Final Report AO-2013-003: Robinson R66, ZK-IHU,
Mast bump and in-flight break-up, Kaweka Range, 9 March 2013

Final Report

Aviation inquiry AO-2013-003

Robinson R66, ZK-IHU
Mast bump and in-flight break-up

Kaweka Range, 9 March 2013

Approved for publication: April 2016

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

The Transport Accident Investigation Commission (Commission) is 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, 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

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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	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	

Robinson Helicopter R66, ZK-IHU

Photograph provided by the operator

Source: mapsof.net

Location of accident

Contents

Figures

Abbreviations

°C	degree(s) Celsius
°T	degree(s) true
AD	airworthiness directive
CAA	Civil Aviation Authority of New Zealand
Commission	Transport Accident Investigation Commission
FAA	Federal Aviation Administration (United States)
FAR	Federal Aviation Regulation (United States)
MGT	measured gas temperature
NTSB	National Transportation Safety Board (United States)
R22	Robinson Helicopter Company helicopter type R22
R44	Robinson Helicopter Company helicopter type R44
R66	Robinson Helicopter Company helicopter type R66
Robinson	Robinson Helicopter Company
RPM	revolution(s) per minute
SFAR	Special Federal Aviation Regulation (United States)

Glossary

centre of gravity	the single point in a helicopter through which the weight (or force of gravity) acts
cyclic stick	one of two main rotor controls. Movement of the cyclic stick causes the rotor blade pitch angles to change, which causes the rotor 'disc' to tilt in the same direction in which the pilot has put the stick. The helicopter then moves in that direction. This can be sideways, forwards or backwards (aft) or any direction
exposition	a description of an operator's organisational structure, and the means and methods for ensuring ongoing compliance with Civil Aviation Rules, which is provided to the Civil Aviation Authority of New Zealand in support of an operator's application for a certificate
flapping	(in the case of the Robinson main rotor blades) the vertical movement of a blade about a hinge perpendicular to the blade span
flight envelope	(or operating envelope) the range of airspeed, load factor and altitude for an aircraft, as established by the design and verified during certification testing
fractography	the examination of the cause of a material failure by studying the characteristics of the fracture surfaces
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 on a helicopter, or (depending on context) the aerodynamic fairing installed around the drive shaft to reduce drag and improve appearance
mast bump	contact between the inboard end of a main rotor blade or the rotor hub and the main rotor drive shaft
moderate turbulence	turbulence that causes: (1) changes in aircraft altitude or attitude; (2) variations in indicated airspeed; or (3) aircraft occupants to feel definite strain against seat belts
servo	an hydraulic actuator attached to a main rotor flight control to reduce the effort required by the pilot to change the rotor tilt or blade pitch angle
spindle	the pitch change bearing of a main rotor blade
sprag clutch	transfers the engine torque to the main rotor transmission. In the event of an engine failure the sprags withdraw, allowing the rotor to continue to turn so that the helicopter can autorotate to a landing
teetering	the see-saw movement of a two-bladed, centrally mounted rotor hub
type rating	the authorisation associated with a pilot's licence that states the pilot is qualified to fly a specific aircraft type

Data summary

Aircraft particulars

Aircraft registration:	ZK-IHU
Type and serial number:	Robinson Helicopter Company R66, 0078
Number and type of engines:	one Rolls-Royce 250C-300 turbo-shaft, serial number RRE 200082
Year of manufacture:	2011
Operator:	Helisika Limited
Type of flight:	commercial air transport
Persons on board:	one
Pilot's licence:	commercial pilot licence (helicopter)
Pilot's age:	39
Pilot's total flying experience:	492 hours, of which 420 hours were in helicopters and 154 hours of those hours were in the R66

Date and time	9 March 2013, 1302[1]
Location	Kaweka Range
	latitude: 39° 07' 44.78" south
	longitude: 176° 12' 34.30" east
Injuries	one fatal
Damage	destroyed

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

1. Executive summary

1.1. On 9 March 2013 a Robinson Helicopter Company (Robinson) R66 helicopter crashed in the North Island's Kaweka Range after experiencing an occurrence known as a 'mast bump'. A main rotor blade then struck the fuselage, causing the helicopter to break up in flight. The pilot, who was the only person on board, was killed.

1.2. The weather was suitable for the flight, which was conducted under visual flight rules in uncontrolled airspace. However, the wind strength had increased during the day, leading to patches of moderate turbulence in the mountainous terrain. It was very likely that turbulence was a factor in the accident. The helicopter's light gross weight and relatively high speed at the time would have exacerbated the effects of any turbulence.

1.3. The Commission found that this accident, when considered alongside four other R66 accidents that have occurred globally in the five years since the helicopter type was introduced into service in 2010, suggested that the R66 was as vulnerable as the smaller Robinson R22 and R44 types to a catastrophic mast bump under certain conditions. The R66 has the same main rotor system design as the R22 and the R44.

1.4. The R66 was certificated by the Federal Aviation Administration of the United States without any special training requirements like those that are mandated for pilots of the R22 and the R44 to reduce the risk of mast bump accidents. That was in spite of having the same main rotor design and a similar response to low G conditions as the R22 and R44. The Civil Aviation Authority of New Zealand accepted the Federal Aviation Administration type certificate for the R66 in April 2011, and also did not require special training for R66 pilots.

1.5. A safety issue arose as a result of there being no special training. A helicopter pilot (or trainee) with no prior experience of flying one of the smaller Robinson types could fly the R66 without necessarily having the knowledge and training that the Federal Aviation Administration acknowledged was essential for pilots of all Robinson types. There was also a risk that a pilot who did have prior R22 or R44 experience would infer, from the lack of any special training requirement, that the R66 did not require the same careful handling as the smaller types.

1.6. Recommendations were made to the Administrator of the Federal Aviation Administration and the Director of Civil Aviation to require additional training as a prerequisite for an R66 type rating.

1.7. It is likely that mast bump accidents with Robinson helicopters will continue to happen unless the dynamic behaviour of the main rotor preceding such a catastrophe is fully understood. A recommendation was made to the Administrator of the Federal Aviation Administration to reinstate uncompleted research into the dynamic behaviour of lightweight helicopter main rotor systems.

1.8. A further recommendation was made to the Director of Civil Aviation to publicise the recent amendments to the Robinson R66 and R44 Pilot's Operating Handbooks that caution against flight in high winds and turbulence.

Safety issues

1.9. The following safety issues were identified in this investigation:

- Four of the seven fatal R66 accidents that have occurred globally since the type was introduced into service in 2010 were mast bump or low-main-rotor–speed accidents. These are accident types seen with the smaller R22 and R44, which have the same main rotor design. However, the R66 was certificated without any special pilot training requirements to mitigate the risk of these types of accident.
- At the time of this accident the flight manuals for Robinson helicopters did not adequately warn pilots of the hazardous operating practices and environmental conditions that can lead rapidly to a catastrophic mast bump.

- Earlier research into the flight control systems and dynamic behaviour of the main rotor of lightweight helicopters, for example, the design used by Robinson, was not completed as intended. Until the behaviour of such rotor systems in conditions of low G and turbulence is fully understood, it is possible that not all of the causal factors of mast bump accidents will be identified.

Findings

1.10. The Commission made the following findings:

- The in-flight break-up was caused by a mast bump and main rotor blade contact with the fuselage.
- The mast bump very likely occurred when the helicopter encountered moderate or greater turbulence, which likely resulted in a condition of low G.[2] The effect of any turbulence would have been exacerbated by the helicopter's light weight and estimated airspeed of 115 knots.
- The possibility that an intentional or inadvertent control input by the pilot contributed to the mast bump cannot be excluded.
- The R66 global accident history, in the five years since the type was introduced into service in 2010, suggests that the R66 is as vulnerable as the smaller R22 and R44 to a catastrophic mast bump under certain conditions.
- The R66 was certificated without any special pilot training requirements to mitigate the risk of a catastrophic mast bump.
- At the time of the accident, the Robinson helicopter flight manuals did not adequately warn pilots of the hazardous operating practices and environmental conditions that can lead rapidly to a catastrophic mast bump. This type of accident is strongly associated with turbulent conditions.
- There is insufficient industry knowledge of why Robinson helicopters are particularly vulnerable to catastrophic mast bump events.
- In spite of the lack of reference in the operator's exposition to mountain flying training, the pilot's training was unlikely to have been a factor in the accident.

Recommendations

1.11. The Commission made the following recommendations:

To the Administrator of the Federal Aviation Administration:

- That he extend the knowledge and training requirements of Special Federal Aviation Regulation No. 73 to pilots of the Robinson R66 helicopter.
- That he reinstate research into the dynamic behaviour of two-bladed, teetering,[3] underslung rotor systems, taking full advantage of available technology, with the aim of achieving the original goal of National Transportation Safety Board (United States) recommendation A-96-12.

To the Director of Civil Aviation:

- That he include the knowledge and training requirements of Special Federal Aviation Regulation No. 73, or an equivalent requirement, as a prerequisite for the issue of a Robinson R66 type rating.
- That he promptly publicise the recent amendments to the Robinson R66 and R44 Pilot's Operating Handbooks that caution against flight in high winds and turbulence, and which advise pilots to reduce power and speed if turbulence is expected or encountered.

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[2] A low-G condition occurs when an object is subjected to a net vertical force less than the force of gravity.
[3] Teetering is the see-saw movement of a two-bladed, centrally mounted rotor hub.

Key lessons

1.12. The key lessons identified from the inquiry into this accident were:

- Pilots must be familiar with the complete Pilot's Operating Handbook for each aircraft type that they fly, as well as the approved flight manuals.
- Pilots of Robinson helicopters, regardless of their experience, should avoid areas of high winds or turbulence, and closely adhere to the manufacturer's advice to reduce airspeed if turbulence is encountered.

2. Conduct of the inquiry

2.1. On Saturday 9 March 2013 the Civil Aviation Authority of New Zealand (CAA) notified the Transport Accident Investigation Commission (the Commission) that an R66 was overdue from a flight and that a search was underway. After the accident site had been located later that day, the Commission opened an inquiry under section 13(1) of the Transport Accident Investigation Commission Act 1990.

2.2. On 10 March 2013 two Commission investigators began an inspection of the accident site. Most of the wreckage was recovered by 12 March 2013, but the main rotor hub and blades were not found until 13 March 2013. The wreckage was taken to the Commission's storage facility near Wellington.

2.3. On 11 March 2013, the National Transportation Safety Board (United States) (NTSB) appointed a staff member to be the Accredited Representative[4] of the United States, the State of Manufacture of the helicopter and the engine. The Accredited Representative's advisers, from Robinson Helicopter Company (Robinson) and Rolls-Royce (the engine manufacturer), assisted the Commission's investigators with a wreckage examination conducted between 15 and 18 March 2013.

2.4. The engine was disassembled and examined on 1 May 2013 at the Rolls-Royce factory in the United States, under the supervision of the NTSB on behalf of the Commission. The flight control hydraulic servos[5] and the engine-transmission clutch were examined at the Robinson factory in the United States, again under NTSB supervision.

2.5. On 9 May 2013 Commission investigators hosted a forum to further their understanding of issues relating to the performance and handling of Robinson helicopters, and the training provided to pilots of Robinson helicopters. At the time the Commission had three open investigations into accidents that involved Robinson helicopters. The forum participants comprised six experienced helicopter instructors, three CAA staff and five Commission staff.

2.6. Two engine accessories, the power turbine governor and the fuel control unit, were examined on 14 May 2013 at the premises of their manufacturer in the United States, under the supervision of a Federal Aviation Administration (United States) (FAA) inspector acting for the NTSB.

2.7. The pathologist who conducted the post-mortem examination of the pilot inspected the helicopter wreckage at the Commission's storage facility.

2.8. The Commission contracted the Defence Technology Agency of the New Zealand Defence Force to determine the failure mode of the main rotor drive shaft.

2.9. On 13 June 2013, after advice that other items of wreckage had been found, the accident site was re-visited with the support of the Royal New Zealand Air Force, and a small amount of material was recovered.

2.10. The Commission obtained information from the NTSB, Robinson and the FAA at various times throughout the inquiry.

2.11. On 24 September 2015 the Commission approved the draft final report for circulation to interested persons for their comment. Submissions were received from three of the interested persons. The Commission has considered all submissions, and any changes as a result of those submissions have been included in this final report.

2.12. On 27th April 2016 March 2016 the Commission approved publication of the final report.

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[4] In accordance with Annex 13 to the Convention on International Civil Aviation.

[5] A servo is an hydraulic actuator attached to a main rotor flight control to reduce the effort required by the pilot to change the rotor tilt or the blade pitch angle.

3. Factual information

3.1. Narrative

3.1.1. On Saturday 9 March 2013, a Robinson R66 helicopter (the helicopter) was being used to ferry hunters and fishermen to and from remote sites in the Kaweka and Kaimanawa Ranges. The pilot had commenced duty at about 0900 and had made five return flights during the morning carrying passengers to or from various landing sites.

3.1.2. The flights were conducted under visual flight rules in uncontrolled airspace. The weather was generally clear and warm but, according to the passengers, some turbulence had been experienced on every flight that day.

3.1.3. On the last flight before the accident flight the pilot flew two hunters to the Mangataramea Hut. The hunters were familiar with helicopters: one had been a pilot for a different operator, and the other had also flown in this helicopter twice before. They described the pilot as engaging and conscientious. They said the flight was "normal" and the conditions "a little gusty" with a "bump" when they crossed one saddle, but otherwise they had no concern.

