flying helicopters. He had flown 2,145 hours on Robinson helicopters, including 950 hours on the R44. The instructor's logbooks recorded that he had flown 2,435 hours of mountain flying and 1,380 hours of instruction, nearly all in Robinson helicopters and mostly in the R22. He had flown about 37 hours in the R44 since re-joining the operator in August 2014, including giving 13 hours of instruction.

3.4.6. The instructor's last competency check and biennial flight review had been conducted on 29 August 2014 and was flown in an AS350 Squirrel. On 29 September 2014 he completed his B-category instructor renewal in R44 ZK-IPY, the accident helicopter.

3.4.7. The instructor held a current class 1 medical certificate valid until 21 February 2015. He had attended a medical examination on 4 February 2015 for the renewal of his certificate and been assessed as fit. The replacement certificate was in the process of being issued at the time of the accident.

3.4.8. In the 48-hour period preceding the accident, the instructor had flown three flights totalling 5.2 hours, including a training flight with the student on the day before the accident. This was recorded in the student's logbook as transitions and introduction to the circuit.[18] In the seven-day period he had flown six flights totalling 10.3 hours. These included 2.5 hours in the R44, of which 1.7 hours were giving instruction. The instructor was observed to be fit and healthy on the day of the accident.

3.4.9. The student was aged 18 years. Since the age of about eight years he had often accompanied pilots while they were undertaking commercial passenger flights on the operator's helicopters. His pilot logbook recorded that he had flown a total of 10 hours of training flight in the R44 helicopter. The first flight had been a 'familiarisation' flight in 2005. He had next flown twice in 2012.

3.4.10. The frequency of the student's flying had increased from April 2014 until the accident flight, when he flew nine flights and accumulated a further seven hours of flying experience. He flew one flight in December 2014, involving take-offs and landings and an introduction to flying 'the circuit'. During February 2015 he flew four flights, three with the instructor and one with another of the operator's pilots who was also a B-category instructor. The four flights flown on 11, 13, 15 and 18 February totalled three hours of dual instruction and were all in the accident helicopter. The exercises that were flown included transitions, hovering, introduction to the circuit and autorotations.[19]

3.4.11. The student was reported to be in good health on the morning of the accident.

3.4.12. The toxicology results for the instructor and student were negative for any performance-impairing substances.

[18] Moving from the hover into forward flight and from forward flight into a hover.

[19] Transition is the term used to describe a helicopter moving from a hover into forward flight or from forward flight to a hover. Autorotation is when the main rotor system is driven by the flow of air up through the rotors, instead of by the engine.

3.5. Meteorological information

3.5.1. The New Zealand Meteorological Service area forecast predicted light northwest winds from the surface to 10,000 feet for the period of the flight. The cloud was predicted to be broken[20] with a base of 5,000 feet, lowering to 3,500 feet in rain showers. Isolated cumulous nimbus or towering cumulous were forecast to develop during the afternoon and to dissipate in the evening. These would be associated with isolated showers. Isolated moderate turbulence during the morning was expected to ease in the afternoon.

3.5.2. The three witnesses who observed the helicopter after it crossed the lake and as it flew into the valley said the day was fine and warm. The wind conditions on the ground were generally calm or near calm, with an occasional light gust passing through. The witnesses aboard the helicopters involved in the subsequent search reported similar conditions.

3.5.3. Air traffic service staff at Queenstown airport recorded the surface wind during the late morning and early afternoon as southwest at between three and seven knots. The other conditions included: 50 km visibility, FEW cloud[21] at 4,500 feet and 5,500 feet, temperature about 19° Celsius and pressure varying between 1,018 and 1,020 hectopascals. At 1413 an updated report recorded an increase in the wind at Queenstown airport to southwest (220° magnetic) at 15 knots, maximum 20 knots. The other parameters remained similar.

3.5.4. The aerodrome meteorological conditions recorded automatically every 30 minutes showed that between 1230 and 1330 the wind was from the southwest at between 9 and 11 knots. The report issued at 1400 recorded the wind varying between southwest and west at 14 knots. Subsequent reports recorded the wind being steady from the southwest at between 7 and 10 knots.

3.5.5. Another source of accurate wind data for the Queenstown area was the Meteorological Service's recordings taken every minute at its aerodrome site. The data showed that during the afternoon the wind direction was from the southwest (between about 235° and 255° True). Wind strength fluctuated between about 5 and 10 knots, with occasional increases to a maximum of 20 knots. The aerodrome was 21 km from the accident site, approximately downwind.

3.6. Operator information

3.6.1. Over The Top was established in 1986 and was certificated by the CAA to carry out air operations under Civil Aviation Rules Part 135, Air Operations – Helicopters and Small Aeroplanes. The previous safety audit by the CAA had been undertaken on 15 May 2014, when three minor findings were issued. The findings related to lapses in documentation concerning management and maintenance practices, and were soon rectified. The CAA's risk assessment of the operator continued to place it in the lower or lowest risk assessment band for this type of operator.

3.6.2. At the time of the accident Over The Top operated the Robinson R44 helicopter involved in the accident and six turbine-powered Airbus[22] helicopters available for charter operations around the Southern Lakes and southwest Fiordland area. The operator also offered a 'U-Fly 2' experience, where a customer could 'fly' the R44 under the supervision of one of its instructors. The operator had three B-category instructor pilots able to perform this work.

3.6.3. The company owner held the following senior positions within the organisation:

- CEO
- responsibility for 'competency assessment'
- responsibility for crew training
- responsibility for flight and ground operations.

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[20] Cloud is reported in oktas (eighths). Broken is 5-7 oktas.
[21] FEW is 1-2 oktas.
[22] Formerly Eurocopter and Aerospatiale.

An external training organisation conducted pilot competency checks, typically alternating between the different helicopter types to help ensure pilots were competent to operate each type.

3.6.4. The operator was the recipient of safety awards issued by national and international organisations, and the CAA.[23] Pilots were encouraged by the operator to gain recognition of their flying and safety efforts. On 3 May 2012 the instructor had received a New Zealand Helicopter Association Silver Safety Award, recognising "more than 10 years' continuous service without accident to self, passengers or crew".

3.7. Additional information

Robinson helicopters

3.7.1. The R44 is a four-seat development of the R22, and was first delivered in 1993. The R44 and R22, and the later R66, share a common two-bladed teetering[24] rotor system unique to Robinson. In 2002 the R44 Raven II version was introduced and offered hydraulically assisted controls, a more powerful engine and improved main rotor blades. This resulted in an increase in performance and maximum allowable weight. More than 5,000 R44 helicopters have been delivered, making it one of the most common helicopters currently in use in the world.[25] At the end of 2014, according to CAA data, 40% of the helicopter fleet in New Zealand comprised Robinson helicopters, with 144 R22s, 186 R44s and five R66s.

3.7.2. During the 1980s the R22 was involved in a disproportionate number of accidents when compared with other helicopter types, so the United States Federal Aviation Administration (FAA) and NTSB initiated several studies regarding the certification and operation of the type. One of the outcomes of the studies was the issuing of FAA Special Federal Aviation Regulation (SFAR) 73 in 1995, which set pilot experience and training requirements for the R22. The requirements were extended to include the R44 because of similar concerns. However, in New Zealand SFAR 73 was applicable to the R22 only. See Commission reports 11-003 and 13-005 for further information on SFAR 73 (TAIC 2011 and TAIC 2013a).

3.7.3. The minimum experience and training requirements, plus the fitment of an engine speed governor as standard equipment, also in 1995, resulted in a decrease in the accident rate.

Rotor head design

3.7.4. The basic teetering rotor head design[26] has been used on a number of two-bladed main rotor systems – for example the Bell 47, developed in 1946, and the Bell UH-1 Iroquois (204/205), developed in 1956, which were both successful helicopters.[27] Both types also incorporate a stabiliser bar positioned at 90° to the main rotor blades to increase main rotor stability. In the 1970s a significant number of helicopter accidents were being attributed to mast bumping, where the main rotor teeters excessively and the hub strikes the mast. If the bumping were sufficiently violent, the damaged mast could fail totally and the main rotor separate. Excessive teetering, possibly compounded by pilot input to the controls, could place excessive loads on the pitch change links that controlled blade angle. Once the pitch change links failed, the blades were free to rotate and be driven into the fuselage of the helicopters. Either scenario usually had disastrous consequences.

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[23] Organisations included the New Zealand Helicopter Association and the Helicopter Association International.
[24] Teetering is the see-saw movement of a two-bladed rotor about the teeter bolt or centrally mounted rotor hub.
[25] Some 4,600 R22s of various models have been manufactured.
[26] Sometimes called a semi-rigid rotor head because it is rigid in the plane of rotation, but can still flap.
[27] Some 5,600 Bell 47 and 16,000 Bell UH-1 helicopters were produced.

3.7.5. Three main factors were identified as leading to mast bumping:

- low-G[28]
- centre of gravity outside limits
- abrupt and excessive control inputs.

3.7.6. Military flight manuals were amended to prohibit low-G manoeuvres and flight into severe or extreme turbulence.[29] The equivalent manuals for the civil versions of the UH-1 Iroquois, the Bell 205, were briefer and contained no similar restrictions.[30]

3.7.7. The Robinson rotor head design is unique in that it incorporates coning or flapping hinges[31] as well as a teeter hinge (see Figure 7). The teeter hinge allows the rotor system to tilt in a particular direction, thus inclining the rotor thrust in that direction. The coning hinge allows individual blades to flap up and down. Flapping[32] is a normal function of flight and is the result of the lift of a blade changing in response to changes in airspeed and angle of attack as the blades rotate. It is also common during start-up and shutdown in windy conditions, where the slow rotation of the blades provides insufficient centrifugal force and stability to maintain the blades in the same plane of rotation. Static or teeter stops are used to control excessive teeter and prevent damage to the mast during this time.

