Final Report AO-2016-007: Collision with terrain, Robinson R44, ZK-HTH,
Glenbervie Forest, Northland, 31 October 2016

The Transport Accident Investigation Commission is an independent Crown entity established to determine the circumstances and causes of accidents and incidents with a view to avoiding similar occurrences in the future. Accordingly it is inappropriate that reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The Commission may make recommendations to improve transport safety. The cost of implementing any recommendation must always be balanced against its benefits. Such analysis is a matter for the regulator and the industry.

Final Report

Aviation inquiry AO-2016-007
Collision with terrain
Robinson R44, ZK-HTH
Glenbervie Forest, Northland
31 October 2016

Approved for publication: February 2019

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

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

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Important notes

Nature of the final report

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

Ownership of report

Citations and referencing

Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1982 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publicly available are cited.

Photographs, diagrams, pictures

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

Verbal probability expressions

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

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

Robinson R44 Raven II ZK-HTH with spray equipment fitted

(Source: J Wegg)

Location of accident

Source: mapsof.net

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Abbreviations

°	degree(s)
CAA	Civil Aviation Authority of New Zealand
Commission	Transport Accident Investigation Commission
ELT	emergency locator transmitter
GPS	global positioning system
km	kilometre(s)
m	metre(s)
RCCNZ	Rescue Coordination Centre New Zealand
Robinson	Robinson Helicopter Company
S/N	serial number

Glossary

collective lever	a control that changes the pitch angle of the main rotor blades by the same amount and at the same time, which changes the total rotor thrust, usually to effect a climb or descent
cyclic stick	a control that changes the pitch angle of the main rotor blades at the same point of their rotation cycle, which causes the rotor disc to tilt in the direction in which the pilot has put the cyclic stick. The helicopter then moves in that direction
datum	a reference point or plane from which measurements are taken
low-G	(or reduced g) an acceleration less than that due to the force of gravity
mast	the main rotor driveshaft of a helicopter
mast bump	contact between the inboard end of a main rotor blade (the spindle) and the main rotor driveshaft (mast)
pitch link	a link between the upper rotating half of the swashplate and a main rotor blade that enables the pilot to change the pitch angle of the blade
pushover	an abrupt forward movement of the cyclic stick
splines	ridges or teeth on a shaft that mesh with grooves on a mating piece to transfer torque
sprag clutch	a component that transmits engine power to the main and tail rotors, and disengages (freewheels) when the engine ceases driving
swashplate	a component that transfers the pilot's cyclic and collective control inputs to the main rotor through two pitch links
teeter stops	two elastomeric blocks that limit the amount of movement about the teeter bolt
teetering	the see-saw movement of a two-bladed rotor about the teeter bolt or centrally mounted rotor hub

Data summary

Aircraft particulars

Aircraft registration:	ZK-HTH
Type and serial number:	Robinson Helicopter Company R44 Raven II, 13529
Number and type of engines:	one IO-540-AE1A5 normally aspirated, reciprocating
Year of manufacture:	2013
Operator:	Helisika Agricultural Limited
Type of flight:	commercial
Persons on board:	two

Crew particulars

Pilot's licence:	commercial pilot licence (helicopter)
Pilot's age:	42
Pilot's total flying experience:	2,060 hours (approximately) 1,630 hours on type

Date and time	31 October 2016, 1258[1]
Location	Glenbervie Forest, near Whāngārei, Northland
	latitude: 35° 37´ 23" S
	longitude: 174° 21´ 56" E
Injuries	two fatal
Damage	helicopter destroyed

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

1. Executive summary

1.1. On Monday 31 October 2016, ZK-HTH, a Robinson R44 helicopter, was being used to conduct aerial spraying of forestry blocks in Glenbervie Forest, north of Whāngārei. The pilot and a forestry contractor were using the helicopter to conduct a pre-spraying survey to ensure that the boundaries of the target blocks were correctly identified, and to check for any hazards and obstacles.

1.2. The helicopter was flying away from the blocks being surveyed and had just crossed a ridge when it crashed into dense bush and caught fire. The helicopter was destroyed and the two occupants were fatally injured.

1.3. The Transport Accident Investigation Commission made the following findings:

- The damage to the helicopter sustained in the accident sequence and subsequent fire, and the lack of any other incontrovertible evidence, meant that the cause or causes of the accident could not be determined.

- A bolt that attaches the pitch link to the pitch horn on one of the main rotors was found to be missing. It is virtually certain that the missing bolt came out of position during the impact sequence, meaning it did not contribute to the accident.

- It was not possible to determine why the cyclic extension for the left seat was installed and if it was being used at the time of the accident or at any time during the flight.