3.1.4. Having delivered the hunters to the hut, the pilot was returning alone via the Waitawhero Saddle and the Oamaru River valley to the operator's base at Poronui Station. The last data transmitted from an on-board 'Spidertracks' unit[6] was as follows:

- time: 0001:30 co-ordinated universal time (1301:30 New Zealand Daylight Time)
- position: 39° 8.23' south, 177° 11.898' east
- altitude: 4,006 feet[7] (1,221 metres)
- ground speed: 124 knots[8]
- heading: 033 degrees true (°T).[9]

3.1.5. When the helicopter was 30 minutes overdue at the base, the operator's chief pilot promptly commenced a search, guided by the last Spidertracks position. No signal was received from the on-board emergency locator transmitter. Although the search was hampered by strong winds and turbulence, the accident site was located later that day in dense bush, approximately 1,500 metres after the last transmitted position (see Figure 1). The fatally injured pilot was found the next morning, about 30 metres from the fuselage. The main rotor, which had separated from the mast,[10] was found three days later.

3.1.6. Based on the last ground speed transmitted by an on-board tracking device, the accident occurred at around 1302 in daylight, 600 metres south of the Oamaru River, at an elevation of approximately 3,400 feet (1,040 metres) above mean sea level.

3.2. Personnel information

3.2.1. The pilot had obtained a private pilot licence (aeroplane) in 1996, then taken a break from flying until he commenced helicopter training in January 2012 on the Robinson R22. Prior to his first solo flight in the R22 he had completed the special awareness and flight training (special training) required for all R22 pilots.[11] He had obtained a private pilot licence

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[6] Spidertracks is a proprietary tracking system that sends the global positioning system-derived position of the unit by text message to a satellite constellation and then to a ground-based server.
[7] Vertical distances in aviation are still expressed in imperial units.
[8] A knot is a speed of one nautical mile per hour.
[9] This was taken to be the track over the ground, rather than the helicopter heading.
[10] The drive shaft is sometimes called the 'mast', although that term may also be applied to the aerodynamic fairing installed around the drive shaft to reduce drag and improve appearance.
[11] Section 3.9 describes this requirement.

(helicopter) in March 2012 and a commercial pilot licence (helicopter) in May 2012. While training for the commercial licence he had also obtained a Robinson R44 type rating.[12]

3.2.2. The operator had hired the pilot on 6 June 2012, on the recommendation of his instructor. The operator's approved external flight examiner had conducted the pilot's initial crew competency check on 15 June 2012, in conjunction with the pilot obtaining an R66 type rating. The examiner had marked the pilot as competent in all of the tested flight tasks, and for 'mountainous terrain awareness'.

Figure 1
Wreckage of fuselage

3.2.3. For the first three months after starting with the operator, the pilot had flown only the R44, mainly on scenic flights from the company's Taupo base. The chief pilot had flown with the pilot until he was familiar with the company's procedures and the many remote landing sites.

3.2.4. For the next three months the pilot had mainly flown the R66, but he had also obtained a type rating for the Hughes 500, another type in the operator's fleet. According to the operator's records, the pilot had been due for recurrent training in April 2013.

3.2.5. The pilot had 492 hours' flight experience, of which 420 hours were in helicopters. The helicopter hours included 350 in Robinson types, with nearly 160 hours in the R66. In the 90 days before the accident he had flown approximately 148 hours, split evenly between the R66 and the Hughes 500.

3.2.6. His last days free of duty had been 2 March and 3 March 2013. In the next five days he had been on duty for 47 hours and flown 10.8 hours, including about four hours on 9 March. Those who spoke with him on 9 March 2013 said he appeared to be well, alert and fit to fly.

[12] A type rating is the authorisation associated with a pilot's licence that states the pilot is qualified to fly a specific aircraft type.

3.2.7. The chief pilot said the pilot had been cautious, disciplined and highly motivated. Amateur videos made by passengers earlier in 2013 showed the pilot flying the R66 conservatively.

3.2.8. The pilot's medical certificate was valid until 15 May 2013 and had no restrictions, endorsements or limitations.

3.3. Aircraft information

General

3.3.1. The R66 is a five-seat, turbine-powered light helicopter that is manufactured by Robinson in the United States. The R66 was certificated by the FAA in October 2010. In many respects it is a larger variant of Robinson's four-seat R44, which itself evolved from the two-seat Robinson R22.[13]

3.3.2. The R66 is powered by a Rolls-Royce 250C-300 (RR300) turbo-shaft engine, also manufactured in the United States. The 300-horsepower engine was certificated by the FAA in December 2007.

3.3.3. All three Robinson types have two-blade, teetering main rotors. The blades have independent flapping hinges, a feature unique to Robinson[14] (see Figure 2). Helicopters with two-blade, teetering main rotor systems must avoid low-G conditions,[15] because these can cause the helicopter to roll without its pilot making a control input (an uncommanded roll) if the tail rotor (sideward) thrust acts at a distance well above the helicopter's centre of gravity.[16] The R66 flight manual prohibited intentional low-G manoeuvres.

3.3.4. The R66 main rotor controls, like those of the R44 and R22, are considered to be sensitive. This is reflected in the following limitation in the flight manual (Robinson Helicopter Company, 2010, p. 2.5):

> CAUTION
> Abrupt control inputs may produce high fatigue stresses and cause catastrophic failure of a critical component.

3.3.5. The Pilot's Operating Handbook comprised the mandatory FAA-approved flight manual, as well as a section of "Safety Tips and Notices" issued by Robinson. These safety tips and notices are applicable to all Robinson types. Several of the safety notices provided guidance to pilots on how to avoid a potentially catastrophic 'loss of control' of the main rotor. 'Loss of control' refers to the main rotor blades flying a path that might be different from that intended by the pilot, perhaps because of a low-G condition or because the rotor revolutions per minute (RPM) have decreased well below the specified, narrow range.

3.3.6. The helicopter involved in this accident had been manufactured in November 2011 and bought by the operator that month. The engine had been manufactured in 2010.

3.3.7. Records indicated that the helicopter had been maintained in accordance with the approved maintenance manual and instructions (see Appendix 1 for details of recent maintenance). The technical log and daily flight record, which were required to be carried in the helicopter, were not found. According to the operator's records the helicopter would have accrued approximately 739 flight hours, and the engine 786 cycles, up to the day before the accident.

3.3.8. The pilot had recorded a fuel endurance of 1.2 hours before departing on the outward leg of the last flight. The typical consumption was 100 litres per hour. Approximately 102 litres of fuel were removed from the helicopter tank after the accident. Using that volume, the gross

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[13] This report refers often to the R44 and R22 because they have the same main rotor system design as the R66, and have had similar types of accident.
[14] Flapping is the vertical movement of the blade about a hinge perpendicular to the blade span. The blades flap as a normal action throughout each revolution. Extreme flapping that can result in a mast bump is not normal.
[15] A low-G condition occurs when an object is subjected to a net vertical force less than the force of gravity. When the vertical force is zero, the object is described as being 'weightless'.
[16] The centre of gravity is the single point in a helicopter through which the weight (or force of gravity) acts.

weight of the helicopter at the time of the accident was estimated to have been 756 kilograms. The permitted weight range was 635 to 1,225 kilograms.

3.3.9. The longitudinal centre of gravity was calculated to have been 101.8 inches rearward of the datum, which was within the allowable range.[17] The lateral centre of gravity was within limits.

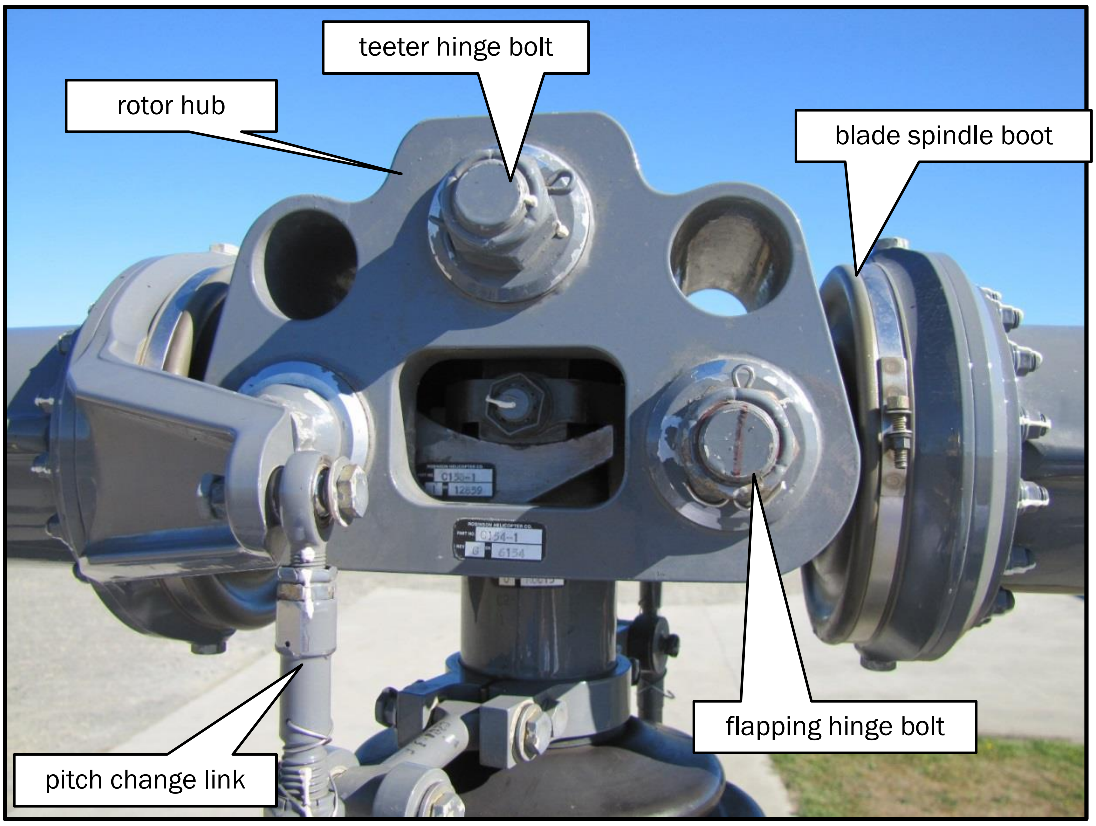

Figure 2
R66 main rotor head

Flight recorders

3.3.10. There was no requirement for the helicopter to be fitted with a flight data recorder, and none was fitted. However, a developmental engine monitoring unit was fitted and it recorded the following parameters once every second:

- gas producer (compressor) speed
- power turbine speed
- torque (the primary indicator of the power being demanded from the engine)
- measured gas temperature.

3.3.11. The recorded parameters had been within the flight manual limits until the accident. After comparing the accident flight with previous flights that day, Rolls-Royce concluded that the engine had been operating normally until the accident (see Appendix 1 for more details).

3.3.12. The Spidertracks unit transmitted the helicopter's position, altitude, ground speed and heading, nominally every four minutes.[18] Therefore, the data gave a coarse approximation of the flight path. The helicopter was approximately 840 feet (256 metres) above ground level at the last position transmitted. The Spidertracks data for all of the flights on 9 March 2013 indicated that the pilot had complied with the rules for minimum height above ground.

[17] The allowable range (given in Imperial units) was 91.0 inches to 102.5 inches.
[18] Refer paragraph 3.1.4.

3.3.13. A Garmin 'GPSmap 196' receiver that used a separate antenna to the Spidertracks unit was also fitted to the helicopter. The Garmin unit, for an undetermined reason, did not record the last flight. However, the data for the previous flights that day were reviewed.

3.4. Meteorological information

3.4.1. On 9 March 2013 a high pressure system had split into separate centres either side of the country and a weak cold front was moving up the North Island. The MetService[19] aviation forecast issued at 0503 for the morning of 9 March 2013 for the Central Plateau area, in which the accident site was located, included the following:

wind at 3,000 feet above sea level	140°T 15 knots
wind at 5,000 feet	130°T 30 knots, temperature +11 degrees Celsius (°C)
freezing level	14,000 feet

areas of broken cloud at 5,000, to 9,000 feet east of Taupo, but clearing in the morning. Nil significant weather.

At 1123 the forecast was amended to add "isolated moderate turbulence[20] expected below 6,000 feet".

3.4.2. The MetService mountain forecast issued at 0435 on 9 March 2013 predicted southeast winds, "strong about and north of the Ruahine Range". The Kaweka Range is the next range north of the Ruahine Range. At 1204 MetService amended the forecast to put the strong winds north of the Kaweka Range.

3.4.3. Visual meteorological conditions prevailed, with no rain. The chief pilot of the operator said that at its base the wind had been from the southeast at 10 to 15 knots. Over the ranges the wind was from the southeast at 15 knots, gusting to 25 knots, and stronger to the east. A passenger picked up at 1100 from a hut that was approximately 15 kilometres south of the accident site and 3,000 feet (914 metres) above sea level said the air temperature there was about 25°C.[21]

3.4.4. Local pilots estimated that the wind speed at the mountain tops was about 25 knots in the morning, increasing during the middle of the day and abating that evening. The chief pilot said that when he began searching for the helicopter, the wind was no more than about 15 knots. Pilots who had searched later said they encountered moderate turbulence. A hunter who was in the Oamaru River valley and heard the crash, said the wind gusts had broken off twigs. That suggested gusts of more than 34 knots.[22] A video taken by a passenger on an earlier flight that day showed small trees at a Mohaka River landing site (approximately 13 kilometres northeast of the accident site) swaying strongly, which suggested a wind of about 20 knots.

3.5. Wreckage and impact information

3.5.1. The wreckage trail was approximately 300 metres long, across a steep, forested ridge that was on the expected route from the Mangataramea Hut to the operator's base (see Appendix 2 for further information on the wreckage). The first items in the trail were pieces of Perspex, lightweight cabin structure and objects from the cabin.

3.5.2. The fuselage, apart from the tail boom and attached tail rotor, had fallen at a steep angle to land at the base of a tree. The tail boom was caught in the top of another tree. There was no fire.

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19 MetService was the certificated provider of aviation meteorological information.