3.7.8. The Robinson main rotor blades are regarded as being lightweight, low-inertia blades when compared with the heavier blades found on other helicopters. While the low-inertia blades offered advantages, one disadvantage was the potential rapid decay in rotor RPM, perhaps in response to poor throttle control, overpitching of the rotor blades or engine failure and slow entry to autorotation. To help address this concern, Robinson provided an automatic carburettor heat control and a more powerful engine, modified the main rotor blades and installed an electronic fuel control governor to help control engine and main rotor speed.

[28] G, sometimes identified as 'g', is the acceleration due to gravity. Low-G is a net force less than the force of gravity. When zero the object is described as weightless.

[29] United States Army and Royal New Zealand Air Force flight manuals for the UH-1 Iroquois included the figure of 0.5g as the minimum load factor.

[30] According to Bell Helicopters, the relevant military organisation was the airworthiness authority for its helicopters, not the civil regulator. The restrictions reflected the types of operation being undertaken.

[31] Robinson uses the term coning hinge.

[32] Flapping is the vertical movement of a blade about a hinge (coning bolt) perpendicular to the blade span.

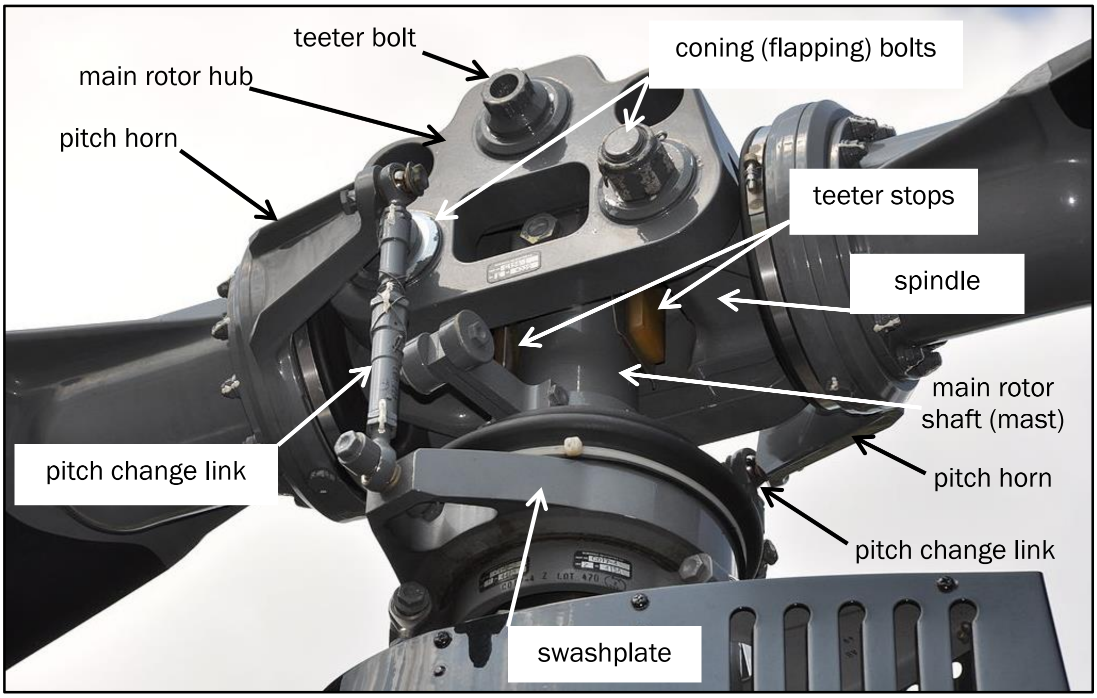

Figure 7
R44 rotor head
(Courtesy of English Wikipedia)

Mast bumping

3.7.9. Mast bumping is the result of extreme teetering. Extreme teetering is when the main rotor, often described as the disc because of the shape it describes, diverges significantly from the normal plane of rotation.[33] This can occur when either the disc or the fuselage moves excessively relative to each other. There are several factors that can, in combination and in some cases singularly, initiate excessive teetering and mast bumping. These are:

- low-G
- turbulence
- large, abrupt control movements by the pilot
- low main rotor speed or RPM.

Low-G

3.7.10. Low-G flight is a situation when the occupants feel a sensation of reduced weight. It can be induced by a pilot moving the cyclic control stick forward. In a helicopter with a teetering rotor head, because of the position of the helicopter's centre of gravity and the tail rotor thrust line, if the pitch forward is sufficiently strong enough and the tail rotor thrust line moves high enough, a roll to the right can be induced.[34] Because of the teetering rotor head design and the gyroscopic stability of the main rotor, the disc attitude will remain stationary or slowly lag behind the fuselage roll. In effect, the pilot will observe the helicopter starting to roll right, but the disc may still be about level. If the pilot applies left cyclic to counter the apparent roll, the angle between the disc and the mast on the left side will be reduced even further – possibly to the point where the spindle (see Figure 7) contacts the mast (mast bumping).

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[33] Often referred to as main rotor divergence. See Air Accidents Investigation Branch (AAIB, United Kingdom) Bulletin 2/2013, G-CHZN.
[34] For a main rotor, like that of the Robinson types, which turn anti-clockwise when viewed from above.

3.7.11. A higher power setting will result in more rotor torque being generated, requiring more tail rotor thrust to balance the torque effect. Therefore, the higher the power setting the greater will be the rate of roll. At a high speed there is a high power setting and a high tail rotor position.

3.7.12. The R44 Pilot's Operating Handbook[35] limitations section stated "Low-G cyclic pushovers prohibited". Immediately following this, a caution[36] alerted pilots that low-G condition "can result in catastrophic loss of lateral control". Pilots were instructed that should low-G be encountered they were to apply gentle aft cyclic, and should a right roll commence they should apply gentle aft cyclic to reload the disc before applying lateral cyclic to stop the roll.

3.7.13. The Pilot's Operating Handbook Section 10 Safety Tips and Notices contained the following tip:

> Never push the cyclic forward to descend or to terminate a pull-up (as you would in an [aeroplane]). This may produce low-G (near weightless) condition which can result in a main rotor blade striking the cabin. Always use the collective to initiate a descent.

A safety notice also discussed low-G and stated that pilots should never demonstrate or experiment with low-G as even highly experienced test pilots had been killed investigating this flight condition (see Safety Notice SN-11 in Appendix 4).

Turbulence

3.7.14. Turbulence is rated as light, moderate, severe or extreme, according to the effect on the aircraft and its occupants. Light turbulence is when the aircraft experiences slight erratic changes in attitude or altitude, whereas extreme turbulence may cause structural damage. The assessment can be subjective. For example, it would not be unusual for the same turbulent conditions to be described as moderate by the pilot of a light helicopter, but as light by the pilot of a large aeroplane.

3.7.15. Turbulence is a known contributor to mast bumping. A large downward gust will unload the rotor disc[37], resulting in low-G. Conversely, an upward gust will increase the angle of attack of the blades, causing the blades to flap. Inappropriate or inadvertent pilot inputs or over-controlling can exacerbate the effects of the turbulence. The Pilot's Operating Handbook contained no limitation for flight in turbulence. Safety Notice SN-32 warned pilots that the improper application of control inputs in turbulence could increase the likelihood of mast bumping.[38]

3.7.16. The notice described the procedures to be followed when encountering turbulence, principally to reduce speed. This had the twin benefits of lowering the tail rotor thrust line, thereby reducing the likelihood of an uncommanded right roll and, secondly, reducing the tail rotor thrust, such that if the helicopter should start to roll right, it would be at a slower rate. The notice also stated that pilots should tighten their seat belts and firmly rest their right forearms on their right legs to prevent unintentional control inputs. The notice noted that the helicopter was more susceptible to turbulence at light weight (see Appendix 4).

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[35] The Pilot's Operating Handbook included the approved flight manual. This document contained, among other things, limitations in the operating of an aircraft and various safety tips and notices.
[36] The Pilot's Operating Handbook used the terms *Caution* and *Note,* with *Caution* being defined as "Equipment damage, injury, or death can result if procedure or instruction is not followed".
[37] The rotor disc is the area swept by the rotor blades each revolution.
[38] This has since been amended to advise that "Flying in high winds or turbulence should be avoided".

Large, abrupt control movements

3.7.17. The R44, like the R22, is very responsive to pilot control inputs. The cyclic control stick in particular requires only light forces to achieve the full range of movement. The hydraulically boosted controls also mean that a pilot has little feedback and thus limited feel of what's happening to the main rotor.

3.7.18. Any large and/or abrupt movement of the cyclic stick will cause the disc to teeter. Excessive movement will result in main rotor movement relative to the mast, reducing the margin between the hub and mast and leading to possible mast bumping. The Pilot's Operating Handbook's limitations section and a safety tip both advised pilots to avoid abrupt control inputs as these produced high fatigue loads and could lead to the failure of a critical component. An NTSB study of R22 accidents involving loss of main rotor control found that "large, abrupt control inputs can lead directly to mast bumping…" (NTSB 1996).

Low main rotor RPM

3.7.19. The coning angle[39] of the disc is the result of the interaction between the lift being generated by the blades and the centrifugal force from their rotation. With the helicopter on the ground at normal operating RPM and with no collective pitch applied, the disc will be flat. In hover the blades will be coned upwards in response to the increase in lift being generated. Were the RPM to decrease while holding the same hover position, the blades would cone upwards because of the reduced centrifugal forces. A secondary effect of the reduced RPM is reduced lift. The collective lever[40] would therefore need to be raised to maintain the same amount of lift. The resulting increase in blade pitch angle increases the drag on the rotor blades and, if not countered, will reduce rotor RPM even further.

3.7.20. If the situation described above continues, the blades will stall – lift will suddenly reduce. The blades will then flap down. In forward flight the stall will not be symmetrical and the retreating blade will stall first.[41] This situation will lead to main rotor divergence, with the stalled retreating blade potentially striking the mast and/or the airframe.

3.7.21. A Pilot's Operating Handbook safety tip stated: "Never allow rotor RPM to become dangerously low. Most hard landings will be survivable as long as the rotor is not allowed to stall". The Pilot's Operating Handbook also contained two safety notices, SN-10 and SN-24, relating to low rotor RPM and fatal accidents (see Appendix 4).