1.4. The Transport Accident Investigation Commission has previously made a recommendation that on-board recorders be fitted to certain classes of helicopter to aid accident investigation. If such a recorder had been fitted and recovered, it would very likely have helped to identify the cause or causes of this accident. No new recommendation was made.

2. Conduct of the inquiry

2.1. The Civil Aviation Authority of New Zealand (CAA) notified the Transport Accident Investigation Commission (Commission) of the accident at 1545 on 31 October 2016. The CAA deployed a team to the site that day to conduct an initial survey.

2.2. On 1 November 2016 the Commission opened an inquiry under section 13(1) of the Transport Accident Investigation Commission Act 1990 and appointed an investigator in charge. Two investigators travelled to Northland that day and took over the site from the CAA team. In accordance with a memorandum of understanding between the New Zealand Defence Force and the Commission, an investigator from the Royal New Zealand Air Force assisted with the Commission's site examination for training purposes.

2.3. On 1 November 2016 the Commission notified the National Transportation Safety Board of the United States of the accident, as the helicopter and its engine had been manufactured in the United States. In accordance with Annex 13 to the Convention on International Civil Aviation, the National Transportation Safety Board appointed a non-travelling Accredited Representative to participate in the investigation. The Accredited Representative appointed the helicopter manufacturer, Robinson Helicopter Company (Robinson), as its Adviser.

2.4. Robinson, as provided for in Annex 13, requested participation in the initial examination of the accident site and the wreckage. The Commission agreed to the request, and a Robinson investigator arrived in New Zealand on 2 November 2016.

2.5. The site examination was completed on 3 November 2016. The wreckage was then taken to the Commission's wreckage facility in Wellington, where investigators from the Commission and Robinson conducted a more detailed examination.

2.6. The Commission's investigators interviewed representatives of the operator (Helisika Agricultural Limited) and persons associated with the spraying operation. Perishable evidence obtained by the CAA team, and copies of photographs taken by them and police personnel who attended the site, were given to the Commission.

2.7. On 8 November 2016 the Commission engaged a consulting laboratory[2] to conduct a metallurgical examination of some components of the helicopter's main rotor control system.

2.8. On 1 December 2016 the Commission published an interim factual report on the accident.[3]

2.9. On 8 December 2016 Commission investigators supervised a detailed examination of the engine at an aviation engineering facility. Several components were subjected to further specialist examination.

2.10. The Commission's Medical Consultant[4] reviewed pathology and toxicology reports and the medical records for the pilot and the passenger.

2.11. In September 2017 the original investigator in charge resigned from the Commission and a new investigator in charge was appointed.

2.12. Between October 2017 and July 2018 Robinson provided additional information that the Commission had requested.

2.13. On 24 October 2018 the Commission approved this draft report for circulation to interested persons for comment. The response time for submissions was extended following a request from one of the interested persons.

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[2] Quest Integrity NZL Limited.
[3] Transport Accident Investigation Commission Interim Report Inquiry AO-2016-007, Collision with terrain, Robinson R44 ZK-HTH, Glenbervie Forest, Northland, 31 October 2016.
[4] Dr Robin Griffiths MB ChB (Hons), FAFPHM, FFOM, FAFOEM, FFOM(I), MACOEM, MPP, Dip Av Med.

2.14. The Commission received seven submissions. The Commission considered the submissions, and changes as a result of those submissions have been included in the final report.

2.15. On 20 February 2019 the Commission approved the final report for publication.

3. Factual information

3.1. Narrative

3.1.1. On Monday 31 October 2016, a Robinson R44 helicopter, registered ZK-HTH (the helicopter), was being used to spray blocks in two commercial forests in Northland that had recently been planted with seedlings. Prior to commencing each spraying task, the pilot flew a short survey flight with a forestry contractor to ensure that the boundaries of the target blocks were correctly identified, and to check for any hazards and obstacles.

3.1.2. At about 1000 the pilot completed spraying eight blocks in Mokau Forest, on the east coast north of Whāngārei. The pilot refuelled the helicopter and flew to a loading area in Glenbervie Forest, shut down the helicopter, and waited for the loader and contractor to arrive. They then had lunch while waiting for a light shower to pass through the area.

3.1.3. At about 1255 the helicopter took off to undertake the survey of the two blocks to be sprayed. The loader prepared the spray product to be loaded on their return. The helicopter was not always visible to the loader during this time, but was occasionally observed being flown at about 100 feet (30 metres [m]) above the terrain at an estimated 50 knots (93 kilometres [km] per hour), which the loader said was 'pretty standard'.