20 Moderate turbulence is regarded as turbulence that causes: (1) changes in aircraft altitude or attitude; (2) variations in indicated airspeed; and (3) aircraft occupants to feel definite strain against seat belts.

21 The passenger had a wristwatch that sensed air temperature and pressure, but to unknown accuracy.

22 The Beaufort Wind Scale relates wind speeds to physical effects. See http://metservice.com/help/help-warning.

3.5.3. One main rotor blade had struck the front right corner of the cabin. Later examination showed that this blade had fractured completely at approximately two-thirds span as it bent under the forward landing skid cross tube. Paint transfer marks showed that the detached outboard section of blade had then struck the tail boom while that was still attached to the fuselage.

3.5.4. There was clear evidence of a heavy mast bump.[23] The main rotor drive shaft was severed approximately 15 centimetres below the hub (see Figure 3). The hub and main rotor blades (apart from the separated outboard end of the blade that hit the tail boom) landed approximately 300 metres from the fuselage, to the right of the line of flight.

3.5.5. Specialists examined the drive shaft fracture, the engine and two of its accessories, and the main rotor control hydraulic servos (see Appendix 1).

3.6. Medical and pathological information

3.6.1. A post-mortem examination determined that the pilot had died as a result of multiple injuries. The pathologist's report stated that some of the injuries were "indicative of restraint against a lap-type seat belt. The other injuries are likely to have been sustained in a fall from the helicopter".

3.6.2. The Commission considered the pathologist's report and noted that there was no evidence of abuse of alcohol or other commonly screened-for drugs.

Figure 3
Main rotor head, showing severed drive shaft

[23] A mast bump is contact between the inboard end of a main rotor blade or the rotor hub and the main rotor drive shaft.

3.7. Survival aspects

3.7.1. The search for the accident site took five hours because no signal was detected from the emergency locator beacon.[24] Search pilots said that after the accident site had been located, they heard in the vicinity a weak signal on frequency 121.5 megahertz. It was later found that the co-axial antenna cable had separated from the beacon in the crash. The Kannad 406 beacon, serial number 2619364-0217, had been tested on 21 February 2013 and its battery was due for replacement in February 2014.

3.7.2. The position reports from the flight tracking unit fitted to the helicopter greatly reduced the size of the initial search area. Not all aircraft are fitted with tracking devices, and their usefulness depends in part on the selected interval between position reports.

3.7.3. The Commission has previously made recommendations regarding the use of flight tracking devices and improvements to the crashworthiness of emergency locator beacons.[25] On 26 February 2014 the Commission recommended that the Director of Civil Aviation:

> a. encourage the use of flight tracking devices, especially for use in aircraft operating in remote areas around New Zealand (005/14)
>
> b. continue to support the international work underway to improve the crash survivability of ELTs and to include GPS information in the data transmitted by such devices (006/14).

3.7.4. On 5th March 2014, the Director replied, in part:

> 005/14 – In our draft recommendation response 31 January 2014, the Director commented that the CAA provide for the fitment of Flight Tracking Devices (FTDs) by operators and this can be achieved in accordance with the relevant provisions of AC 43-14. The CAA will continue to encourage operators to fit FTDs in this manner. The CAA considers the action sufficient to satisfy the closure of the Commission's recommendation.
>
> 006/14 – in the same response letter, the Director commented that the CAA already supports in principle the ICAO and manufacturers' efforts to improve the crash survivability of ELTs and accuracy of position reporting. The work is ongoing and in this context the CAA requests that the recommendation be closed.

3.8. Organisational and management information

3.8.1. The operator was certificated by the CAA to perform air operations under Civil Aviation Rules Part 135, Air Operations – Helicopters and Small Aeroplanes. The certificate had been re-issued on 26 February 2013.

3.8.2. The operator had established the base at Poronui Station in 1988, primarily to fly hunters and fishermen to remote locations in the Kaimanawa and Kaweka Ranges. Four pilots were employed on a roster basis. The chief pilot had held the position since 1996. On the day of the accident the chief pilot and the accident pilot had shared the flying tasks.

3.8.3. The fleet comprised the R66, an R44 and a Hughes 500. The operator's chief pilot said that the lighter weight and high maximum cruise speed of the R66 were attractive features, and training the company's pilots to fly the R66 had been straightforward because of the type's similarities with the R44.

3.9. Special training requirements for pilots of Robinson helicopters

3.9.1. The history of mast bump accidents with the smaller R22 and R44, and the actions taken to reduce their incidence, is pertinent to this R66 investigation, because the three types have the same main rotor system design and a similar response to low G. In 1996 the NTSB completed

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[24] An emergency locator beacon transmits a primary signal on 406 megahertz for detection by search and rescue satellites. A lower-power, longer-duration secondary signal on 121.5 megahertz is to assist search aircraft to home to the site.

[25] Refer to Commission inquiry 11-003, in-flight break-up, ZK-HMU, Robinson R22, near Mount Aspiring, 27 April 2011.

a special investigation into R22 mast bump accidents.[26] An overview of that investigation and the actions taken by the FAA in response is in Appendix 3.

3.9.2. During the NTSB investigation the FAA committed to establishing Flight Standardization Boards that would determine the operational and training requirements for pilots of future helicopters.[27] The requirements were to include any additional knowledge or skills necessary for a typical pilot to handle the normal and emergency procedures applicable to a new type. The first Flight Standardization Boards were established in February 1995 for the R22 and R44. The Boards recognised the knowledge and skill gaps that existed, stating that any person who wished to operate either type (FAA, 1995a, p. 7), (FAA, 1995b, p. 7):

> should complete a training program designed to enhance awareness of the hazards associated with certain characteristics of light helicopters. **Flight conducted in normal operating conditions may cause an encounter with such hazards** [emphasis added].

3.9.3. The Boards determined that it was necessary for R22 and R44 pilots to understand the effects of low G and how to make a safe recovery from a low-G condition. Those topics are relevant for any helicopter with a two-bladed, teetering, underslung rotor system, but in 1995 they were not in the helicopter pilot licence training syllabus of the FAA (nor that of the CAA). They have since been added to training syllabuses.[28]

3.9.4. To formalise the Boards' determinations, the FAA in March 1995 published Special Federal Aviation Regulation No. 73 (SFAR 73), which mandated 'Special Training and Experience Requirements' for all pilots of R22 and R44 helicopters, including pilots who were already qualified to fly either type.

3.9.5. On 29 June 2009 the FAA concluded that SFAR 73 should be permanent for both the R22 and the R44, even though, by then, pilot training syllabuses included the relevant topics. However, in New Zealand the requirement for R44 pilots to have the special training had been unintentionally deleted in 2004 as a result of a CAA flight manual amendment.[29]

3.9.6. The R66 Flight Standardization Board considered the relevance of SFAR 73 when it assessed the R66. Its report stated (FAA, 2010, Part 2, Section 6):[30]

> Of primary concern to the Flight Standardization Board in evaluation of the R66 is the published [SFAR 73] specifying training, testing and checking requirements for the R22 and R44. Because the R66 is a growth variant of the R44 and R22 … the [Board] elected to evaluate the R66 for operational suitability, specific flight characteristics, and specific training, testing and checking requirements for pilots.

3.9.7. The R66 Flight Standardization Board confirmed that the awareness topics listed in SFAR 73 for R22 and R44 pilots applied equally to R66 pilots, by stating (FAA, 2010, Part 1, section 6):

> Pilot awareness of certain aerodynamic factors with this type of rotor system is essential. This includes awareness of low 'G' operations and recovery techniques, rotor blade stall potential, energy management, and low RPM recovery techniques.

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[26] At the time, loss-of-main-rotor-control accidents accounted for more than a third of R22 accidents in the United States. During the special investigation the scope was widened to include similar R44 accidents.
[27] A Flight Standardization Board's role is distinct from that of the FAA's Aircraft Evaluation Group, whose test pilots evaluate the handling characteristics of new helicopters and confirm that they comply with airworthiness requirements.
[28] See, for example, Advisory Circular 61-3, www.caa.govt.nz/Advisory_Circulars/AC061_3.pdf, p. 106 and the CAA Helicopter Flight Instructor Manual, www.caa.govt.nz/Publications/Other/Heli_Flt_Inst_Manual.pdf, p. 93.
[29] The requirement was reinstated during the course of this inquiry. See paragraph 3.9.14.
[30] Flight Standardization Board report, Robinson R-66 Helicopter, 13 October 2010. Accessed from http://fsims.faa.gov/wdocs/fsb/robinson%20r-66%20fsb.pdf.

3.9.8. A member of the R66 Flight Standardization Board explained that 'this type of rotor system' meant any two-bladed, teetering, underslung main rotor system.[31] However, no similar pilot training requirement has been mandated for any other helicopter manufacturer.

3.9.9. The R66 Flight Standardization Board noted that the R66, R44 and R22 had similar rotor designs. Robinson has described the R66 flight characteristics as 'substantially similar' to those of the R44.[32] Despite that, the Board determined that there was no need for R66 pilots to have the special training or any minimum flight experience. The Board's report stated, in part (FAA, 2010, Part 2, Section 6):

> The R66 did not demonstrate unique or unusual handling characteristics in the subject areas specified in the SFAR 73 … the R66 does not require specific training for unique flight characteristics … R66 inclusion in SFAR 73 is inappropriate.

3.9.10. In May 2013 Commission investigators conducted a forum with senior helicopter instructors and expert staff of the CAA to gain a better understanding of the situation in New Zealand regarding the training of Robinson helicopter pilots and the operational experience with the helicopters (see Appendix 4).

3.9.11. The forum instructors, of whom two had given R66 flight instruction, were of the view that R66 pilots ought to have the same training and experience requirements as R22 and R44 pilots because the rotor design, limitations and response to low G of the three types were essentially the same. However, at present, a trainee helicopter pilot in New Zealand or the United States could complete their initial training for a licence on an R66, with no requirement for any special training and experience like that mandated for R22 and R44 pilots.

3.9.12. Between March 2014 and March 2015, the CAA conducted a review of SFAR 73 in the context of the NZ aviation system. This was in response to a recommendation made by the Commission during an inquiry into an R22 accident (see footnote 25). The review conclusions included the following:[33]

> d) …as a result of the similarities of [the R22, R44 and R66] combined with New Zealand accident data it is important that R44 and R66 pilots have a clear understanding of [the topics covered in the Robinson special training] and mitigation strategies
>
> e) However … there is currently no mechanism for requiring that those flying the R44 and R66 have had that training.

3.9.13. In April 2015 the CAA issued a consultation document, 'Robinson Helicopter Fleet', that described its proposals for regulatory change to: standardise the conduct, and improve the oversight, of the special Robinson training in New Zealand; restore the special training requirement for R44 pilots (that had been inadvertently removed in 2004)[34]; and to make the SFAR 73 special training applicable to R66 pilots.

3.9.14. Following the public consultation of the proposed changes, the Director applied to the Court in October 2015 for a Warrant of Authority to Impose Conditions on the operation of R22 and R44 helicopters. One of the operating conditions that the Court granted reinstated SFAR 73 special training for New Zealand R44 pilots, with effect from 6 November 2015.

3.9.15. The Director did not apply to the Court for an authority to impose conditions on the operation of the R66. The CAA stated at the time that the Director would monitor the outcome of this inquiry and any recommendations that the Commission might make.

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[31] Teleconference, Transport Accident Investigation Commission, NTSB, FAA; 30 January 2014.

[32] Email to the Commission, 12 June 2015, from the Robinson Certification Manager.

[33] At the time of the CAA's review, New Zealand did not require SFAR 73 training for R44 pilots.

[34] The background to the removal of the requirement for R44 pilots was given in Commission report 11-003, in-flight break-up, ZK-HMU, Robinson R22, near Mount Aspiring, 27 April 2011.

4. Analysis

4.1. Introduction

4.1.1. This accident was the first in New Zealand to involve an R66. It was the fourth fatal R66 accident globally since the type's certification in 2010, and the second in which the main rotor had separated in flight (see Appendix 5).[35] At the time, approximately 300 R66 helicopters had been manufactured, with five of them registered in New Zealand.

4.1.2. The damage showed that a mast bump had preceded the in-flight break-up. A mast bump is usually a result of the blades having exceeded the allowable range of flapping. Robinson noted in its Safety Notice SN-11 that "severe in-flight mast bumping usually results in main rotor shaft separation and/or rotor blade contact with the fuselage" (Robinson Helicopter Company, 2010).

4.1.3. Previous investigations and advice in the Pilot's Operating Handbooks indicated that the causal factors of mast bump accidents involving Robinson helicopters included:

- abrupt flight control inputs by a pilot
- a decrease in the main rotor RPM below the allowable flight range
- a low-G condition.

4.2. What happened?

4.2.1. There was clear evidence of a severe mast bump and that a main rotor blade had struck the cabin. The main rotor drive shaft separated under a combination of bending, torsional and inertial effects, resulting from its being driven by the engine while the blades were prevented from turning because they had struck the fuselage.

4.2.2. The recorded engine parameters (see Appendix 1) indicated that the engine had been operating normally and within limits. Damage to the engine and attached components showed that it was still operating at impact. The steady engine operation meant it was very unlikely that the mast bump followed a low-rotor-RPM state. Some minor maintenance inconsistencies were identified, but no pre-existing technical defect that could have preceded the mast bump event was found. Nor was any evidence found of an unusual event, such as incapacitation, involving the pilot.

4.2.3. The data transmitted by the Spidertracks unit and the recorded global positioning system tracks indicated that the pilot had flown the expected flight paths at safe heights. Based on the last data transmitted by the Spidertracks unit, and witnesses' observations, the environmental and aircraft conditions were assumed to be as follows:

- altitude: 4,000 feet (1,219 metres)
- ground speed: 124 knots
- track: 033°T
- air temperature: 15°C
- wind: 135°T, 20 knots.