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[39] The coning angle is the angle formed between the span-wise length of the main rotor blades and their tip path plane. The angle varies according to the resultant of the centrifugal force due to RPM and the lift that is demanded.

[40] The collective lever is the control that changes the pitch angle of the main rotor blades by the same amount and at the same time, which changes the total rotor thrust, usually to effect a climb or descent.

[41] Because of the relative airspeed over the blades, to generate the same amount of lift the retreating blade will be at a higher pitch angle than the advancing blade.

4. Analysis

4.1. Introduction

4.1.1. The Commission determined that it was virtually certain the helicopter experienced a mast bump event, which resulted in the main rotor blades striking the fuselage. Thereafter the helicopter broke up in flight.

4.1.2. The Commission has not been able to establish conclusively what initiated or contributed to the mast bump. The uncertainty around the circumstances of this accident is 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-flight break-ups are destructive, making it difficult to determine with certainty whether a mechanical failure of some kind could have initiated the mast bump.

4.1.3. There have been many other fatal mast bump accidents involving Robinson helicopters in New Zealand and around the world that have gone largely unexplained. It is difficult to identify the lessons from an accident and make meaningful recommendations to prevent similar accidents if the underlying causes cannot be determined. This is a serious safety issue that the industry, including pilots, operators, the manufacturer and the regulator, will need to address.

4.1.4. A remedy for the lack of reliable data concerning specific accidents is to record flight data and cockpit video. At present International Civil Aviation Organisation (ICAO) standards do not require flight data recorders to be installed in small and medium helicopters. However, lightweight and affordable recorders are available and are installed as standard equipment in some helicopters. In addition, technical means are available for detecting, and therefore recording, the positions of flight and engine controls on helicopter types that have previously been unsuited for the collection of digital data.

4.1.5. The Commission has therefore made a recommendation to the Secretary for Transport, and given notice of that recommendation to the Director of the CAA, to promote through the appropriate ICAO forum 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.

4.1.6. Since 1996 the Commission and the CAA have collectively investigated 12 accidents or incidents involving R22, R44 and R66 helicopters where mast bumping occurred. Some common themes were identified (refer to Appendix 1 for details).

4.1.7. In six of the 12 accidents the helicopters had very likely encountered turbulence. In cases where turbulence had not been severe, high speed, high engine power and/or over-controlling by the pilots were considered to be possible contributing factors. Eight of the accidents occurred in mountainous or hilly terrain. Five of the occurrences involved pilot training of some form. Six occurred while the helicopters were in transit between two locations, and a seventh was during cross-country navigation training. Of the accidents where the main rotor blades struck the helicopters, five were to the fuselage and five to the tail boom. The remaining two were mast bump incidents where the main rotor blades did not strike the helicopters.

4.1.8. On 9 March 2013 a Robinson R66 helicopter suffered a mast bump and in-flight break-up in the Kaweka Ranges. (See Commission report AO-2013-003.) As a result of that inquiry, on 25 February 2016 the Commission recommended to the Administrator, Federal Aviation Administration of the United States that he “reinstate research into the dynamic behaviour of two-bladed, teetering, underslung rotor systems, taking full advantage of available technology, with the aim of achieving the original goal of NTSB recommendation A-96-12. (005/16)”.

4.1.9. The following analysis discusses in more detail what happened. There are generally four factors that, usually in combination, can potentially lead to mast bumping. They are:

- low-G
- turbulence

- large, abrupt control movements by the pilot
- low main rotor speed or RPM.

Each of these has been considered in relation to the circumstances of this accident.

4.2. What happened

4.2.1. The crushing of the teeter stops found on the rotor head was a clear indication of a mast bump. Other rotor head damage found included broken pitch change links, a bent rotor shaft and scoring on the inside of the hub from excessive movement of the spindle tusks. This damage was a typical signature of a significant mast bump.

4.2.2. A significant mast bump event often results in the main rotor blades striking the fuselage. In this case one of the main rotor blades (the red blade) struck the cabin area of the fuselage twice. The first strike was through the top left side of the cabin. The second strike, as little as 0.15 seconds after the first[42], hit the upper instrument console and left handle of the cyclic control stick. The blade then swung under the fuselage to strike the rear of the left skid. The tip bent around the skid and separated to the right of the flight path (see Figure 8). The main fuel tank located on the left side was dislodged early in the sequence and also ejected out to the right of the flight path.

Figure 8
Main rotor blade strike on rear of left skid

4.2.3. The spread of the wreckage on the ground was typical of an in-flight break-up initiated by a mast bump and the main rotor blades striking the fuselage.

4.2.4. It is clear that mast bumping initiated the in-flight break-up of the helicopter. What is not so clear is what caused the mast bump. Several possibilities were examined.

[42] At a main rotor speed of 408 RPM or 6.8 revolutions per second, the red blade would take 0.15 seconds for one rotation.

Engine or transmission failure

4.2.5. An engine or transmission failure was unlikely to have contributed to this accident. A normal pilot response to this type of failure would be to enter the helicopter into autorotation by lowering the collective lever, thus avoiding low rotor RPM (one of the known causes of mast bumping). The frequent practice of an autorotation after a simulated engine failure forms part of the helicopter pilot training syllabus. The instructor was an experienced helicopter pilot. It would therefore have been unlikely for him to allow an engine or transmission failure to result in a low rotor RPM, even if the student was flying at the time.

4.2.6. In support of this hypothesis, the teardown examination of the engine revealed no faults. The 'trapped' engine readings and the scoring marks on the engine cooling fan and adjacent areas confirmed that the engine had been operating at the time of the in-flight break-up. It could not, however, be established how much power the engine was delivering at the time.

4.2.7. The restricted fuel flow to the #5 nozzle and cylinder was not significant and at worst would have caused only minor rough running of the engine, which may not have even been noticeable to the pilots. There would have been ample power available to fly the helicopter back to Queenstown. It would be unusual for a rough-running engine alone to result in reduced main rotor RPM.

4.2.8. The fuel control unit was examined as part of the investigation and determined to have been functioning correctly at the time of the accident. It was considered very unlikely to have contributed to the accident for a number of reasons. Firstly, an examination of the unit found no fault. Secondly, the engine was still operating at the time of impact. And thirdly, a fuel control unit failure, even to full flow, should have been easily handled by the instructor and at worst resulted in a forced landing – not an in-flight break-up.

4.2.9. A drive belt or clutch failure was unlikely to have contributed to the accident. Power is transmitted from the engine to the rotor drive system through vee-belts and a clutch arrangement. One of the two V-belts was partially split but both were otherwise intact, with no evidence of their having rolled off their pulleys or excessive slippage. The longitudinal split in one of the drive belts matched rubber transfer marks on an adjacent section of the engine frame, making it virtually certain that the split occurred when the helicopter broke apart and caused the engine frame to make contact with the drive belt.

4.2.10. The clutch locked and free-wheeled normally and the transmission rotated freely. The internal damage found in the clutch assembly was consistent with the engine continuing to try to drive the transmission and main rotor when the red blade struck the fuselage.

4.2.11. When a pilot engages the clutch switch, an electric actuator raises the upper drive sheave to tension the belts that drive the main and tail rotors. When the belts are properly tensioned, the actuator automatically switches off.

4.2.12. The hot stretch found in the 'clutch caution light' filament was evidence that the light was illuminated when the control panel was disrupted. However, this would not have been unusual because the clutch caution light illuminates whenever the actuator automatically energises to re-tension the belts in flight, and stays on until the belts are properly tensioned. For this reason, "occasional illumination of the clutch light during flight is not uncommon" (Pilot Operating Handbook). Additionally, any relative movement between an engine and the transmission during a break-up sequence is likely to affect momentarily the tension of the drive belts, causing the actuator to energise and the caution light to illuminate.

4.2.13. Fuel starvation or contamination was unlikely to have been a factor in the accident. The main fuel tank had contained fuel and, based on the calculated fuel load at the start of the flight, there should have been sufficient fuel for a further two hours of flying. The main fuel filter contained fuel and had no obvious contaminants. The fuel lines from the tank to the engine were free of any obstruction and the engine was operating at the start of the break-up sequence. The aerodrome fuel supply was tested for quality and the fuel found to have met the required quality.

Component failure

4.2.14. The fracture of the red main rotor blade was close to the change in chord, which was where a fatigue failure had occurred the previous month on another R44 helicopter.[43] However, the fractures where both the blue and red main rotor blades separated from the helicopter were confirmed by metallurgical examinations to be the result of overload failure, not fatigue failure. That is, they were torn from the helicopter by the forces involved during the in-flight break-up or from impact with trees and the ground. The two near-90° downward bends of the blade were examined and determined to be the result of overload resulting from the initial rotor divergence and mast bump.

4.2.15. An examination of the main rotor and tail rotor drives also found no pre-existing faults. All other damage to the helicopter can reasonably be attributed to the sequence of in-flight break-up and impact with the surrounding terrain. Staff from the Institute of Environmental Science and Research (ESR) examined both main rotor blades for evidence of a bird strike. None was found.

4.3. Mast bumping

4.3.1. As mentioned above, low-G, turbulence, large, abrupt control movements by a pilot, and low main rotor speed or RPM are all factors or conditions known to contribute to mast bumping. Some of these factors can be interrelated. A helicopter can momentarily enter low-G due to turbulence. Pilots can cause low-G by their control input alone. A pilot's incorrect flight control response to a helicopter being buffeted by turbulence can exacerbate rather than alleviate a low-G situation, and thus create a mast bump situation that otherwise might not have occurred.

4.3.2. In Robinson's opinion, turbulence alone does not cause mast bumping, but rather it is a pilot's control input in response to turbulence that creates the problem. However, this hypothesis has not been tested.

4.3.3. Another key factor is the speed of the helicopter at the time. An increase in the speed or power setting will increase the onset of the event and reduce the time for the pilot to make the correct response (paragraph 3.7.11).

Low rotor RPM

4.3.4. Low rotor RPM was unlikely to have been a factor in this accident. As mentioned above there is no evidence that supports any major issue with the engine or transmission that could have resulted in a significant drop in main rotor RPM.

4.3.5. Low rotor RPM can be induced by pilots when helicopters are engaged in tight manoeuvres, such as stock mustering and hunting activities. However, in this case the helicopter was as likely as not being flown directly down the valley on its return to Queenstown in order for the instructor to make his next appointment.

4.3.6. A third argument is provided by Robinson, which says, "Experience has generally been that low-G mast bumping usually results in the rotor blade or blades contacting the cabin, and low RPM rotor stall usually results in the rotor blade or blades contacting the tail cone [tail boom]. There are exceptions to this…". In this case the main rotor blades contacted the cabin.

4.3.7. A fourth and more definitive argument is that low main rotor RPM events result in both main rotor blades coning upwards, which usually results in a similar creasing of the upper blade surface on both main rotor blades. There was no evidence of this signature damage on the two main rotor blades recovered from the accident site.

Turbulence

4.3.8. The wind conditions were reported by witnesses on the ground as calm or light. However, what was experienced by the witnesses on the ground may not have been the same as those

[43] This occurrence is still being investigated by the Commission (Inquiry AO-2015-003).

at 1,000 feet above the valley floor and several kilometres away. Similarly, the conditions that the people in the searching helicopters experienced may not have been the same as the conditions an hour or more earlier.

4.3.9. The New Zealand Meteorological Service data recorded at Queenstown aerodrome was not an exact representation of the conditions in the valley at the time. However, what the data does show is that while the wind direction remained steady, there were constant variations in the strength of the wind. The 15-20 knots recorded at Queenstown could have been enough to generate light turbulence. Mountainous terrain can cause wide variations in turbulence from one area to the next. Therefore it was about as likely as not that there was light or even moderate turbulence in the valley at times.

4.3.10. The weather conditions were certainly suitable for the flight. If turbulence were a factor, which of the two pilots was flying at the time could be relevant. The instructor was an experienced helicopter pilot with 2,145 hours on Robinson helicopters, including 950 hours on the R44 type. None of the scenarios presented so far should have caused him any concern.

4.3.11. There is some evidence to suggest that the student was controlling the helicopter at the time of the accident. The helicopter was fitted with dual controls, which included an extension see-saw handle arrangement on top of the main cyclic control stick. The pilot flying pulls the extension handle down to a comfortable position in order to fly the helicopter. The other end of this extension is consequently in a raised position.

4.3.12. The angle at which the main rotor blade entered the cabin and struck the cyclic control stick suggested that the cyclic extension handle was angled down to the right as it would have been had the student been flying. While not conclusive, it is about as likely as not that the student was flying at the time.

Pilot-induced low-G

4.3.13. Low-G can be induced by pilots, perhaps inadvertently when transitioning from a climb to level or descending flight, or deliberately – for example if an instructor is demonstrating to a student the method for recovering from a low-G condition.

4.3.14. In-flight demonstrations of low-G are prohibited for Robinson helicopters, yet there is strong evidence that in New Zealand some instructors are demonstrating to students the onset of the characteristic right roll that will occur if a helicopter enters a low-G situation. This evidence comes from an expert conference the Commission hosted in relation to another accident involving a Robinson helicopter, and also from New Zealand industry training forums hosted by Robinson.

4.3.15. There is no evidence to suggest that such a demonstration was being made at the time of this accident. However, it is known that the instructor had demonstrated the procedure to at least one student in the past.

4.3.16. Eight former students of the instructor and several fellow pilots were questioned about his flying and whether he had performed low-G demonstrations. Only one student said that the instructor had demonstrated the lead-up to low-G with the helicopter becoming "light", but they said that this stopped before it started to roll. All the students and pilots agreed that the instructor had been a very thorough and professional instructor and pilot, and had had a good empathy with his students. They said he had not and would not have undertaken any random manoeuvre that would have knowingly endangered the helicopter.

4.3.17. It would have been unusual for the instructor to be demonstrating to this student the effect of entering low-G at his stage of learning, with only 10 hours' flying logged. Additionally, the circumstances discussed above indicate that the practical part of the instruction flight was essentially over, with the helicopter simply returning to base within an expected timeframe. It is therefore very unlikely that the instructor was demonstrating low-G.

Helicopter speed/power setting

4.3.18. The speed of the helicopter and how it was being manoeuvred at the time of the accident is important for understanding the possible factors that contributed to the mast bumping.

4.3.19. The helicopter was fitted with a TracPlus satellite tracking system. The system transmitted a message via satellite every two minutes to the operator's base, where it was displayed and recorded. If satellite connectivity was momentarily lost for some reason, the unit would continue trying to establish a link. Once the link was re-established, updated data would be transmitted.

4.3.20. Each transmission included the time the message had been sent and received by the satellite and the helicopter's position, groundspeed and altitude at that point in time. The approximate track the aircraft was flying at this time was also calculated and presented in degrees True.

4.3.21. The system calculated the straight-line speed and direction at the time of transmission. Any deviation or manoeuvres that took place between the transmissions or any changes in speed could not be shown.

4.3.22. A review of the tracking data showed that, with a few exceptions, information was being transmitted about every two minutes for the duration of the flight. During the flight into the operating area the groundspeed ranged between 80 and 100 knots, with a maximum of 108 knots. While in the Lochy River valley the helicopter was performing semi-regular orbits, and occasionally becoming stationary as if in hover. This was consistent with the observations of the witnesses on the ground.

4.3.23. Before starting to leave the valley the helicopter likely flew a left orbit, followed by a nearly 180° turn before heading down the valley (see Figure 9). The straight-line distance from the last data report made at 1340:30 to the start of the wreckage field was two nautical miles (3.73 km).

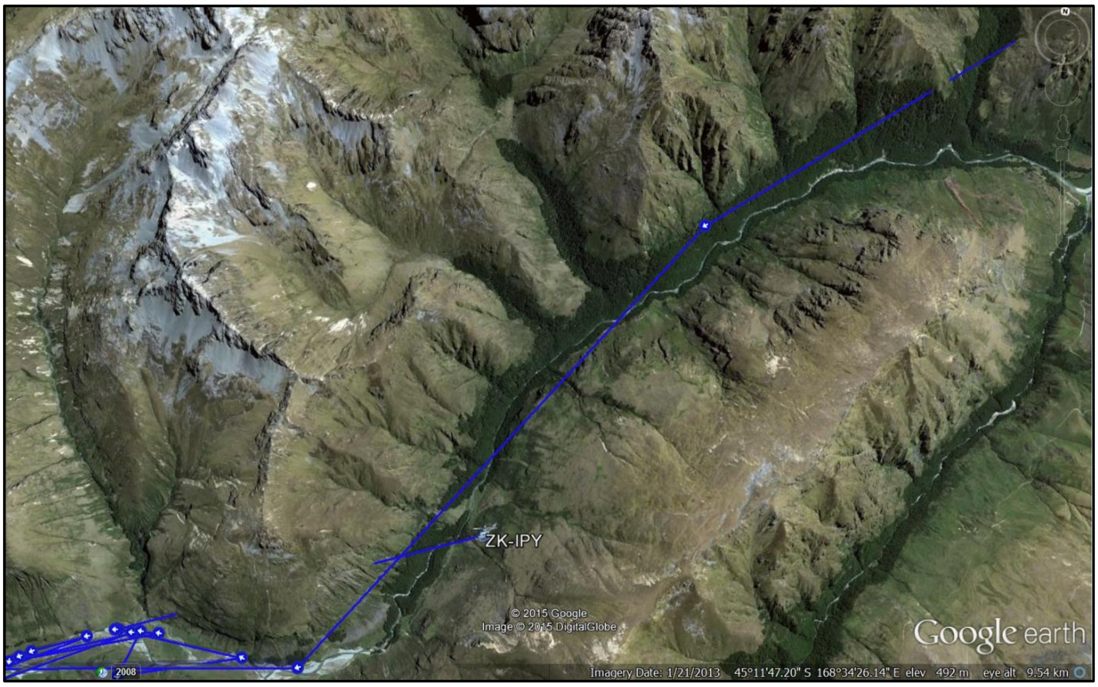

Figure 9
Track presentation and accident location[44]

4.3.24. The tracking data shows that, at the last recorded position, the pilot had climbed the helicopter to a sufficient height above the terrain to be able to enter autorotation and select the most suitable area to land had a problem been encountered.[45] It also showed the helicopter was then flying at a moderate groundspeed of 102 knots. The almost calm wind conditions in the area meant the airspeed would have been similar to the groundspeed. At this speed it would have taken about one minute and 10 seconds to travel from the last recorded position to overhead the accident site. However, the precise timing of the accident is not known, so the track data can tell us nothing other than that the helicopter was proceeding back towards Queenstown and had been travelling at a speed of 102 knots in the two minutes before the accident.

4.3.25. The instructor would have still been under the impression that he needed to return to Queenstown by 1400 for his next scheduled flight. At a groundspeed of 102 knots the helicopter would have reached the aerodrome at about 1350. It is likely therefore that the helicopter was flying directly back to Queenstown rather than conducting further flight training manoeuvres or deviating for any other reason.

4.3.26. As mentioned above, the higher the speed, the greater is the risk of encountering a low-G situation for whatever reason, and the pilot has less opportunity to recognise and respond appropriately to the situation. Robinson has recognised this risk and recommended that speed be reduced to below 70 knots if turbulence is encountered.

4.3.27. Flying at 100 knots or more and encountering a pocket of unexpected turbulence while under the control of a low-flying-time student pilot is a reasonably high-risk situation. A helicopter could feasibly enter a low-G condition and suffer mast bumping in less than one second. An instructor would be unlikely to have time to intervene.

Training and awareness

4.3.28. Accidents involving mast bumping occur worldwide and are not unique to New Zealand. Both New Zealand and Australia were considered by Robinson to have higher rates of these types of accident than other countries. Discussions with ATSB staff identified some significant differences in the accident signatures. Most of the Australian accidents had involved low rotor RPM or excessive control input. These were often related to intense manoeuvring of the helicopters close to the ground, for example during cattle mustering. The New Zealand accidents were more commonly related to turbulence and low-G, often resulting in the masts separating, an event rarely seen in Australia.