4.2.4. Using these values, the helicopter's indicated airspeed was estimated to have been 115 knots shortly before the accident.[36,37] The maximum permitted airspeed in smooth air under the same conditions was 123 knots.[38] Therefore, although relatively high, the airspeed was within limits.

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[35] There have since been three more fatal R66 accidents, of which one likely involved a mast bump.
[36] Calculated with an Airtour CRP-5 flight computer (circular slide rule).
[37] Robinson conducted a test flight in January 2016 under almost identical conditions and recorded an indicated airspeed of 118 knots with 75% torque, the approximate power at the time of the accident (see Appendix 1).
[38] The maximum indicated airspeed was 140 knots for gross weights below 998 kilograms when at sea level, but it reduced with increasing altitude or air temperature.

4.2.5. Turbulent conditions persisted all day, with strong wind gusts near the middle of the day. The conditions were generally as forecast, including the shift northwards of the area affected by strong wind. Experienced local pilots who had been flying around the time of the accident, or who took part in the search, said conditions were unpleasant.

4.2.6. Most of the R66 passengers that day said they had not been bothered by the turbulence and had experienced worse conditions, but one had commented to the pilot that they were "getting knocked around a bit, more than in the Hughes 500". The pilot had agreed and said he would have preferred to be in the Hughes. The chief pilot later said the Hughes was available if the pilot had considered it would have been more suitable.

4.2.7. The following observations were made by passengers on four different flights:

- The seat belt felt tighter as the helicopter encountered a bump.
- The pilot was "countering gusts, which were mainly sideways rather than vertical".
- One noticed the pilot "whack the joystick to the left aggressively" to counter a "lurch to one side" as the helicopter came over a ridge (but the other person on that flight did not recall that).
- The hunters on the flight before the accident said conditions had been gusty.

4.2.8. Moderate turbulence can result in momentary conditions of low G. A seat belt feeling tighter during a gust or bump is consistent with that effect. If the pilot had indeed moved the cyclic[39] stick "to the left aggressively", he was very likely correcting a right roll. The roll might have been caused by a gust, but the helicopter could also roll right if a significant low-G condition were encountered at high speed or with high power. The right roll is caused by the tail rotor thrust line acting above the helicopter's centre of gravity. Robinson cautioned that if an uncommanded right roll occurred during a low-G condition, aft cyclic had to be applied before applying any left cyclic to stop the roll. Applying left cyclic first would change the plane of rotation of the main rotor blades without the underslung fuselage following, and that risked a mast bump.

4.2.9. Robinson has for a long time recommended that pilots reduce airspeed if turbulence is encountered, because the reduced speed (and power) lessen the effect of turbulence and the chance of an uncommanded right roll developing. That advice was contained in Safety Notice SN-32, which was in the Pilot's Operating Handbook for each Robinson helicopter type (see Appendix 6). When it was first issued in 1998, and at the time of this accident, the opening sentence of Safety Notice SN-32 stated:

> Flying in high winds or turbulence should be avoided.

That sentence was replaced in May 2013 (shortly after this accident) with:

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

The new sentence shifted the emphasis of the safety notice from advising pilots to avoid hazardous weather conditions, to suggesting that "improper" handling was the cause of mast bump accidents in high winds and turbulence. The notice recommended that pilots who encountered turbulence should reduce power and the airspeed to between 60 and 70 knots if the turbulence was "significant". It also stated that pilots should not over-control, but removed the earlier advice to "avoid large or abrupt control movements". The revised notice added that a lightly-loaded helicopter was more susceptible to turbulence.

4.2.10. In February 2016 Robinson revised Safety Notice SN-32 again; restoring the advice to avoid flight in high winds or turbulence, and emphasising the need to reduce speed if turbulence was encountered while operating at light-weight (see paragraph 6.4 and Appendix 7).

[39] The cyclic stick is one of two main rotor controls. Movement of the cyclic stick causes the rotor blade pitch angles to change, which causes the rotor 'disc' to tilt in the same direction in which the pilot has put the stick. The helicopter then moves in that direction. This can be sideways, forwards or backwards (aft) or any other direction.

4.2.11. The weight of the helicopter at the time of the accident was estimated to have been 756 kilograms, which was at the light end of the allowable range of 635 to 1,225 kilograms. The airspeed about 30 seconds before the accident was approximately 115 knots, well above the recommended speed of 60 to70 knots for 'significant' turbulent conditions.

4.2.12. The statements of witnesses on earlier flights and in other helicopters indicated that it was very likely the helicopter encountered moderate or greater turbulence on the return trip when the accident occurred. The light weight, and possibly a relatively high speed, would have exacerbated the effect of the turbulence. If the pilot had reacted to the turbulence with an inappropriate flight control input – for example, an abrupt input, or by applying left cyclic in response to a right roll when experiencing low G – that could have caused the mast bump and the main rotor blade contact with the fuselage.

Findings

1. The in-flight break-up was caused by a mast bump and main rotor blade contact with the fuselage.

2. The mast bump very likely occurred when the helicopter encountered moderate or greater turbulence, which likely resulted in a condition of low G. The effect of any turbulence would have been exacerbated by the helicopter's light weight and estimated airspeed of 115 knots.

3. The possibility that an intentional or inadvertent control input by the pilot contributed to the mast bump cannot be excluded.

4.3. Safety issues

4.3.1. While it was very likely that turbulence and the helicopter's speed and weight contributed to the accident, the Commission also identified the following safety issues:

- four of the seven fatal R66 accidents that have occurred globally since the type was introduced into service in 2010 were mast bump or low-main-rotor-RPM accidents, accident types seen with the smaller R22 and R44, which have the same main rotor design.[40] However, the R66 was certificated without any special pilot training requirements or operating restrictions such as the minimum pilot experience and maximum wind strength that apply to the R22

- the flight manuals for Robinson helicopters did not adequately warn pilots of the hazardous operating practices and environmental conditions that can lead rapidly to a catastrophic mast bump

- earlier research into the flight control systems and dynamic behaviour of the main rotor of lightweight helicopters, such as the design used by Robinson, was not completed as intended. Until the behaviour of such rotor systems in conditions of low G and turbulence is fully understood, it is possible that not all of the causal factors of mast bump accidents will be identified.

4.3.2. These issues, and some observations about CAA audits, are discussed below.

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[40] As of 24 November 2015, more than 650 R66 helicopters had been delivered.

4.4. Certification process for the R66

4.4.1. A general requirement for the certification of a light helicopter (or 'rotorcraft') was that a pilot of average skill must be able to take off, climb, turn, land and otherwise manoeuvre the helicopter without any danger of over-stressing it. Federal Aviation Regulation (FAR) Part 27 stated this requirement as follows:

> **§27.141 General.**
>
> The rotorcraft must—...
>
> (b) Be able to maintain any required flight condition and make a smooth transition from any flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the limit load factor under any operating condition probable for the type.

4.4.2. The FAA advised that the 'required flight conditions' and 'operating conditions probable for the type' meant typical flight manoeuvres, not environmental conditions. The only environmental considerations relevant to FAR 27.141 were the altitude and temperature ranges in which the manufacturer expected the helicopter to operate. Another FAR[41] considered the effects of wind, but only in regard to the helicopter's controllability when hovering.

Helicopter response to low G

4.4.3. Since the R66 was certificated in 2010, the flight manual Limitations section has contained the following caution against making control inputs that could cause a low G condition and result in a mast bump:

> **CAUTION**
>
> A pushover (forward cyclic maneuver) performed from level flight or following a pull-up causes a low-G (near weightless) condition which can result in catastrophic loss of lateral control
> ...

4.4.4. Turbulence can also cause a hazardous low-G condition. However, turbulence, unlike altitude and temperature, is an environmental condition that cannot be predicted or controlled under test conditions. The FAA advised that the only consideration of a helicopter's behaviour in turbulence was the test pilot's qualitative assessment of the amount of cyclic control available to overcome a moderate gust.[42] As two-bladed, teetering main rotor systems like that used by Robinson were not intended for low-G flight, the FAA did not consider low G to be an 'operating condition probable for the type'. Therefore, the R66 certification programme was not required to test the helicopter's response to low G.

4.4.5. Some turbulence is not uncommon when flying, and prudent flying suggests that it ought to be anticipated in mountainous areas. The New Zealand experience is that mast bump accidents are more likely to occur in mountainous terrain. Although turbulence is not an operating condition contemplated by FAR 27.141, it is a normal operating hazard. A low-G condition, which can result from turbulence, is one of the hazards that the Flight Standardization Boards included in the special training for the R22 and R44.

4.4.6. Following the Kaweka R66 accident, a very experienced New Zealand helicopter instructor reported having been surprised when an R66 rolled at a high rate in a low (but positive) G condition. When the FAA was asked whether this characteristic was seen during the R66 certification programme, it replied it had not, stating:[43]

> Right roll characteristics were not described in any certification flight test reports released to the Fort Worth [Aircraft Evaluation Group] or the [Flight Standardization Board] for the R66. Uncommanded right roll did not manifest itself during any maneuvers specified in the [Practical Test Standards] during

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[41] FAR 27.143, Controllability and maneuverability.
[42] FAA AC27-1B, section 27.143 refers.
[43] Email, 18 December 2013, from FAA Accident Investigation Division.

> performance of the [Flight Standardization Board], nor in any of the certification flight test conducted by the [Los Angeles Aircraft Certification Office] (LACO).

4.4.7. A representative of the FAA Los Angeles Aircraft Certification Office confirmed that the general flight characteristics tested during the R66 certification had not specifically considered the type's response to low G.[44] Yet Robinson considered that the various R66 certification flight tests had included "every likely manoeuvre to be performed in service, including manoeuvres that exceeded flight limitations", a reference to push-over (low-G) manoeuvres that were otherwise prohibited for all three Robinson types.

4.4.8. The lowest recorded G during the certification flight tests was +0.4 G (Robinson Helicopter Company, 2014, p. 3.18). That became the target minimum G for the R66 Main Rotor Flapping Angle Survey conducted in May 2014, one year and two months after the Kaweka accident and more than three years after the R66 Flight Standardization Board met. That survey recorded a minimum G of +0.33 (Robinson Helicopter Company, 2014, p. 4.7).

4.4.9. Although the FAA stated that none of its test pilots had encountered uncommanded right roll during the R66 certification programme and that Robinson had not provided any evidence to the FAA of this characteristic, videos of the rotor flapping survey flights showed that roll does occur with low G. However, in each case the test pilot initiated recovery action as soon as the anticipated roll began. The survey showed that the R66 responds to low G in the same way as the R22 and R44.

Main rotor blade to fuselage clearance

4.4.10. Robinson's Safety Notice SN-11 noted that a severe mast bump could lead to main rotor blade contact with the fuselage. A catastrophic accident is almost inevitable after blade contact. It is obvious that the main (and tail) rotors must remain clear of the helicopter structure under all operational conditions. That requirement is covered by the following certification requirement:

> **§27.661 Rotor blade clearance.**
>
> There must be enough clearance between the rotor blades and other parts of the structure to prevent the blades from striking any part of the structure during any operating condition.

4.4.11. Following the NTSB's special investigation into R22 mast bump and low-main-rotor-RPM accidents, of which most involved a main rotor blade striking the fuselage, the NTSB stated that it was concerned that "other highly responsive helicopters are likely to be designed and built that may have characteristics similar to the R22" and that "there is a need for the FAA to consider the responsiveness of helicopters (especially lightweight, high performance helicopters such as the R22) as part of the certification process" (NTSB, 1996, p. 27). As a result of this concern, the NTSB recommended in 1996 that the FAA:

> Require helicopter manufacturers to provide data on the response of helicopters to flight control inputs to be used as part of the certification process, and require operational limitations or other measures for those helicopters that are highly responsive (recommendation A-96-11).

4.4.12. The NTSB changed the status of that recommendation to 'Closed – Acceptable Action' in 2000 after the FAA stated that its revised guidance to manufacturers addressed large control inputs by pilots **and low-G manoeuvres** that may affect blade-fuselage clearance[45] [emphasis added].

4.4.13. The R66 has the same main rotor design and some similar flight characteristics to the R22 and the R44, and the R66 certification programme took advantage of these similarities. For example, the FAA accepted the results of the earlier R44 rotor flapping survey as complementary evidence that the R66 met the certification blade clearance requirement. Robinson explained the rationale for that approach:[46]

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[44] Teleconference, 30 January 2014, FAA, NTSB, Transport Accident Investigation Commission.

[45] Published in Advisory Circular 27-1, as amended.

[46] Email to the Commission, 12 June 2015, from the Robinson Certification Manager.

> Compliance with 14 CFR 27.661 was demonstrated in conjunction with flight testing for demonstration of compliance with the flight requirements of 14 CFR Part 27, and in-flight strain measurements for demonstration of compliance with the fatigue requirements of §27.571 …
>
> The maneuvers included in the flight tests … are considered to include every likely maneuver to be performed in service, including maneuvers that exceed flight limitations. The main rotor flight strain survey included push-over maneuvers that induced low-g conditions similar to those documented in the [R66] Main Rotor Flapping Angle Survey report (RTR 673) [see paragraph 4.4.7]. While the results of these flight tests did not include measurements of blade clearance, the absence of any unusual blade behavior in the course of the flight tests was considered sufficient for demonstration of compliance with §27.661.
>
> As the flight characteristics and geometry of the R66 are substantially similar to those of the R44, and comprehensive blade clearance data was available for the R44 indicating blade clearance margins are large, direct measurements of blade clearance were not considered necessary for the R66.