4.3.29. About 60% of New Zealand's terrain is designated as mountainous[46], the rest is mostly undulating and hilly. Turbulence generated by the wind moving over rough terrain is therefore a common feature of flying around New Zealand at low levels. Pilots are trained to be aware of turbulence, recognise its potential affects and avoid or mitigate them where possible. However, by its very nature the presence or intensity of turbulence cannot always be predicted. Refer paragraph 3.5.1.

4.3.30. The Pilot's Operating Handbooks for each of Robinson's three helicopter models contained the same safety tips and notices relating to low-G, low rotor RPM and turbulence. The introduction of SFAR 73 with its pilot experience and training requirements helped to reduce the incidence of low-G and low RPM accidents around the world, including in countries with mountainous terrain similar to New Zealand's. The same reduction was not evident in New Zealand, perhaps due in part to the terrain. Operators and pilots therefore need to be aware that there is a minimal margin for safety when operating in mountainous regions, at light weight, at high speed and/or at high power and in turbulent conditions.

4.3.31. Another possible factor was how SFAR 73 was being implemented, including different minimum experience requirements and safety awareness training. A discussion involving senior instructors on Robinson helicopters, CAA representatives and Commission

[45] The last two data points showed that the helicopter had been climbed at an average rate of about 350 feet per minute.
[46] Aeronautical Information Publication (AIP New Zealand), GEN 3.3-17 and 3.3-18, effective 12 May 2005.

investigators[47] found that the content, understanding and delivery of the Robinson safety awareness training varied between instructors in New Zealand (see Commission reports 11-003 and AO-2013-005, TAIC 2011, 2013b). A recommendation to the New Zealand Director of Civil Aviation was made on the subject.[48] The safety actions section of this report gives an update on progress.

4.3.32. Robinson has expressed a view that New Zealand instructors who attempt to demonstrate low-G could be one reason for the high rate of mast bump accidents in New Zealand involving Robinson helicopters. The rationale for its view is that a demonstration of low-G does not replicate the true situation and could engender a false sense of security in the pilot about their ability to recover from a low-G situation. Pilots may believe that it is easy to recover from a low-G situation, when in fact, if it happens, the roll is very rapid, leaving the pilot (no matter how experienced) virtually no time to react before a mast bump occurs. A severe mast bump is usually fatal.

4.4. Emergency locator transmitter (ELT)

4.4.1. Although this accident was not survivable, the non-performance of the ELT is of interest. The ELT is fitted to guide search and rescue to an accident site in a timely manner. For any case where the occupants survive the accident, the performance of the ELT could mean the difference between survival and not.

4.4.2. In this case the force of the accident was sufficient to activate the ELT but also to tear it from its mount, thereby disconnecting it from its external aerial. The internal aerial operated as intended, but the weaker signal was unable to be detected by the geostationary satellite positioned to the north of New Zealand. This was likely the result of a combination of the satellite's low angle, the mountainous terrain and bush cover. A low-Earth-orbit satellite did detect a signal message from the ELT approximately one hour and 35 minutes after the accident. With no GPS (global positioning system) data, a second satellite pass would have been required to provide a more accurate position. The ELT also activated a secondary signal[49] that was heard by a searching helicopter, but the signal was faint and too weak to provide a homing signal.

4.4.3. The ELT was found to have made 192 burst transmissions between activating and being turned off by rescue personnel. A burst occurred every 50 seconds, confirming that the ELT was active for two hours and 43 minutes, plus or minus a minute. Because the exact time for which the ELT was switched off was not known, the time of the accident could not be refined any more than that derived from the helicopter's tracking system.

4.4.4. The Commission has previously commented on the performance of ELTs and made safety recommendations to the CAA on the need to improve the performance of ELTs and promote the use of other tracking technologies (TAIC, 2011). The Commission has also made comment on technologies to locate vessels and rail vehicles. This accident reinforces those still-active recommendations.

[47] Forum hosted by the Commission on 9 May 2013.
[48] Report 11-003, recommendation 003/14.
[49] A signal transmitted on 121.5 megahertz that carried an audible alert tone.

5. Findings

5.1. The helicopter suffered a mast bumping event that resulted in a main rotor blade contacting the cabin area and initiated an in-flight break-up.

5.2. An examination of the wreckage revealed no pre-existing defects or mechanical failures that would have resulted in mast bumping. However, the damage to the helicopter meant that some kind of mechanical issue contributing to the accident could not be fully excluded.

5.3. The weather was generally calm and suitable for the training flight. There were about as likely as not to have been pockets of light to moderate turbulence in the area, but this alone should not have resulted in significant mast bumping.

5.4. The airspeed of the helicopter as it flew down the valley returning to Queenstown was as likely as not at least 102 knots when the accident occurred.

5.5. The student was about as likely as not to have been flying the helicopter when the mast bumping occurred.

5.6. The cause of the mast bumping event that initiated the in-flight break-up could not be conclusively determined.

5.7. The causes and circumstances of helicopter mast bumping accidents are unlikely to be fully understood until a means of recording cockpit imagery and/or other data is made available.

6. Safety actions

General

6.1. The Commission classifies safety actions by two types:

(a) safety actions taken by the regulator or an operator to address safety issues identified by the Commission during an inquiry that would otherwise result in the Commission issuing a recommendation

(b) safety actions taken by the regulator or an operator to address other safety issues that would not normally result in the Commission issuing a recommendation.

Safety actions addressing safety issues identified during an inquiry

6.2. The CAA advised that in response to previous Commission recommendations, several reviews were conducted between March 2014 and March 2015.[50] The reviews included:

(a) an examination of existing requirements in New Zealand, the USA and Australia

(b) an examination of current Robinson accident data

(c) an examination of current Robinson safety awareness training in New Zealand and the USA

(d) meetings with the Commission, Robinson, the FAA, experienced flight examiners and instructors, and the New Zealand Helicopter Association.

The results of the reviews are included in a *Robinson Helicopter Fleet Consultation Document,* and were published on the CAA's website: https://www.caa.govt.nz/pilots/robinson_helicopter_safety.html. The document's conclusions and proposed actions are listed in Appendix 2.

On 6 November 2015 the CAA announced that the District Court at Wellington had given approval for the Director of Civil Aviation to introduce special conditions for pilots of R22 and R44 helicopters, with effect from 1 July 2016. This action will bring New Zealand into line with FAA requirements and will "improve the level and consistency of training delivered by the aviation industry". Key elements of the training include that:

- a new syllabus of R22/R44 'ground' and 'in-flight training' is prescribed
- it will be completed by CAA certified 119 and 141 organisations or operators that have approved Robinson safety courses
- it will be delivered by suitably approved and qualified A or B category instructors
- a general aviation examiner with Robinson safety awareness privileges must approve the A and B category instructors delivering the awareness training
- the training will be required when new pilots are type-rated
- ongoing refresher training will be required every 24 months
- the amount of dual instruction a student requires before flying solo on the R22 and R44 has been lifted to 20 hours
- CAA recognises the existing Robinson factory safety course.

The full list of conditions approved by the Court is also available at https://www.caa.govt.nz/pilots/robinson_conditions.pdf. An Advisory Circular was also to be released in early 2016.

[50] CAA email dated 22 October 2015.

6.3. In February 2016 Robinson amended Safety Notice SN-32 by inserting an introductory sentence that had been deleted in May 2013. The sentence stated that: "Flying in high winds or turbulence should be avoided." The amendment also advised pilots to "reduce speed" when flying solo or lightly loaded.

Safety actions addressing other safety issues

6.4. Nil.

7. Recommendations

General

7.1. The Commission may issue, or give notice of, recommendations to any person or organisation that it considers the most appropriate to address the identified safety issues, depending on whether these safety issues are applicable to a single operator only or to the wider transport sector. In this case, recommendations have been issued to the Secretary for Transport, with notice of these recommendations given to the Director of Civil Aviation.

7.2. In the interests of transport safety, it is important that these recommendations are implemented without delay to help prevent similar accidents or incidents occurring in the future.

Recommendation

7.3. The Commission has not been able to establish conclusively what initiated or contributed to the mast bump event. 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-flight break-ups are destructive, making it difficult to determine with certainty whether mechanical failures of some kind could have initiated the mast bumps.

There have been many other fatal mast bump accidents involving Robinson helicopters in New Zealand and around the world that have gone largely unexplained. It is difficult to identify the lessons from an accident and make meaningful recommendations to prevent similar accidents if the underlying causes cannot be determined. This is a serious safety issue that the industry will need to address.

A remedy for the lack of reliable data concerning specific accidents is to record flight data and cockpit video. At present ICAO standards do not require flight data recorders to be installed in small and medium helicopters. However, lightweight and affordable recorders are available and are installed as standard equipment in some helicopters. In addition, technical means are available for detecting, and therefore recording, the positions of flight and engine controls on helicopter types that have previously been unsuited for the collection of digital data.

7.3.1. On 27 July 2016 the Commission recommended to the Secretary for Transport that he promote, through the appropriate ICAO forum, 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. (014/16)

On 18th August 2016, the Ministry of Transport replied:

> The Ministry considers that such a recommendation is premature as the costs and benefits of such a recommendation have not been canvassed. The Ministry appreciates that the Commission may have been minded to make such a recommendation because of the lack of available data. The Ministry suggests that prior to making a recommendation, some more work should be undertaken to determine the benefits and costs of flight data and video recording in cockpits.

7.3.2. On 27 July 2016 the Commission gave notice to the Director of Civil Aviation that a recommendation has been made to the Secretary for Transport that he promote, through the appropriate ICAO forum, 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. (015/16)

On 11 August 2016, the Civil Aviation Authority replied:

> The Director has considered the recommendation and in view of the Secretary for Transport's response to the Commission on the matter of cockpit video recorders and/or other forms of data capture, the Director is prepared to accept the recommendation but with a caveat that reflects the Secretary's response, i.e, That the Director of Civil Aviation conduct a safety and cost benefit exercise of installing flight data and/or cockpit video in certain classes of helicopters.

In that regard the Director will initiate an issue assessment paper on recording devices for certain classes of helicopters. Given the timeframe of such a study is likely to be lengthy; the Director cannot provide a completion date at this stage.

8. Key lesson identified

8.1. 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.

9. Citations

AAIB, 2013. Air Accidents Investigation Branch *Bulletin 2/2013 (Robinson R22) G-CHZN EW/C2012/01/01.*

NTSB, 1996. National Transportation Safety Board *Special Investigation Report NTSB/SIR-96/03*, *Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents,* adopted 2 April 1996.

TAIC, 2011. Transport Accident Investigation Commission *Inquiry 11-003: In-flight break-up ZK-HMU, Robinson R22 near Mount Aspiring, 27 April 2011.*

TAIC, 2013a. Transport Accident Investigation Commission *Aviation Inquiry AO-2013-003 Robinson R66, ZK-IHU Inflight break-up Kaweka Range, 9 March 2013.*

TAIC, 2013b. Transport Accident Investigation Commission *Aviation Inquiry AO-2013-005: In-flight loss of control, Robinson R22, ZK-HIE, near New Plymouth, 30 March 2013.*

Appendix 1: Review of mast bumping accidents in New Zealand

Investigation reference	Report title	Operation	Terrain	Weight	Blade strike location	Handling likely a factor	Turbulence likely a factor	Experience likely a factor	Helicopter performance likely a factor
TAIC 91-001	Robinson R22 Beta ZK-HDC, main rotor separation after mast bumping in turbulence, near Hukerenui, North Auckland, 4 January 1991	Transiting at low level	Hilly	Heavy	Fuselage	Yes	Yes	Yes	No
CAA 96/3239	Robinson R22 Beta ZK-HDD, Matawai, Gisborne, 5 December 1996	Night transit	Mountainous	Medium	Tail boom	Yes	No	Yes	No
CAA 02/71	Robinson R22 Beta ZK-HEZ, Balfour Range, near Fox Glacier, 14 January 2002	Venison recovery	Mountainous	Heavy	Tail boom	Yes	No	No	Yes
CAA 03/127	Robinson R22 Beta ZK-HUL, Masterton, 17 January 2003	Training – solo	Flat	Light	Fuselage	Yes	No	Yes	No
CAA 04/39	Robinson R22 Beta ZK-HXT, 10 km north-east of Taupo, 10 January 2004	Transiting at low level	Flat	Heavy	Fuselage	Yes	No	Yes	No
TAIC 08-007	Robinson R22 Alpha ZK-HXR, loss of control, Lake Wanaka, 1 November 2008	Transiting	Mountainous	Light	Fuselage	Yes	Yes	No	No
CAA 10/3987	Robinson R22 Beta ZK-HIP, loss of rotor RPM, Bluff Harbour, 14 October 2010	Training – dual	Flat	Heavy	Fuselage	Yes	No	Yes	No
TAIC 11-003	Robinson R22 Beta ZK-HMU, inflight break-up, near Mt Aspiring, 27 April 2011	Training – dual cross-country	Mountainous	Heavy	Tail boom	No	Yes	No	Yes
CAA 12/4957	Robinson R22 Beta ZK-HCG, loss of main rotor control, Cardrona Valley, Wanaka, 8 November 2012	Transiting	Mountainous	Light	Tail boom	Yes	Yes	Yes	No
TAIC AO-2013-003	Robinson R66 ZK-IHU, inflight break-up, Kaweka Range, 9 March 2013	Transiting	Mountainous	Light	Fuselage	Yes	Yes	Yes	No
TAIC OA-2013-005	R22 Beta ZK-HIE, inflight loss of control, near New Plymouth, 30 March 2013	Training – dual	Flat	Medium	(Mast bump only)	Yes	No	?	No

Investigation reference	Report title	Operation	Terrain	Weight	Blade strike location	Handling likely a factor	Turbulence likely a factor	Experience likely a factor	Helicopter performance likely a factor
CAA 15/1229	Robinson R22 Beta ZK-HMW, mast bump, Clevedon, 19 March 2015	Training – dual	Mountainous	Heavy	(Mast bump only)	Yes	No	Yes	No

Appendix 2: *Robinson Helicopter Fleet Consultation Document* results

The CAA's *Robinson Helicopter Fleet Consultation Document* concluded that:

(a) There is an absence of rigour in the regulatory oversight of Robinson safety awareness training, in that the CAA has no way of conducting oversight of those giving the training, or the content of the training that is given;

(b) Similarly, there is no mechanism for ensuring that those providing Robinson safety awareness training have been assessed as appropriate for conducting that training;

(c) Robinson safety awareness training is necessary for the safe operation of the R22;

(d) Although the R44 and R66 are less susceptible than the R22 to the risks focused on in Robinson safety awareness training, as a result of the similarities of these aircraft types combined with New Zealand accident data it is important that R44 and R66 pilots have a clear understanding of these risks and mitigation strategies;

(e) However, despite that, there is currently no mechanism for requiring that those flying the R44 and R66 have had that training;

(f) The 10-hour minimum flight experience requirement for first solo flight in the R22 does not match the 20 hour period required in the SFAR;

(g) The current R22 flight manual contains seemingly contradictory statements concerning Low G hazard training, which is now prohibited by Robinson; and

(h) The flight manual includes requirements as to enhanced autorotation which, while consistent with the SFAR, are redundant in New Zealand due to our generic helicopter training requirements.

The CAA proposed to:

(a) Require all Robinson safety awareness training to be done under the authority of either a Part 119 or Part 141 certificate;

(b) Require the training given to be acceptable to the Director;

(c) Require those persons delivering Robinson safety awareness training to have been approved to do so by a flight examiner;

(d) Require Robinson safety awareness training as part of the type rating requirements for the R44 and R66;

(e) Require Robinson safety awareness training to be completed by all pilots who hold R44 and R66 type ratings and who wish to exercise the privileges of those type ratings;

(f) Increase the minimum flight experience for first solo flight in an R22 from 10 hours to 20 hours;

(g) Amend the R22 flight manual to remove references to Low 'G' flight demonstration and enhanced autorotations.

Appendix 3: Detailed summary of wreckage examination and testing

All major components of the helicopter, including flight and engine controls, main rotor and tail rotor assembles, landing skids, and fuselage were accounted for at the site and removed for further examination.

Flight controls

Dual flight controls had been installed.[51] The cyclic control stick had broken off near the floor. Both the left and the right cyclic extension handles had been broken off, with the left extension handle having an impact mark that matched the curve of the leading edge of a main rotor blade. The collective lever was nearly fully down. However, the distance between the slider slot and the centre of the friction bolt corresponded to the collective lever having been raised about 15% when the bolt was broken. The tail rotor pedals had broken off at the push-pull tubes below the cabin floor.

Connectivity of the flight controls through to the main rotor and tail rotor was established. No evidence of pre-impact failure or problems was found.

Engine and controls

The mixture control in the cockpit was found in the full rich position, while the mixture control lever on the fuel control servo was in a position close to full lean. The throttle twist grip on the right-seat collective lever was close to fully off, while the throttle arm on the fuel control servo was in a position beyond full throttle. These anomalies were considered to be a result of the major disruption to the assemblies during the in-flight break-up and impact with the ground.

The engine cooling fan displayed scoring around its perimeter and on the inlet cone surfaces. Similar scoring marks were found on the steel tubing adjacent to the upper drive belt sheave and on the forward end of the tail cone's bottom surface. The marks on the steel tubing were parallel to the direction of sheave rotation, and the marks at the forward end of the tailcone were parallel to the direction of rotation of the engine cooling fan. The right oil cooler had a series of dents that matched the starter ring gear.

The drive belts were intact, except one that had a partial split. There was no evidence that the belts had rolled off. The belt tension actuator was fractured between the anti-rotation scissors. The distance between the anti-rotation scissors was measured to be 0.9 inches. When tensioned normally the distance is between 0.8 inches and 1.1 inches. The upper and lower belt tension actuator bearings rotated freely.

The clutch was examined and found to lock and free wheel normally. The temperature alerting decal on the clutch showed no record of any excessive stress. The clutch was examined by a licensed engineer familiar with the R44 and clutch assembly. The clutch assembly was fitted with a Revision 'H' sprag and showed "virtually no sign of 'in service' wear". Tear damage was found on about one-third of the circumference of the inner race. This matched marks on the same end of each pall. The damage was in the direction of drive. The main rotor gearbox rotated freely, despite the main rotor drive shaft being bent about 10º.

The engine was removed and taken to an approved aircraft engine overhaul facility and subjected to a bulk strip inspection[52] under the supervision of a Commission investigator. Maintenance records matched the engine and all applicable airworthiness directives were found to have been embodied.

The numbers 3 and 5 cylinders had impact damage, including pieces of wood embedded between the cylinders.[53] However, all cylinders were able to be removed for examination. The valve train, piston assemblies and spark plugs were found to be serviceable. The crank shaft and connecting rods were all able to be turned without restriction. No contamination was found in any of the filters.

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[51] A second set of flight controls to permit instruction from the left seat.
[52] The disassembly of the engine to its individual components.
[53] This was the side of the engine that was leaning against the tree.

Engine accessories, including the magnetos, fuel control unit and fuel pump were all removed and tested, with no defects found. The fuel control unit was free of any contamination. The testing of the fuel flow divider did identify a 'slightly restricted flow due to tiny metallic particle contamination' for the #5 nozzle.

In summary, the engineering company determined that 'no evidence was found of any pre impact defect that would have affected the engine's ability to run. The restriction in the #5 nozzle may have caused the engine to run slightly rough with minor power loss'. The instructor and student were very unlikely to have noticed any difference in helicopter performance.