4.4.14. The FAA considered the R66 main rotor flapping survey to have confirmed that the type complied with rotor clearance requirements. The Robinson survey report concluded:

> Based on the test data in this report, it is clear that the R66 rotor system will not stall, exceed teeter limits, or allow blade contact with the airframe when the aircraft is flown within the approved operating envelope (Robinson Helicopter Company, 2014, p. 4.28).[47]

4.4.15. While the R66 rotor flapping survey demonstrated rotor clearance and that the helicopter had an acceptable response to control reversals (a form of abrupt controlling), the report made the following comments that illustrated a difference between test flying and what an average pilot might experience, and that flight test results might not be transferable between similar types:

> Although control reversal flight characteristics may be similar between Robinson models, small changes in airspeed and pilot technique may produce large changes in flight characteristics and component loads during the maneuver …
>
> While control reversals were performed during the original R66 certification program, they were generally performed quickly enough such that rapid roll rates were not generated (Robinson Helicopter Company, 2014, p. 3.13).
>
> Although low G flight characteristics may be similar between Robinson models, **the exact boundary between 'safe recovery can be performed' and catastrophic mast bumping cannot be predicted**. Small changes in entry speed and pilot technique may produce large changes in roll rates (Robinson Helicopter Company, 2014, p. 3.19) [emphasis added].

4.4.16. This acknowledged fine line between safe and unsafe outcomes clearly illustrates the hazard a low-G condition poses for a Robinson helicopter. Flight in moderate or greater turbulence can result in a low G condition, which means flight in turbulence is a risk that needs be mitigated. It also brings into question another conclusion in the Robinson blade flapping survey report: that the rotor system will not allow blade contact with the fuselage when the helicopter is flown within the approved limits. This issue is discussed in section 4.6.

Summary of certification issue

4.4.17. The R66 certification programme was not required to test the helicopter's response to low G, in spite of low G being known to present a serious risk of mast bump for the R22 and R44. Robinson stated that the R66 certification flights included manoeuvres that induced low-G conditions similar to those in the main rotor flapping survey, but the effects, if any, were not documented. The rotor flapping survey videos confirmed that the R66 responded to low G in the same way as the R22 and R44. For all three types, an incorrect pilot reaction to an uncommanded roll could result in a catastrophic mast bump.

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[47] The operating, or flight, envelope is the range of speed, load factor and altitude for an aircraft, as established by the design and verified during certification testing.

4.4.18. The similarity of the three Robinson types in their response to low G shows a need for similar knowledge and skill requirements for the pilots of any of the types. The Flight Standardization Boards for all three Robinson types considered that it was essential for pilots to have an understanding of the helicopters' response to low G, but the R66 Board declined to require special training for R66 pilots.[48]

4.4.19. Therefore, at present, a person with no prior piloting experience can train for a helicopter pilot licence on the R66. The Flight Standardization Board expected R66 pilots to have the same essential knowledge regarding Robinson flight and handling characteristics as pilots of the R22 and R44, but no special training was mandated for the R66.[49] Insufficient pilot knowledge and experience has been indicated as a likely factor in the South Dakota and Colombia R66 accidents (see Appendix 5).

4.4.20. Pilots (like the pilot in this accident) who are qualified to fly the R22 or R44 could infer from the lack of any special training for the R66 that the R66 does not require the same careful handling as the smaller types. The emerging accident trend and instructional experience to date suggest that the R66 does require the same careful handling.

4.4.21. This accident and many others reinforce the need for pilots of Robinson helicopters, including the R66, to understand fully the need for careful handling to avoid low G, have a clear appreciation of the danger of flight in turbulent conditions, which can also cause low G, and understand the importance of reducing airspeed if turbulence is encountered.

4.4.22. When the R66 Flight Standardization Board met, the type had not entered operational service. The R66 accident history to date indicates that the Boards' decision not to recommend an extension of SFAR 73 to R66 pilots should be reconsidered. The Commission is recommending that the Administrator of the FAA extend the knowledge and training requirements of SFAR 73 to pilots of the R66.[50]

4.4.23. Following a review of Robinson safety training in New Zealand, the CAA issued a consultation document outlining its intention to require pilots to complete, in essence, the SFAR 73 training as part of an R66 type rating, and also its intention to reinstate the SFAR 73 training for R44 pilots. Following industry consultation, the Director of Civil Aviation (the Director) obtained Court authority to reinstate the SFAR 73 training for the R44, but no application was made to the Court in respect of the R66. Therefore, the Commission is recommending that the Director require pilots to complete the SFAR 73 training, or an equivalent requirement, as a prerequisite for the issue of an R66 type rating.

Findings

4. The R66 global accident history, in the five years since the type was introduced into service in 2010, suggests that the R66 is as vulnerable as the smaller R22 and R44 to a catastrophic mast bump under certain conditions.

5. The R66 was certificated without any special pilot training requirements to mitigate the risk of a catastrophic mast bump.

4.5. Flight manual references to hazardous practices and conditions

4.5.1. The available information on the fatal R66 accidents to date suggested that not all of the involved pilots had flown the smaller R22 or R44 and received the SFAR 73 training applicable to those types. But even those pilots who did have R22 or R44 experience were unable to avoid their accidents.

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[48] Refer section 3.9, Special training requirements for pilots of Robinson helicopters.

[49] Robinson submitted that the pilot training syllabus in the United States covered all of the awareness topics in SFAR 73, including low G.

[50] Refer to section 3.9 of this report.

4.5.2. If a flight condition is so critical that any exceedance could be catastrophic, such as the low G pushover described in paragraph 4.4.3, the flight manual should contain an explicit 'warning', using the terminology that has become standard in aviation and other technical industries.[51] The FAA guidelines recommended the use of 'warning' if there was a risk of death or injury, and used 'caution' for situations with a risk of equipment damage.[52] However, Robinson's flight manuals followed the United States General Aviation Manufacturers Association's Specification No.1, which did not define 'warnings', 'cautions' and 'notes'. Instead, Robinson defined 'caution' to include the risk of death or injury as well as equipment damage.

4.5.3. Robinson provided good, plain-language guidance for various aspects of flight operations, in the Safety Tips and Notices section of the Pilot's Operating Handbooks. For example, Safety Notice SN-32, High Winds or Turbulence (see Appendix 6) contained critical information to help pilots avoid mast bumps. The information deserved to be headed 'Warning', because a mast bump would likely be catastrophic. However, the safety notices were not a part of the FAA-approved flight manual. Therefore, apart from the conditional limits in airworthiness directive 95-26-04 for the R22, there was no reference to turbulence in any FAA-approved Robinson flight manual at the time of this accident.

4.5.4. Since 2008, in addition to this accident, the Commission has inquired into two R22 and one R44 mast bump accidents, in circumstances where turbulence was a factor. The CAA has also investigated another two R22 accidents of this sort in that period.

4.5.5. For this reason, the Commission disagreed with an industry view, expressed at the May 2013 flight instructors' forum, that the lack of an explicit warning about the sensitivity of Robinson helicopters to turbulence was not a safety issue. The accident record indicated that it is an issue and that the hazard should be explicitly stated and appropriate mitigation put in place.

4.5.6. In January 2015 Robinson increased the attention given to the hazard of turbulence by adding the following Caution to the Normal Procedures sections of the R66 (and R44) flight manuals:

CAUTION

If turbulence is expected, reduce power
and use a slower than normal cruise speed.

4.5.7. Each pilot of an aircraft shall, before beginning a flight, be familiar with the aircraft flight manual.[53] That requires pilots to be aware of any changes to the manual. Amendments are normally notified by manufacturers to registered owners of the aircraft type and to subscribers to an amendment notification service for the type. The full, current content of each Robinson Pilot's Operating Handbook is also freely available on-line.

4.5.8. The addition of the above Caution to the Robinson R66 and R44 flight manuals, and the changes made in February 2016 to Safety Notice SN-32, has significantly increased the attention given to the hazard of turbulence and could help reduce the incidence of mast bumps, provided pilots are made aware of and understand the significance of this important information. Given the critical importance these latest 'Cautions' published by Robinson helicopters have for improving the safety of Robinson helicopter flight safety in New Zealand, the Commission considers these changes warrant wider publicity within New Zealand. Accordingly, the Commission recommended to the Director of Civil Aviation that he promptly publicise the changes to the New Zealand helicopter community.

4.5.9. In April 2015 the Commission recommended that the Administrator of the FAA require Robinson to use the term 'warning' for those operating conditions and practices that involve a risk of personal injury or loss of life.[54] On 17 November 2015 the FAA replied that Robinson flight manuals included a definition of 'Caution' that was a combination of the traditional

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[51] This issue was discussed in Commission inquiry report 11-003, in-flight break-up, ZK-HMU, Robinson R22, near Mount Aspiring, 27 April 2011; and inquiry report 13-005, in-flight loss of control, Robinson R22, ZK-HIE, near New Plymouth, 30 March 2013.
[52] FAA Advisory Circular 27-1 refers.
[53] Civil Aviation Rule 91.219.
[54] Recommendation 007/15, in inquiry report 13-005.

(industry practice) definitions of Warning and Caution. The FAA believed “there would be little added value in having Robinson change its flight manuals” and therefore it considered the recommendation “Closed Not Adopted”.

Finding

6. At the time of the accident, the Robinson helicopter flight manuals did not adequately warn pilots of the hazardous operating practices and environmental conditions that can lead rapidly to a catastrophic mast bump. This type of accident is strongly associated with turbulent conditions.

4.6. Dynamic behaviour of the Robinson main rotor system

4.6.1. The R66 main rotor flapping survey report, like that for the R44 and the earlier FAA special certification reviews of the R22 (see Appendix 3), concluded that the rotor system will not allow blade contact with the fuselage when the helicopter is flown within the approved limits. Investigations into in-flight break-up accidents, which typically show evidence of a mast bump, have rarely proven that the pilots mishandled the helicopter or exceeded the flight manual limits. Causal factors other than pilot handling and the operating environment may have been involved. Therefore, preventive actions other than pilot training, operational limitations and flight manual clarity may be required.

4.6.2. The recommendation made in 1996 by the NTSB to the FAA to examine the design and the dynamic behaviour of the Robinson main rotor (as the exemplar lightweight rotor system) for any possible contribution to such accidents was closed before the research was completed. The Georgia Institute of Technology found in their theoretical study that “gusts under moderate conditions seem not to be a problem”, but they recommended further study of the problem (see Appendix 3, paragraph 10). The lack of exact knowledge on the dynamics of main rotor blade behaviour persists.

4.6.3. The introduction to the FAA’s airworthiness directive 95-26-04 (for the R22) inferred that the FAA anticipated corrective design changes to reduce or eliminate this type of accident. The airworthiness directive stated, in part:

> Until the FAA completes its research into the conditions and aircraft characteristics that lead to main rotor blade / fuselage contact accidents, and corrective type design changes and operating limitations are identified …

4.6.4. Robinson made changes to the engine controls to reduce the risk of low rotor RPM, but the main rotor system design remains unchanged. The NTSB special investigation “found no direct evidence of an unstable blade or rotor system design. The extensive operational history, the wreckage evidence, flight tests, and computer simulations indicate that a dynamically unstable [R22] main rotor system is unlikely” (NTSB, 1996, p. 25). The NTSB recognised that there could be other explanations for the accidents.

4.6.5. The avoidance of conditions that might cause a main rotor to strike the fuselage relies primarily on pilots maintaining the correct rotor RPM, and their diligent observance of the prohibition against deliberate low G and the caution to “avoid abrupt control inputs”. Pilots should learn what constitutes an ‘abrupt’ control input during their initial training. The NTSB noted that the 1995 flight tests of the R44 rotor flapping angles “were not (and could not safely be) conducted to determine the helicopter’s response to large, abrupt cyclic inputs” and “the flight test did not provide the data needed to determine the mechanism for the blade diverging into the body” (NTSB, 1996, p. 23).

4.6.6. Post-certification flight testing of the R22 (in 1982) and the R44 (1995) by Robinson and the FAA concluded that each helicopter was safe when “flown within its approved limitations” and “could safely perform any nominal flight activity without main rotor divergence tendencies” (NTSB, 1996, p. 23). However, a helicopter could be operating within the approved limits, but unintentionally exceed a design limitation without a pilot input; for example, when encountering low G or in turbulence. The R22 and R44 Flight Standardization Boards in 1995 noted that “flight conducted in normal operating conditions may cause an encounter with such hazards”.

4.6.7. Robinson submitted that turbulence alone cannot lead to low G mast bumping, adding that an improper input or reaction by the pilot was also required. Although it is clear from operational experience that Robinson helicopters can be operated safely in some degree of turbulence, the Commission considers that Robinson has not proven conclusively that a pilot input is necessary for a mast bump, for the following reasons:

- The rotor system behaviour in turbulence has not been fully tested.
- The low G conditions that have been tested were planned manoeuvres as part of blade flapping surveys. In those tests, the test pilot initiated recovery action immediately the helicopter began the expected right roll, thereby avoiding any subsequent dynamic response.
- No minimum G is specified for Robinson helicopters, and little cognisance is given to the counter-intuitive response required of a pilot (who is unlikely to be a test pilot) faced with an un-commanded right roll under low G.
- Many of the fatal Robinson mast bump accidents in New Zealand have occurred in turbulent conditions, and it was impossible to state what control inputs were or might have been made immediately prior to the mast bumps.

4.6.8. The critical and sensitive nature of the flight controls was made clear in the R66 rotor flapping survey report, which stated “the exact boundary between ‘safe recovery can be performed’ and catastrophic mast bumping cannot be predicted”. Studies by the NTSB and manufacturers have shown that, due to the relative movement of the main rotor blades and the fuselage during manoeuvres, the required separation can be lost completely in less than a second. All of the conditions that can lead to a Robinson main rotor blade striking the fuselage have not been fully explained, but it is too dangerous to explore the problem with flight tests. Until the dynamic behaviour of the rotor system under conditions of low G is fully understood, it is likely that not all of the causal factors in accidents of this type will be identified, and therefore the appropriate recommendations to prevent a recurrence might not be made.