Main rotor

Both of the pitch change links, which connect the swashplate to the main rotor blades and control the pitch angle of the blades, had failed in overload,[54] likely after a reverse bending motion (see Figure 10). Both teeter stops were split horizontally through the middle, and their retention brackets were bent. The droop stops and tusks were intact. There was arc-shaped scoring on both sides of the hub and denting above the blade spindles. The denting was deeper above the blue blade than the red blade. The red blade had rotated more than 90° with the pitch horn found sitting above the head. The drive collar/yoke for the upper swashplate had rotated about 90° anti-clockwise on the shaft.[55]

Both main rotor blades had fractured (see Figure 11). Because the fracture of the red blade was near the point where another R44 blade had failed, which the CAA suspected had been due to fatigue, the Commission had this blade examined by a metallurgist at the earliest opportunity. The metallurgist's initial assessment was that the blade had failed in overload. Subsequent detailed examination by the same laboratory and a further examination by an ATSB metallurgist confirmed this. The ATSB also determined that the failure of the blue blade was also the result of overload and not fatigue. Both blades were examined for signs of any pre-existing delamination or dis-bonding, and none was found.[56]

The red blade (serial #3709) had an initial 90° downward bend approximately 0.6 m from the hub. A second 90° twisting downward bend a further 1.9 m along the blade matched where the leading edge spar had fractured. The rest of the blade had fractured a further approximately 30 centimetres along, near the change in chord. There was significant scoring of the blade's lower surface around this area. The marks were multi-directional. The tip of the blade was folded upward about 75° for about 20 centimetres behind the leading edge spar.

The blue blade (serial #3761) had fractured about 1.4 m from the hub. A further approximately 1.5 m of the trailing edge doubler had been torn out from the outboard portion of the blade. The blade was mostly straight with an approximately 30° upward bend about 0.6 m from the hub.

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[54] Overload is the common term used to describe the mode of failure where the force sustained exceeded the material's physical strength or design load.
[55] The normal direction of rotation of the main rotor is anti-clockwise when viewed from above.
[56] The earlier R44 'Dash 2' and 'Dash 5' blades were subject to a Continuing Airworthiness Notice following several cases of disbonding near the blade tip. The Dash 7 blades fitted to ZK-IPY were not subject to the same inspection requirement.

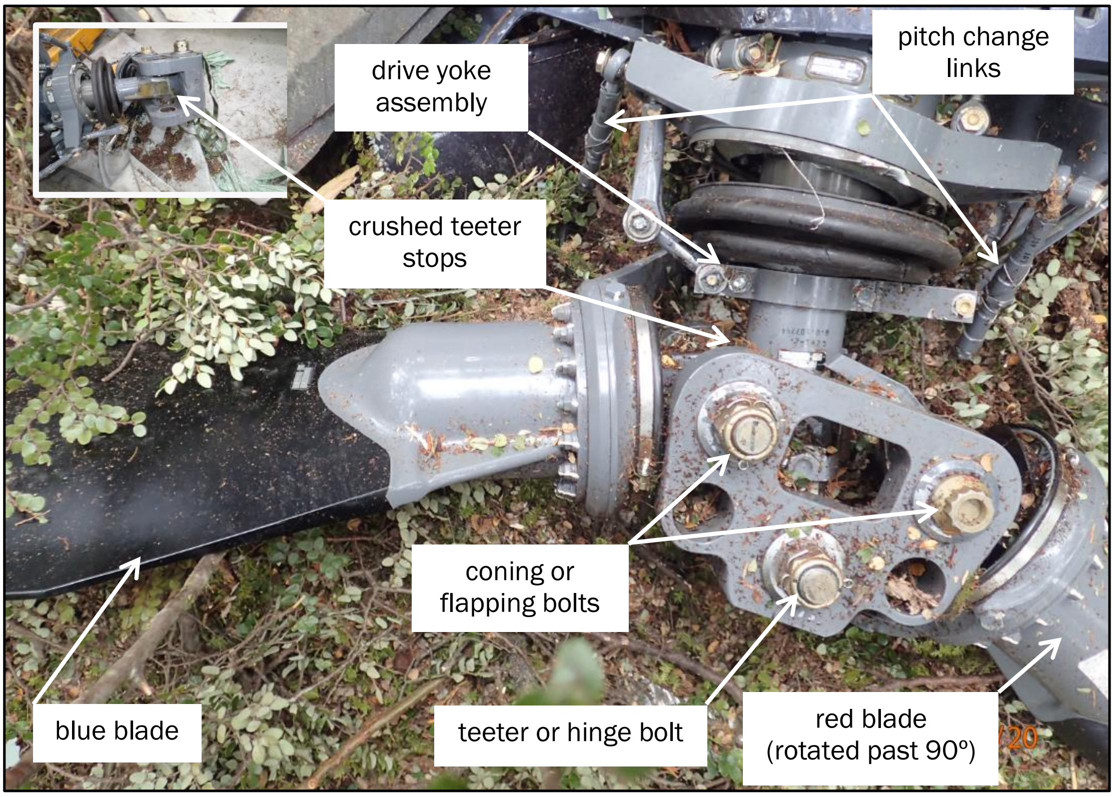


Figure 10
Main rotor head showing broken components and extreme flapping of blades

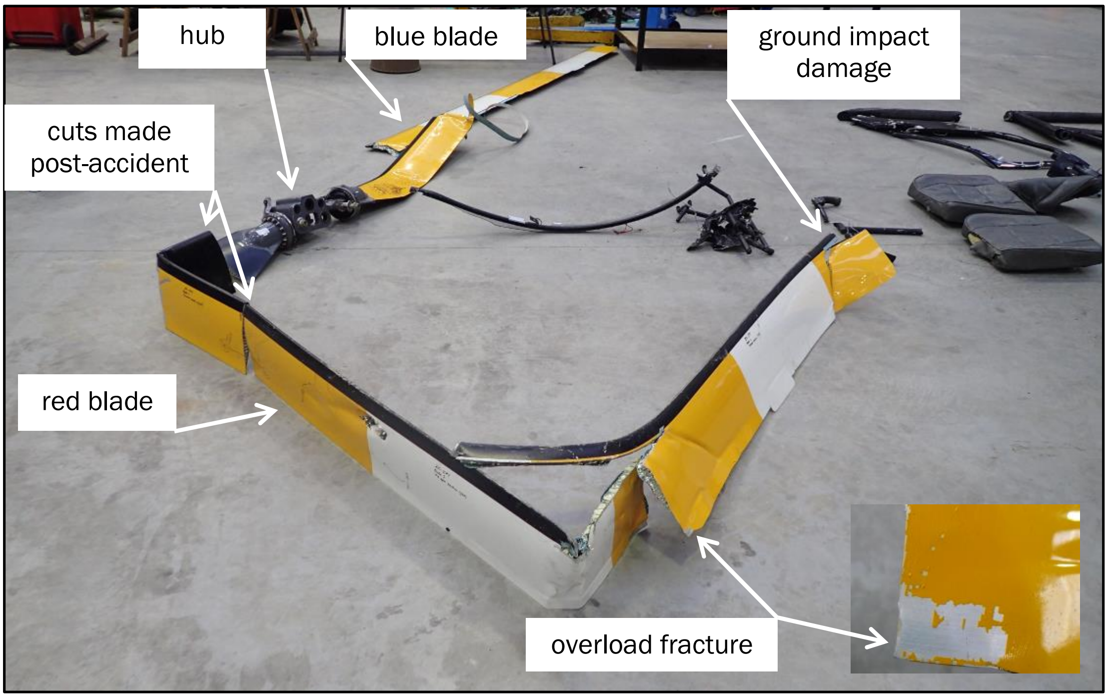


Figure 11
Main rotor blade damage

Tail rotor

The intermediate and aft flexible couplings were bent and separated. The gearbox and tail rotor assembly had separated, with the gearbox able to be rotated freely. One tail rotor blade was essentially straight while the second had two large bends along its length. There was no rotational damage found on the drive assembly aft of the main transmission. The drive shaft was bent but intact.

Fuselage

The airframe and cabin was severely distorted and displaced/bent to the left. Some components, for example the windshield centre frame bow and sections of the doors, had separated from the main wreckage. The instrument console was broken in several places. There was evidence of a main rotor blade having struck the instrument console and the windshield bow and the cabin roof above the left windshield also displayed distortions that approximated to the leading edge of a main rotor blade.

The two left side doors when reassembled had a fracture line that ran through the upper portion of the doors. Both fuel tanks had separated from the fuselage and had significant deformation. Both tanks had bladders installed and their caps were in place. The tanks were found empty, however the smell of fuel about the wreckage and the heavy ground indent and smell where the main tank had landed, indicated both tanks contained some fuel on impact. The main fuel filter was intact and found to contain fuel that was consistent with the correct fuel for the helicopter. The filter screen was clean and vent lines free of obstruction.

The tail boom was straight with two large impact marks, one on the underside near the fuselage attachment and a second on the upper surface near the empennage. The empennage had broken off with damage on the horizontal and upper vertical stabilizers.

The left skid and the toe or front section of the right skid had broken from the landing gear. The left skid was recovered in four sections. The section located between the two cross-tubes, displayed a deformation on the underside that matched the shape of a main rotor blade leading edge.

Instruments and readings

The upper instrument console, found near the start of the wreckage trail, had a deformation consistent with having been struck by a main rotor blade. The instruments normally held by the upper console had been dislodged, with the exception of the vertical speed indicator. Most of the warning lights at the top of the console were either broken or missing. The only light showing evidence of 'hot stretch'[57] was the clutch light. None of the temperature indication stickers on gear boxes and the hydraulic pump showed any evidence of excessive heat having been generated in these components.

The ignition was in the OFF position with the key broken off at the switch face. The clutch switch had lifted and was disengaged. The governor and fuel valve were on. Trapped engine instrument readings included oil pressure about 25 [psi], oil temperature about 75 [°F] and cylinder head temperature about 200 [°F]. The rotor tachometer needle was on the bottom peg, while the engine needle was bent at a reading of about 58%. The vertical speed indicator read 300 feet per minute down.

[57] Hot stretch can indicate that the filament was hot, and therefore illuminated, at the time of impact.

Safety Notice SN-10

Issued: Oct 82 Rev: Feb 89; Jun 94

FATAL ACCIDENTS CAUSED BY LOW RPM ROTOR STALL

A primary cause of fatal accidents in light helicopters is failure to maintain rotor RPM. To avoid this, every pilot must have his reflexes conditioned so he will instantly add throttle and lower collective to maintain RPM in any emergency.

The R22 and R44 have demonstrated excellent crashworthiness as long as the pilot flies the aircraft all the way to the ground and executes a flare at the bottom to reduce his airspeed and rate of descend. Even when going down into rough terrain, trees, wires or water, he must force himself to lower the collective to maintain RPM until just before impact. The ship may roll over and be severly [sic] damaged, but the occupants have an excellent chance of walking away from it without injury.

Power available from the engine is directly proportional to RPM. If the RPM drops 10%, there is 10% less power. With less power, the helicopter will start to settle, and if the collective is raised to stop it from settling, the RPM will be pulled down even lower, causing the ship to settle even faster. If the pilot not only fails to lower collective, but instead pulls up on the collective to keep the ship from going down, the rotor will stall almost immediately. When it stalls, the blades will either "blow back" and cut off the tail cone or it will just stop flying, allowing the helicopter to fall at an extreme rate. In either case, the resulting crash is likely to be fatal.

No matter what causes the low rotor RPM, the pilot must first roll on throttle and lower the collective simultaneously to recover RPM **before** investigating the problem. It must be a conditioned reflex. In forward flight, applying aft cyclic to bleed off airspeed will also help recover lost RPM.

Safety Notice SN-11

Issued: Oct 82 Rev: Nov00

LOW-G PUSHOVERS – EXTREMELY DANGEROUS

Pushing the cyclic forward following a pull-up or rapid climb, or even from level flight, produces a low-G (weightless) flight condition. If the helicopter is still pitching forward when the pilot applies aft cyclic to reload the rotor, the rotor disc may tilt aft relative to the fuselage before it is reloaded. The main rotor torque reaction will then combine with tail rotor thrust to produce a powerful right rolling moment on the fuselage. With no lift from the rotor, there is no lateral control to stop the rapid right roll and mast bumping can occur. Severe in-flight mast bumping usually results in main rotor shaft separation and/or rotor blade contact with the fuselage.

The rotor must be reloaded before lateral cyclic can stop the right roll. To reload the rotor, apply an immediate gentle aft cyclic, but avoid any large aft cyclic inputs. (The low-G which occurs during a rapid autorotation entry is not a problem because lowering collective reduces both rotor lift and rotor torque at the same time.)

Never attempt to demonstrate or experiment with low-G maneuvres [sic], 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 maneuvre [sic] which could result in a low-G condition. Low-G mast bumping accidents are almost always fatal.

NEVER PERFORM A LOW-G PUSHOVER!!

Safety Notice SN-24

Issued: Sep 86 Rev: Jun 94

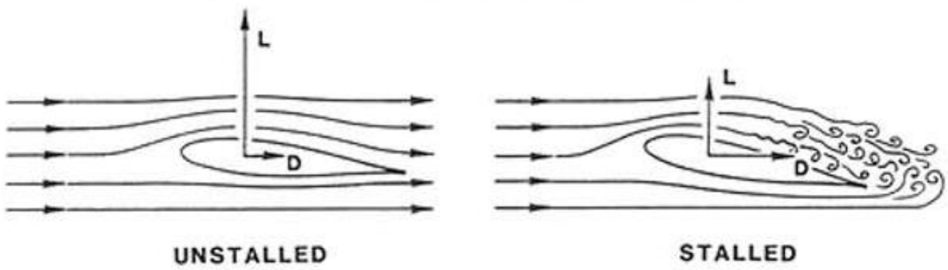
LOW RPM ROTOR STALL CAN BE FATAL

Rotor stall due to low RPM causes a very high percentage of helicopter accidents, both fatal and non-fatal. Frequently misunderstood, rotor stall is not to be confused with retreating tip stall which occurs only at high forward speeds when stall occurs over a small portion of the retreating blade tip. Retreating tip stall causes vibration and control problems, but the rotor is still very capable of providing sufficient lift to support the weight of the helicopter.

Rotor stall, on the other hand, can occur at any airspeed and when it does, the rotor stops producing the lift required to support the helicopter and the aircraft literally falls out of the sky. Fortunately, rotor stall accidents most often occur close to the ground during takeoff or landing and the helicopter falls only four or five feet. The helicopter is wrecked but the occupants survive. However, rotor stall also occurs at higher altitudes and when it happens at heights above 40 or 50 feet AGL it is most likely to be fatal.

Rotor stall is very similar to the stall of an airplane wing at low airspeeds. As the airspeed of an airplane gets lower, the nose-up angle, or angle-of-attack, of the wing must be higher for the wing to produce the lift required to support the weight of the airplane. At a critical angle (about 15 degrees), the airflow over the wing will separate and stall, causing a sudden loss of lift and a very large increase in drag. The airplane pilot recovers by lowering the nose of the airplane to reduce the wing angle-of-attack below stall and adds power to recover the lost airspeed.

The same thing happens during rotor stall with a helicopter except it occurs due to low rotor RPM instead of low airspeed. As the RPM of the rotor gets lower, the angle-of-attack of the rotor blades must be higher to generate the lift required to support the weight of the helicopter. Even if the collective is not raised by the pilot to provide the higher blade angle, the helicopter will start to descend untii the



Wing or rotor blade unstalled and stalled.

Safety Notice SN-24 (continued)

upward movement of air to the rotor provides the necessary increase in blade angle-of-attack. As with the airplane wing, the blade airfoil will stall at a critical angle, resulting in a sudden loss of lift and a large increase in drag. The increased drag on the blades acts like a huge rotor brake causing the rotor RPM to rapidly decrease, further increasing the rotor stall. As the helicopter begins to fall, the upward rushing air continues to increase the angle-of-attack on the slowly rotating blades, making recovery virtually impossible, even with full down collective.

When the rotor stalls, it does not do so symmetrically because any forward airspeed of the helicopter will produce a higher airflow on the advancing blade than on the retreating blade. This causes the retreating blade to stall first, allowing it to dive as it goes aft while the advancing blade is still climbing as it goes forward. The resulting low aft blade and high forward blade become a rapid aft tilting of the rotor disc sometimes referred to as "rotor blow-back". Also, as the helicopter begins to fall, the upward flow of air under the tail surfaces tends to pitch the aircraft nose-down. These two effects, combined with aft cyclic by the pilot attempting to keep the nose from dropping, will frequently allow the rotor blades to blow back and chop off the tailboom as the stalled helicopter falls. Due to the magnitude of the forces involved and the flexibility of rotor blades, rotor teeter stops will not prevent the boom chop. The resulting boom chop, however, is academic, as the aircraft and its occupants are already doomed by the stalled rotor before the chop occurs.

Safety Notice SN-32

Issued March 1998 Revised May 2013

<u>HIGH WINDS OR TURBULENCE</u>

A pilot's improper application of control inputs in response to high winds or turbulence can increase the likelihood of a mast bumping accident. The following procedures are recommended:

1. If turbulence is expected, reduce power and use a slower than normal cruise speed. Mast bumping is less likely at lower airspeeds.

2. If significant turbulence is encountered, reduce airspeed to 60 – 70 knots.

3. Tighten seat belt and firmly rest forearm on right leg to prevent unintentional control inputs.

4. Do not over-control. Allow aircraft to go with the turbulence, then restore level flight with smooth, gentle control inputs. Momentary airspeed, heading, altitude, and RPM excursions are to be expected.

5. Avoid flying on the downwind side of hills, ridges, or tall buildings where the turbulence will likely be most severe.

The helicopter is more susceptible to turbulence at light weight. Use caution when flying solo or lightly loaded.

Recent Aviation Occurrence Reports published by the Transport Accident Investigation Commission (most recent at top of list)

AO-2013-008	Boeing 737-300, ZK-NGI, Loss of cabin pressure, near Raglan, Waikato, 30 August 2013
AO-2013-003	Robinson R66, ZK-IHU, Mast bump and in-flight break-up, Kaweka Range, 9 March 2013
AO-2014-002	Kawasaki BK117 B-2, ZK-HJC, Double engine power loss, Near Springston, Canterbury, 5 May 2014
AO-2013-006	Misaligned take-off at night, Airbus A340, CC-CQF, Auckland Airport, 18 May 2013
AO-2010-009	Addendum to Final Report: Walter Fletcher FU24, ZK-EUF, loss of control on take-off and impact with terrain, Fox Glacier aerodrome, South Westland, 4 September 2010
AO-2012-002	Airbus A320 ZK-OJQ, Bird strike and subsequent engine failure, Wellington and Auckland International Airports, 20 June 2012
AO-2013-005	In-flight loss of control, Robinson R22, ZK-HIE, near New Plymouth, 30 March 2013
AO-2013-007	Boeing 737-838, ZK-ZQG, stabiliser trim mechanism damage, 7 June 2013
AO-2013-009	RNZAF Boeing 757, NZ7571, landing below published minima, Pegasus Field, Antarctica, 7 October 2013
AO-2013-002	Robinson R44, ZK-HAD, engine power loss and ditching, Lake Rotorua, 24 February 2013
11-007	Descent below instrument approach minima, Christchurch International Airport, 29 October 2011
11-006	Britten-Norman BN.2A Mk.III-2, ZK-LGF, runway excursion, Pauanui Beach Aerodrome, 22 October 2011
11-003	In-flight break-up ZK-HMU, Robinson R22, near Mount Aspiring, 27 April 2011
12-001	Hot-air balloon collision with power lines, and in-flight fire, near Carterton, 7 January 2012
11-004	Piper PA31-350 Navajo Chieftain, ZK-MYS, landing without nose landing gear extended, Nelson Aerodrome, 11 May 2011
11-005	Engine compressor surges, 18 September 2011

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