4.6.9. Since 1995, computational sciences and aerospace engineering have advanced to such a degree that a fuller understanding of the dynamic behaviour of lightweight, teetering, underslung rotor systems ought to be possible. For example, instrumented, remotely controlled helicopters could provide data on the rotor behaviour under conditions that are too dangerous for test pilots. Such a project could help to eliminate mast bump accidents.

4.6.10. Therefore, the Commission is recommending that the Administrator of the FAA reinstate research into the dynamic behaviour of two-bladed, teetering, underslung rotor systems, taking full advantage of the technology now available, with the aim of achieving the intended goals of NTSB recommendation A-96-12.

Finding

7. There is insufficient industry knowledge of why Robinson helicopters are particularly vulnerable to catastrophic mast bump events.

4.7. Civil Aviation Authority audits

4.7.1. The pilot was effectively making his own operational decisions because he flew alone, but he was still under the close supervision of the chief pilot. The operator was required to have a training programme that ensured its pilots were competent to perform their assigned duties.[55] The relevant advisory circular, 119-3, specified that the programme should include a mountain flying element if the area of operations included mountainous terrain. Most of the operator's work was in a designated mountainous area.

4.7.2. The CAA issued a specific approval to persons and certificated training organisations who could conduct advanced mountain training. Neither the operator nor its authorised flight training provider held that approval.

4.7.3. An operator's training programme could be varied, but the reason had to be noted in the affected pilot's training record. The operator's records did not show that the pilot in this case had completed or been excused from mountain flying training relevant to his role. However, the training records did show that he had been supervised over most of the operator's routes and into most landing sites, including the Mangataramea Hut. The chief pilot explained that those flights had included demonstrations of and discussions about mountain flying procedures, as had the pilot's R66 type rating training and his initial competency check with the external flight examiner. Although the operator's records did not show that the pilot had been given mountain flying training specific to the role, it is highly likely that he had received such training. Therefore, the Commission determined that the pilot's training was unlikely to have been a factor in the accident.

4.7.4. The safety of the New Zealand civil aviation system relies, in part, on the effectiveness and reliability of the CAA's risk-based surveillance system. The primary tools in this system included the routine audits and spot checks of operators' adherence to the standards and conditions of their aviation documents. The focus of the audits is "on what is actually happening versus the procedures that the organisation has documented to show how it carries out its activities" (CAA, 2012, p. 8).

4.7.5. The CAA conducted a routine audit of the operator in March 2010. The operator was re-certified in February 2013, two weeks before the accident.

4.7.6. A further routine audit was conducted in March 2014. The report of that audit, in line with the CAA's policy, contained no commentary by the auditors on the operator's performance or relative safety risk. The report included a summary of approximately 480 rules (or sections of rules) "that were tested during this audit", all of which were ticked to show that the operator was "found to be compliant". The size of the list was so inordinately large for an audit as to call into question the integrity of the audit. The CAA later agreed[56] that:

> this audit report is unlikely to portray an accurate representation of the rules sampled … staff are now more conscious of the expectation and importance of only marking off the rules that were checked.

4.7.7. The Surveillance Risk Assessment Form prepared prior to that audit had a recommendation, made on 20 February 2014 by the CAA unit manager, for auditors to "conduct an in-depth audit of the [operator's] pilot training and competency programme" and to "review the company's approach to mountain flying training". These were appropriate instructions to make following the Kaweka accident. The post-audit report stated that the operator's exposition[57] complied with Rule 135.553(a) regarding training programmes. However, the Commission's staff found no reference to mountain flying training in the exposition as late as July 2015. As a result of the Commission asking for this anomaly to be explained, the CAA in August 2015 asked the operator to submit a revised training programme.

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[55] Civil Aviation Rule 135.553(a) refers.

[56] Email from CAA Manager Safety Investigation, 20 August 2015.

[57] An exposition is a description of an operator's organisational structure, and the means and methods for ensuring ongoing compliance with Civil Aviation Rules, which is provided to the CAA in support of an operator's application for a certificate.

4.7.8. Regardless of the audit errors, the Commission determined that the pilot's training, and specifically his training for mountain flying, was unlikely to have been a factor in the accident.

Findings
8. In spite of the lack of reference in the operator's exposition to mountain flying training, the pilot's training was unlikely to have been a factor in the accident.

5. Findings

5.1. The in-flight break-up was caused by a mast bump and main rotor blade contact with the fuselage.

5.2. The mast bump very likely occurred when the helicopter encountered moderate or greater turbulence, which likely resulted in a condition of low G. The effect of any turbulence would have been exacerbated by the helicopter's light weight and estimated airspeed of 115 knots.

5.3. The possibility that an intentional or inadvertent control input by the pilot contributed to the mast bump cannot be excluded.

5.4. The R66 global accident history, in the five years since the type was introduced into service in 2010, suggests that the R66 is as vulnerable as the smaller R22 and R44 to a catastrophic mast bump under certain conditions.

5.5. The R66 was certificated without any special pilot training requirements to mitigate the risk of a catastrophic mast bump.

5.6. At the time of the accident, the Robinson helicopter flight manuals did not adequately warn pilots of the hazardous operating practices and environmental conditions that can lead rapidly to a catastrophic mast bump. This type of accident is strongly associated with turbulent conditions.

5.7. There is insufficient industry knowledge of why Robinson helicopters are particularly vulnerable to catastrophic mast bump events.

5.8. In spite of the lack of reference in the operator's exposition to mountain flying training, the pilot's training was unlikely to have been a factor in the accident.

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. In January 2015, the following was added to the Normal Procedures section of the R66 (and R44) flight manuals:

CAUTION

If turbulence is expected, reduce power
and use a slower than normal cruise speed.

6.3. On 29 October 2015, the Director of Civil Aviation was granted a Warrant of Authority to Impose Conditions on the operation of Robinson R22 and R44 helicopters in New Zealand. The conditions included reinstatement of the SFAR 73 training for R44 pilots. For the full list of conditions, see https:/www.caa.govt.nz/pilots/robinson_conditions.pdf

6.4. In February 2016, Robinson amended Safety Notice SN-32, 'High winds or turbulence'. One of the changes reinstated the previous advice that 'flying in high winds or turbulence should be avoided' (see Appendix 7).

Safety actions addressing other safety issues

6.5. 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 Director of Civil Aviation (New Zealand) and to the Administrator of the FAA (United States).

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.

Recommendations

7.3. The CAA adopted the requirements of SFAR 73 for both the R22 and the R44 when the SFAR was first issued in 1995. The FAA made SFAR 73 permanent in 2009, for both R44 and R22 pilots.

7.4. The R66 main rotor system is the same design as those of the R22 and R44. Therefore, and with the knowledge that four of seven fatal R66 accidents to date have been mast bump or low-main-rotor-RPM accidents, the 'essential' aerodynamic and handling knowledge and training that are prescribed in SFAR 73 for R22 and R44 pilots should be thoroughly understood and observed by R66 pilots. This goal would be achieved by the FAA extending SFAR 73 to include R66 pilots. It would be appropriate for the CAA to take that action, regardless of the FAA's response.

7.5. The addition to the Robinson R66 (and R44) flight manuals, in January 2015, of a Caution concerning flight in turbulence, and the changes made in February 2016 to Safety Notice SN-32, significantly increased the attention given to turbulence. Although the changes would have been notified to most registered owners of Robinson helicopters and subscribers to an amendment notification service, and are available on the Robinson website, their wider publication could help reduce the incidence of mast bump accidents in New Zealand.

7.6. The inherent risks involved with flight testing lightweight helicopters with two-bladed, teetering, underslung rotor systems have precluded a full understanding of how the main rotor dynamics might have contributed to mast bump accidents. Mathematical modelling about 20 years ago made a contribution to this knowledge, but the model was not completely validated. Advances in technology since then, including the use of remotely piloted helicopters, provide an opportunity to complete this research.

To the Director of Civil Aviation

7.7. On 25 February 2016 the Commission recommended to the Director of Civil Aviation that he:

7.7.1. Include the knowledge and training requirements of Special Federal Aviation Regulation No. 73, or an equivalent requirement, as a prerequisite for the issue of a Robinson R66 type rating. (002/16).

On 8 March 2016, the Civil Aviation Authority replied in part:

> On the basis that the FAA has twice rejected the inclusion of the Robinson R66 model in SFAR 73, the Director will not implement the recommendation, but will continue to monitor advice from Robinson Helicopters and the FAA with respect to the operation of R66 helicopters.

7.7.2. Promptly publicise the recent changes to the Robinson R66 (and R44) Pilot's Operating Handbooks that caution against flight in high winds and turbulence, and which advise pilots to reduce power and speed if turbulence is expected or encountered (011/16).

On 1 April 2016, the Civil Aviation Authority replied:

> The Director does not consider it necessary to promptly publicise the recent changes to the Robinson R66 (and R44) Pilot's Operating Handbooks that caution against flight in high winds and turbulence, and which advises pilots to reduce power and speed if turbulence is expected or encountered.
>
> The amended safety notice by Robinson is freely available on their website. In addition, operators of Robinson helicopters are required to regularly amend their Pilot's Operating Handbooks and this activity includes incorporating changes to information such as safety notices.

To the Administrator, Federal Aviation Administration.

7.8. On 25 February 2016 the Commission recommended to the Administrator, FAA that he:

7.8.1. Extend the knowledge and training requirements of Special Federal Aviation Regulation No. 73 to pilots of the Robinson R66 helicopter. (004/16)

7.8.2. 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)

On 9 June 2016, the FAA replied:

> The FAA received this safety recommendation on May 4, 2016. We are evaluating the recommendation and will propose an action plan, if appropriate. We will coordinate with Robinson Helicopters during this process and provide an update by August 1, 2016.

8. Key lessons

8.1. Pilots must be familiar with the complete Pilot’s Operating Handbook for each aircraft type that they fly, as well as the approved flight manuals.

8.2. Pilots of Robinson helicopters, regardless of their experience, should avoid areas of high winds or turbulence, and closely adhere to the manufacturer’s advice to reduce airspeed if turbulence is encountered.

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Appendix 1: ZK-IHU maintenance and post-accident testing

1. Recent maintenance

1.1. The previous scheduled maintenance was a 100-hour check completed on 21 February 2013 at 699 flight hours. At that check the main rotor swash plate lower scissor link ball-end was replaced because of wear. Earlier airframe maintenance of note included the following:

Date	Flight hours	Action
9 July 2012	354	main rotor blade spindle boots[58] replaced due oil leak.
6 October 2012	406	(1) spindle boots replaced again, because of contact with main rotor hub (2) main rotor pitch links upper rod ends and lower links replaced because of wear.
18 January 2013	601	spindle boot (blade serial number 0217) replaced again due wear from contact with the main rotor hub.

1.2. Robinson advised that the cause of spindle boots rubbing on the hub was likely to be improper spindle boot installation or a flight event that included excessive coning and/or teetering. The company that usually maintained the helicopter said the replacement frequency was high, but not unheard of in the smaller R44, which uses similar parts.

1.3. Robinson R66 Service Letter 06, issued on 21 December 2012, recommended a check of the tail rotor drive shaft damper assembly for incorrect installation during manufacture. The check was to be done when the drive shaft was next removed, but no opportunity for that had arisen before the accident. Later inspection showed that the damper had been installed incorrectly. Robinson advised that incorrect installation did not affect damper performance.

1.4. In September 2012 the engine oil filter went into bypass mode after being blocked by carbon particles. Rolls-Royce advised that the degree of contamination was normal for the type of oil being used. The oil and filter element were replaced, the magnetic chip plugs were checked and a satisfactory ground run was carried out. Another oil filter bypass occurred in October 2012, but no contamination was found. As the oil filter case was suspected of being defective, it was replaced. No further problems were reported with the oil system.

1.5. Robinson R-66 Service Bulletin 05B, issued on 21 December 2012, required the replacement of the engine-to-gearbox sprag clutch retaining bolt, which eliminated play between the engine power take-off shaft and the clutch splines.[59] The bulletin required the task to be completed within the next 100 flight hours after receipt of the bulletin or by 31 March 2013, whichever occurred first. The helicopter accrued approximately 180 hours, and had two 100-hour inspections, between 22 December 2012 and the time of the accident, without the bolt having been replaced. The primary maintenance provider attributed the hours' overrun to changing parts requirements and availability caused by two revisions in 18 days to the original bulletin.

1.6. When the clutch was removed from the helicopter after the accident, it did not turn freely in the freewheel direction. The clutch was examined at the Robinson factory on 10 May 2013, under the supervision of the NTSB. The report on the examination commented that the damage to the clutch was typical of impact damage.[60]

1.7. The next annual review of airworthiness was due on 4 December 2013.

[58] The spindle is the pitch change bearing of the main rotor blade. The boots are flexible covers that retain the bearing lubricant.
[59] A sprag clutch transfers the engine torque to the main rotor transmission. In the event of an engine failure, the sprags withdraw, allowing the rotor to continue to turn so that the helicopter can autorotate to a landing.
[60] The Commission considered that the sprag clutch maintenance was not a factor in the accident.

2. Post-accident testing

Engine monitoring unit

2.1. The engine monitoring unit recorded the following parameters once every second:

- gas producer (compressor) speed ('N1')
- power turbine speed ('N2')
- torque (the primary indicator of the power being demanded from the engine)
- measured gas temperature (MGT).

2.2. During the 10 seconds prior to the end of the recorded data, when the data became anomalous, the average values of the parameters were:

Torque (%)[61]	N1 (%)	N2 (%)	MGT (^{0}F)
75	93	100	1130

2.3. According to the flight manual, the maximum allowable MGT for 75% torque (at a pressure altitude of 4,000 feet and an assumed temperature of 15^{0}C) was approximately 645^{0}C (1,193^{0}F). Therefore the engine parameters were within the flight manual limits until immediately prior to the accident.

Engine and engine accessories

2.4. Under the supervision of an NTSB investigator, Rolls-Royce disassembled and examined the engine at its manufacturing plant in the United States. The Rolls-Royce report noted that "nothing was discovered which would prohibit normal engine operation" and that all observations were "consistent with engine operation at impact".

2.5. The power turbine governor[62] and fuel control unit[63] were disassembled and inspected by their manufacturer, Honeywell, at its plant in the United States. These inspections were performed under the supervision of an FAA inspector, acting for the NTSB. For both items, the Honeywell report stated, in part:

> discounting impact damage, no condition could be found that would prevent normal operation.

Main rotor control hydraulic servos

2.6. Pilot control of the main rotor pitch was assisted by three hydraulic servos. The servos were examined under the supervision of the NTSB on 10 May 2013 at the Robinson factory, where they had been manufactured. The servo that had been installed in the forward left position (one of the two cyclic servos) operated smoothly but, because of impact damage, it could not be tested against production specifications. For each of the other two servos, Robinson's examination report stated:

> A functional test was performed and the servo operated within production specifications.

Main rotor drive shaft

2.7. The Defence Technology Agency of the New Zealand Defence Force conducted a metallurgical and fractographic[64] examination of the main rotor drive shaft to determine the failure mode. The Agency's report[65] commented:

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[61] The torque was recorded by the monitoring unit in units of pressure, but was displayed to pilots as a percentage. The recorded data was converted using a formula provided by Robinson.
[62] Model AL-AA2 Part number 2549170-2, serial number HR49120.
[63] Model DP-N2, part number 2549196-1, serial number HR60017.
[64] Fractography is the examination of the cause of a material failure by studying the characteristics of the fracture surface.
[65] Technical Memorandum C1281, Main rotor drive shaft failure of R66 ZK-IHU, 19 June 2013.

> Failure occurred by overload and the nature of the fracture indicates that significant bending and torsional loads were applied … The direction of torsional loading was consistent with power being applied to the rotor while the rotor was abruptly decelerated, perhaps through contact with the airframe or some other object.

2.8. The Agency's report included the following conclusions:

- fracture of the main rotor drive shaft was due to excessive loading with no evidence of pre-existing cracking or defect
- fracture of the mast exhibits evidence that severe mast bending combined with torsional loading from the power train caused the overload failure
- mast wall thicknesses were found to be essentially consistent with those specified for the R66 mast. Analysis indicated that the shaft material was consistent with the specified material (4340 steel).

Appendix 2: Further accident site information

1. The location of the accident is shown in Figure 4 and the distribution of the major wreckage in Figure 5.

2. Both landing skids were attached to the fuselage, but the snowshoe-type heels were separated and the toe of the left skid had also fractured.

3. The tail rotor drive shaft had separated at the forward flexible coupling, and the tail boom had separated aft of the oil cooler. The tail rotor blades had minor impact damage only, indicative of little or no rotation when the tail boom fell into the trees. The tail rotor guard and the lower vertical stabiliser were damaged, but most likely during the recovery of the tail boom.

4. The main transmission could be turned without obvious noise or restriction. The engine-to-transmission drive shaft had fractured at the forward flexible coupling. The surrounding braided oil lines were wrapped around the drive shaft along its length. Damage to the engine casings was caused by external impacts. Damage to the pneumatic lines precluded a thorough checking of that system.

5. Fuel flow was demonstrated from the fuel tank to the fuel pump, and from the pump to the fuel nozzle on the engine combustor. The nozzle was found to be satisfactory during the later tear-down examination of the engine. Both magnetic plugs were visibly clean.

6. The push-pull rods under the cockpit floor for the collective, lateral cyclic and tail rotor controls were severed as a result of the main rotor blade strike.[66] The fore-aft cyclic control was bent. Control continuity was established from rearward of the underfloor disruption to the hydraulic servos. No conclusions could be drawn as to the pre-impact positions of the flight controls.

7. Owing to the extensive damage to the cockpit instrument pedestal, no significant information was obtained from the instruments. The wreckage was examined for any evidence of a bird strike, but none was found.

8. The fuel tank was made of a puncture-resistant, flexible material that was not damaged, even though adjacent structure and panels were torn and disrupted.

[66] The collective lever and the cyclic stick are two of a pilot's controls for the main rotor. The collective lever is used to change the main rotor blade pitch angles collectively, which causes the helicopter to climb or descend. Cyclic stick movement causes the rotor blade pitch angles to change at the same point during their rotation cycle, which causes the rotor to tilt in the direction that the pilot has put the stick. The helicopter then moves in that direction.

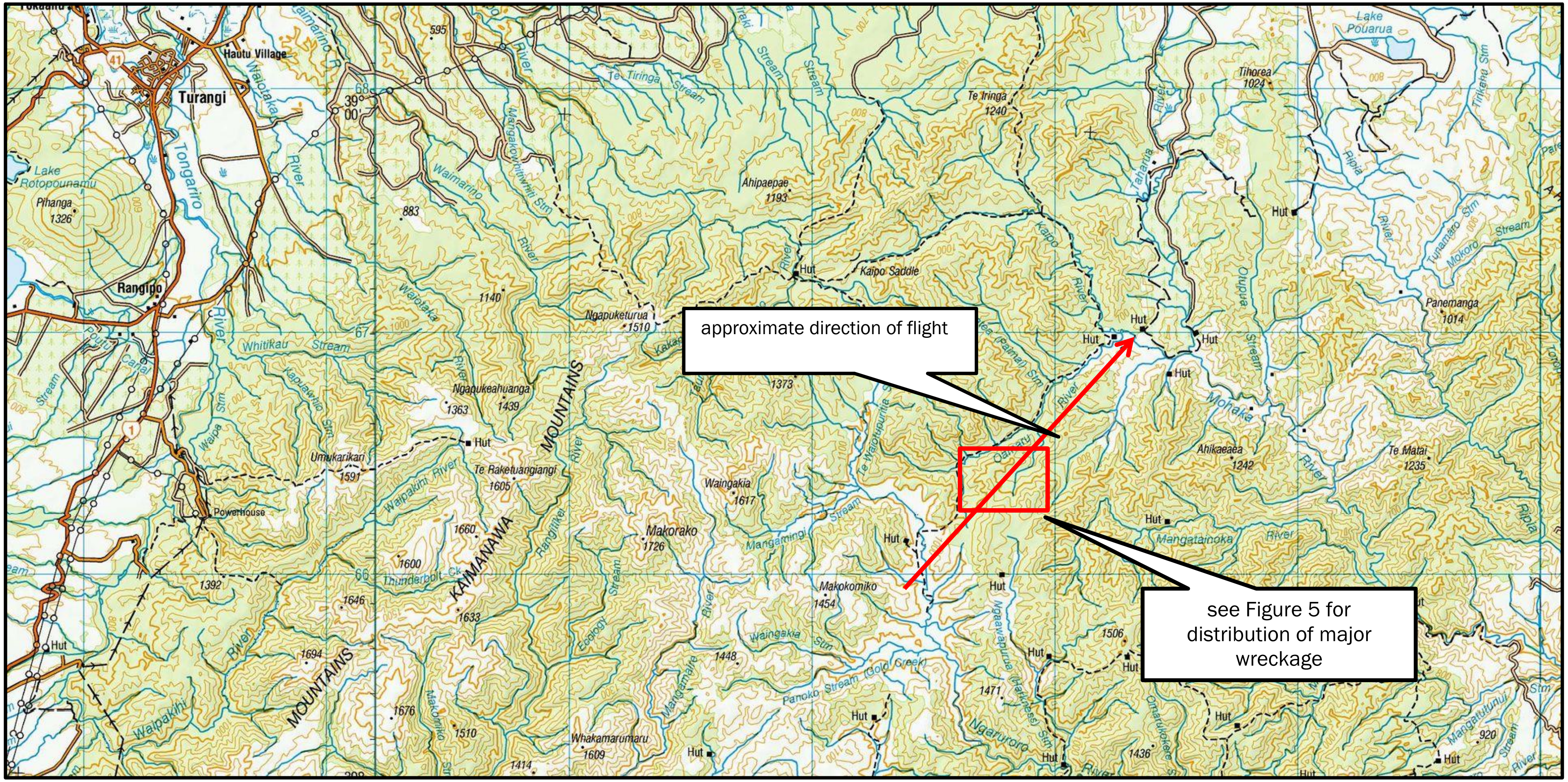

Figure 4
Accident site

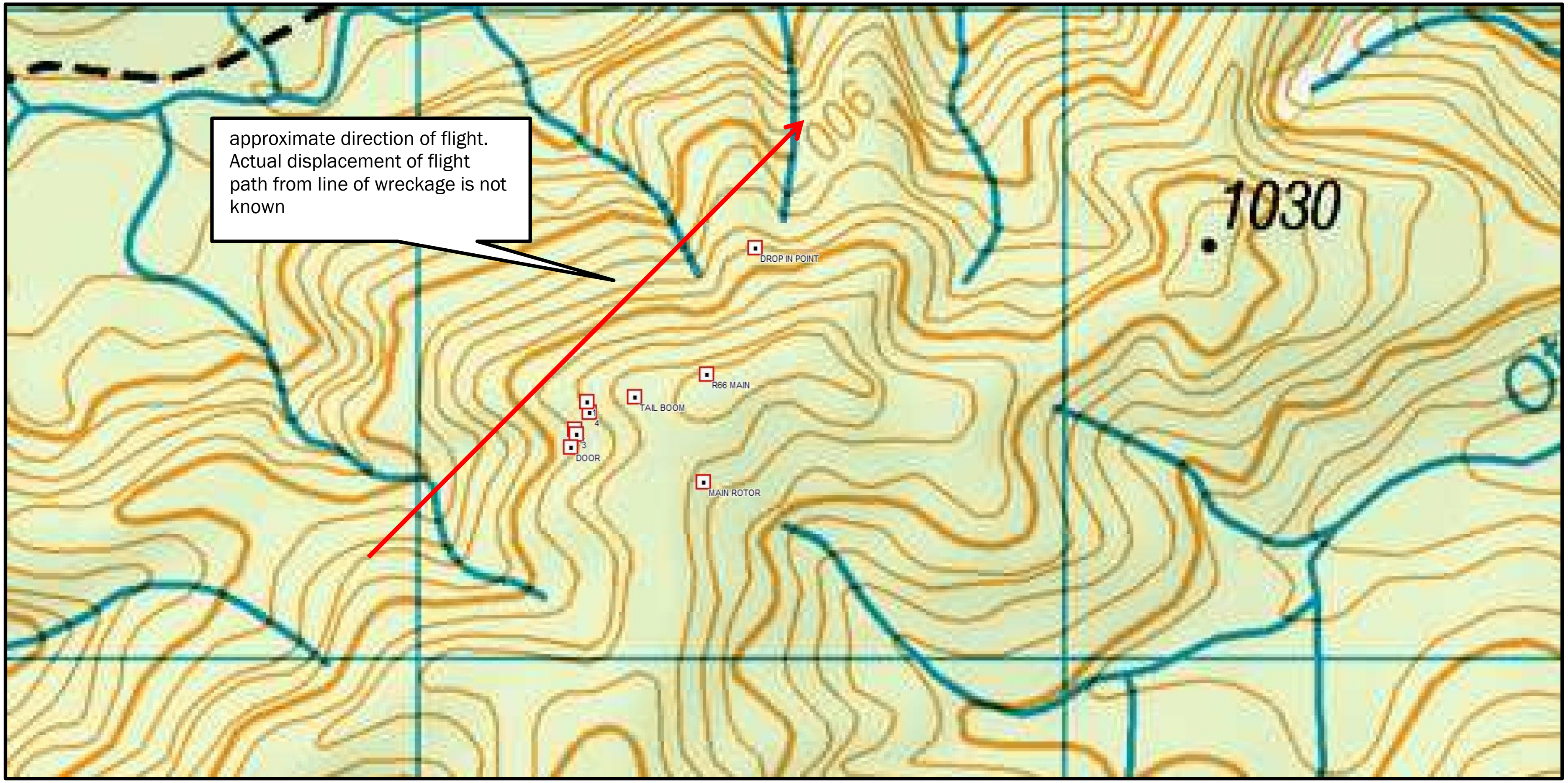

Figure 5
Distribution of major wreckage

Appendix 3: The NTSB special investigation of Robinson accidents

1. In 1994, concerned by the number of unexplained R22 accidents that involved a mast bump or low main rotor RPM ('loss of main rotor control'), the NTSB commenced a special investigation to examine those accidents and the certification history and handling qualities of the R22. The investigation was later expanded to include similar R44 accidents.

2. In response to the initial recommendations made by the NTSB during the investigation, the FAA issued airworthiness directives (ADs) that limited R22 and R44 operations in high winds and turbulence. The final versions, AD 95-26-04 for the R22 and AD 95-26-05 for the R44, were issued in 1996. AD 95-26-04 was later made permanent, but AD 95-26-05 was rescinded in 2004 after a review of the R44 in-service experience.[67]

3. AD 95-26-04 included, in part, the following information:

   - Until the FAA completes its research into the conditions and aircraft characteristics that lead to main rotor blade / fuselage contact accidents, and corrective type design changes and operating limitations are identified, Model R22 pilots are strongly urged to become familiar with the following information and comply with these recommended procedures.
   - **Main Rotor Stall**: … Any flight condition that creates excessive angle of attack on the main rotor blades can produce a stall. Low main rotor RPM, aggressive manoeuvring, high collective angle (… high density altitude, over-pitching … during climb, or high forward airspeed) … The effect of these conditions can be amplified in turbulence.
   - **Mast Bumping**: Mast bumping may occur with a teetering rotor system when excessive main rotor flapping results from low 'G' … or abrupt control input … High forward airspeed, turbulence and excessive sideslip can accentuate the adverse effects of these control movements.
   - To avoid these conditions, pilots are strongly urged to follow these recommendations:
   - Maintain cruise airspeeds between 60 [knots] and less than 0.9 [of maximum permitted airspeed] …
   - Avoid large, rapid forward cyclic inputs in forward flight, and abrupt control inputs in turbulence.

4. The FAA also issued SFAR 73 in 1995 to mandate specified awareness and flight training for all pilots of R22 and R44 helicopters. SFAR 73 required that the special training be delivered by an authorised instructor and completed by every pilot before "manipulating the controls" of a Robinson helicopter. The SFAR 73 also stipulated that an annual flight review be undertaken in the applicable helicopter type until a specified minimum experience was attained, after which biannual flight reviews, in the relevant type, were required.[68] SFAR 73 was made permanent in June 2009.

5. The NTSB special investigation report noted that the FAA had conducted three special certification reviews of the R22 between 1982 and 1994. Each review had concluded that the R22 was safe "when flown within its operating limitations". However, the NTSB found no evidence that the FAA had acted on internal recommendations regarding the certification testing of light helicopters and their dynamic stability during manoeuvres (NTSB, 1996, pp. 20,21).

6. Robinson conducted flight tests of the R22 in 1982 to survey rotor teeter clearances and the response to flight control inputs, and concluded that the R22 main rotor system "would not stall, exceed its teeter clearance, or contact the tail boom when the aircraft is flown within its approved limitations" (NTSB, 1996, p. 23). Similar tests conducted with the R44 in 1995 concluded that "the R44 could safely perform any nominal flight activity without main rotor divergence tendencies" (NTSB, 1996, p. 23). However, because "the tests were not (and could not safely be) conducted to determine the [R44's] response to large, abrupt cyclic inputs … the flight test did

[67] Robinson took other action to improve the R22, including installation of an electronic fuel control governor (which helps to control main rotor speed), a more powerful engine, and an automatic carburettor heat control.
[68] On 11 June 2015, Robinson published a tutorial on SFAR 73 at www.gyronimosystems.com/SFAR.

not provide the data needed to determine the mechanism for the blade diverging into the body" (NTSB, 1996, p. 23).

7. The obvious constraints on hazardous flight testing led to a mathematical simulation model of R22 main rotor dynamics being developed by the Georgia Institute of Technology School of Aerospace Engineering (Schrage, 1995).[69] The project ended due to a lack of funds before the model was fully validated or had researched all of the areas of interest (for example, divergent modes of the rotor that led to blade-fuselage strikes) (NTSB, 1996, p. 24). However, for those areas of the flight envelope that were validated, the model verified the theory that push-overs (which cause a low-G condition) could lead to a main rotor blade striking the fuselage.

8. The Georgia Institute of Technology report stated that "within the scope of this investigation no [static droop] stop contact or rotor/tail boom strikes occurred in the normal operating range of the helicopter", but some of the scenarios did produce notional mast bumps and hub contact with the droop stop (Schrage, 1995, p. 127).

9. The report concluded, in part (Schrage, 1995, p. 133):

> The results from the cases executed in this report fall into three basic categories: (i) cases where no excessive flapping was observed, (ii) cases where larger than normal flapping behavior was observed, and the various limits of the blade and hub were exceeded, and (iii) cases where there was indication of a definite tail boom strike. The primary objective of many of the cases executed in this investigation was to find as many flight conditions as possible which fall in the last category. As one would expect these cases correspond to maneuvers with large pilot inputs, cases where rotor stall is a factor, severe gusts among others. Thus, some cases have been identified, where the simulation model seems to indicate a potential failure mode. These are primarily related to rotor stall at lower rpm ... In case of pushover scenarios, simulation results indicate a sensitivity to abrupt aft cyclic under conditions of deep rotor stall. Gust under moderate conditions, seems not to be a problem even at high gross weights.

10. The Georgia Institute of Technology report recommended further areas of study, but the FAA confirmed in 2013 that the intended research had not been completed.

11. Studies by the NTSB and manufacturers have shown that a low-inertia main rotor blade can strike the fuselage in just a few revolutions. That would take less than half a second for an R66 main rotor operating at the normal speed of 408 RPM.

12. The NTSB's special investigation "found no direct evidence of an unstable blade or rotor system design. The extensive operational history, the wreckage evidence, flight tests, and computer simulations indicate that a dynamically unstable main rotor system is unlikely" (NTSB, 1996, p. 25). The NTSB recognised that many factors, including large, abrupt pilot control inputs, were possible explanations for the accidents.

13. The summary of the NTSB special investigation report stated, in part (NTSB, 1996, p. 27):

> The Board is also concerned that in the future, other highly responsive helicopters are likely to be designed and built that may have characteristics similar to the R22. Consequently, the Safety Board believes that as a part of the certification process for highly responsive helicopters, the FAA should establish operational requirements, student pilot training requirements, and instructor pilot requirements, such as those imposed on the R22 and R44, to ensure that pilots at all levels of qualification and skills can adequately operate the helicopter. The Safety Board concludes that although the response rate of the R22 to cyclic input is not unsafe so long as the special operating rules remain in place, there is a need for the FAA to consider the responsiveness of helicopters (especially lightweight, high performance helicopters such as the R22) as part of the certification process to determine if special operating rules or guidance are necessary. Thus, the Safety Board believes that the FAA should require helicopter manufacturers to provide data on the response of helicopters to large, abrupt cyclic inputs as a part of the certification process and

[69] Retrieved 15 December 2014 from http://hdl.handle.net/1853/52548.

> require operational limitations or other measures for those helicopters that are more responsive, such as the R22.

14. The NTSB made the following recommendations to the FAA at the conclusion of its special investigation (NTSB, 1996, p. 31):

> Ensure that Special Federal Aviation Regulation 73, the Flight Standardization Board specifications, and the airworthiness directives applicable to the operation of the R22 and R44 are made permanent (A-96-9)
>
> Establish, for future certification of highly responsive helicopters, operational requirements, student pilot training requirements, and instructor pilot requirements, such as those imposed for the R22 and R44, necessary to ensure that pilots of all levels of qualification and skills can adequately operate the helicopter (A-96-10)
>
> Require helicopter manufacturers to provide data on the response of helicopters to flight control inputs to be used as part of the certification process, and require operational limitations or other measures for those helicopters that are highly responsive (A-96-11)
>
> In conjunction with the National Aeronautics and Space Administration, continue the development of the simulator model of lightweight helicopters, using flight tests and whirl tower tests as needed to validate the model, to create a national resource tool for the study of flight control systems and main rotor blade dynamics. If any unusual main rotor blade system characteristics are found, ensure that the information and data gathered are disseminated to the appropriate agencies and industry (A-96-12).

15. The status of recommendation A-96-9 was changed to 'Closed–acceptable action' in December 1996 after the FAA agreed to make the listed documents permanent.

16. The status of recommendation A-96-10 was also changed to 'Closed–acceptable action' in December 1996 after the FAA committed to establishing a Flight Standardization Board for each newly certificated helicopter to determine the operational and pilot training requirements.

17. In response to recommendation A-96-11, the FAA twice amended Advisory Circular 27-1, Certification of Normal Category Rotorcraft. The changes added guidance to manufacturers on a means of compliance with regulation 14CFR27.661, which requires rotor-fuselage clearance "for any operating condition". In a letter to the NTSB seeking closure of the recommendation, the FAA stated that the guidance material addressed large control inputs by pilots and low-G manoeuvres. As a result, on 17 March 2000 the NTSB changed the recommendation status to 'Closed–acceptable action'.

18. Recommendation A-96-12 was closed by the NTSB in 1998 after it received a submission from the FAA, which read in part:[70]

> The FAA has reviewed the merits of developing a simulation tool for aiding the certification of future helicopter flight control systems/blade dynamics and has determined that such a tool would have limited application. This determination considered the actions that have already been accomplished and the status of the NASA initiative. The behavior of certain rotor system configurations may become unpredictable and dangerous beyond certain boundaries. For this reason, the FAA established a certified operating envelope. Due to the combination of extremely complex flight control inputs, non-linear environmental gust effects and the inherent difficulties in various rotor blade airfoil/hub designs, development of a single generic mathematical model to predict acceptable flight limitations would have limited application. Subsequent validation of the math model would involve extensive testing with significant risk to flight safety.

19. The NTSB accepted that "the bulk of the effort towards continued math modelling of lightweight rotor systems will be conducted by [the National Aeronautics and Space Administration] and the FAA has reached the limits of its technical involvement".

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[70] www.ntsb.gov/safety/safety-recs/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-96-012, accessed 17 July 2015.

Appendix 4: Participants in the helicopter forum, 9 May 2013

Name	Position	Experience and expertise
Larry Bennett	Former Chief Executive and Chief Pilot, North Shore Helicopters	Airline transport pilot licence (helicopter) (ATPL(H)) Category A instructor General aviation flight examiner 15,500 flight hours
Paul Breuilly	CAA, Team Leader, Safety Investigation Unit	
Tim Burfoot	Transport Accident Investigation Commission, Chief Investigator of Accidents	
Jim Finlayson	Chief Pilot, Ice Aviation	ATPL(H) and ATPL (aeroplane) Category A instructor General aviation flight examiner
David Gill	CAA, Team Leader Airworthiness	Bachelor of Engineering (Mechanical)
Ian McClelland	Transport Accident Investigation Commission, Investigator of Accidents	
Andy McKay	CAA, Aviation Examiner	Category A and D instructor General aviation flight examiner
Rama Rewi	Transport Accident Investigation Commission, General Counsel	
Neil Scott	Chief Pilot, Garden City Helicopters	ATPL(H), commercial pilot licence (aeroplane) (CPL(A)) Category A, D and E instructor for both helicopters and aeroplanes General aviation flight examiner for both helicopters and aeroplanes 24,800 flight hours
Dave Sowman	Head of Training – Utility, HNZ New Zealand	CPL (helicopter) (CPL(H)) and CPL(A) Category A, D and E instructor General aviation flight examiner 7,600+ rotary wing flight hours
Simon Spencer-Bower	Chief Executive and Chief Flying Instructor, Wanaka Helicopters	CPL(H) and CPL(A) Category A helicopter instructor Category D aeroplane instructor General aviation flight examiner 21,000 flight hours, 18,600 on helicopters, 15,000 on Robinsons
Barry Stephenson	Transport Accident Investigation Commission, Investigator of Accidents	
Ian Wakeling	Chief Executive and Chief Pilot, Aviation Development	CPL(H) and CPL(A) Category B instructor General aviation flight examiner Former Vice President and production test pilot, Fairchild-Hiller Helicopters 16,000 flight hours
Peter Williams	Transport Accident Investigation Commission, Deputy Chief Investigator of Accidents	

Appendix 5: Robinson R66 fatal accidents

Date	Location	Registration	Circumstances
12 July 2011	Santiago Vila de Giradot, Colombia	N810AG	Unauthorised instruction by pilot with little Robinson experience. Low RPM rotor stall and main rotor strike on fuselage.
1 October 2011	Philip, South Dakota, USA	N266CY	In-flight break-up; main rotor detached. Benign weather. Pilot's experience on Robinsons undetermined, but R66 training not completed.
3 January 2013	Caraguatatuba, São Paulo, Brazil	PR-DUB	Report not available, but indications of loss of control after flying into cloud.
9 March 2013	Kaweka Range, New Zealand	ZK-IHU	In-flight break-up; main rotor detached. Likely moderate turbulence. Low-time pilot with R22 and R44 experience.
27 July 2013	Noxen, PA, USA	N646AG	Night-time, loss of control after flying into fog.
22 November 2013	Guaiba Island - Mangaratiba, Brazil	PR-MXM	Report not available, but indications of main rotor separation in turbulence.
28 June 2014	Temnolesskaya, Russia	RA-1588G	Report not available, but indications of loss of control after flying into cloud.

Appendix 6: Robinson Safety Notice SN-32 (revised May 2013)

ROBINSON
HELICOPTER COMPANY
2901 Airport Drive, Torrance, California 90505 Phone (310) 539-0508 Fax (310) 539-5198

Safety Notice SN-32

Issued: March 1998 Revised: May 2013

HIGH WINDS OR TURBULENCE

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 right forearm on right leg to prevent unintentional control inputs.
4. Do not overcontrol. 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.

Appendix 7: Robinson Safety Notice SN-32 (revised February 2016)

ROBINSON
HELICOPTER COMPANY
2901 Airport Drive, Torrance, California 90505 Phone (310) 539-0508 Fax (310) 539-5198

Safety Notice SN-32

Issued: March 1998 Revised: May 2013; Feb 2016

HIGH WINDS OR TURBULENCE

Flying in high winds or turbulence should be avoided.

A pilot's improper application of control inputs in response to turbulence can increase the likelihood of a mast bumping accident. If turbulence is encountered, the following procedures are recommended:

1. Reduce power and use a slower than normal cruise speed. Mast bumping is less likely at lower airspeeds.
2. For significant turbulence, reduce airspeed to 60–70 knots.
3. Tighten seat belt and rest right forearm on right leg to minimize unintentional control inputs. Some pilots may choose to apply a small amount of cyclic friction to further minimize unintentional inputs.
4. Do not overcontrol. 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 turbulence will likely be most severe.

The helicopter is more susceptible to turbulence at light weight. Reduce speed and use caution when flying solo or lightly loaded.

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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
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11-001	Bell Helicopter Textron 206L-3, ZK-ISF, Ditching after engine power decrease, Bream Bay, Northland, 20 January 2011
11-002	Bombardier DHC-8-311, ZK-NEQ, Landing without nose landing gear extended Woodbourne (Blenheim) Aerodrome, 9 February 2011

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