3.1.4. At 1309 the Rescue Coordination Centre New Zealand (RCCNZ) received an automatic alert that the emergency locator transmitter (ELT) fitted to the helicopter had activated briefly at 1258. RCCNZ contacted the operator, who then phoned the loader. The loader was already concerned that the helicopter had not returned from what was expected to be a 10-minute flight, so began a search for the helicopter.

3.1.5. The helicopter had crashed and caught fire. Smoke from the fire led searchers to the site (see Figure 1). Both occupants were later found deceased in the wreckage.

Figure 1
Accident site

3.2. Site information

3.2.1. The accident site was in hilly terrain, 1.5 km north of the loading area, in an area of native bush within the forest blocks. The site was on a north-facing slope about 150 m north of and below a forestry road that ran along a ridgeline. The tree canopy was about 20 m high with thick undergrowth (see Figure 2). Damage to the trees indicated that, after striking the tree-top canopy, the helicopter had descended through the trees at a descent angle of about 50 degrees (°).

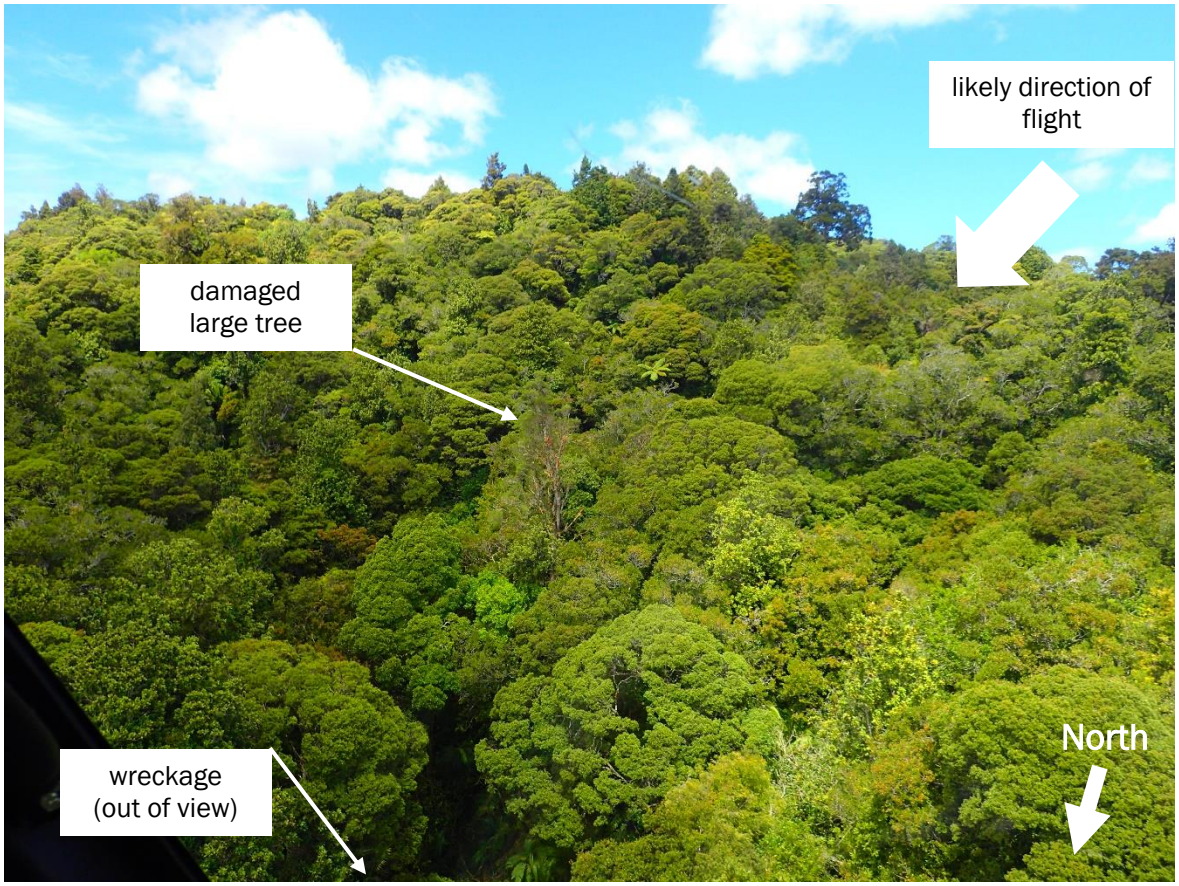

Figure 2
Site location

3.3. Weather

3.3.1. A large anticyclone covered the country, providing generally fine weather. Whangarei Aerodrome was 16 km to the south of the accident site. The weather recorded there at 1300 was a northerly surface wind of about 5 knots (10 km per hour), 20 km visibility and broken cloud[5] at 4,000 feet (1,200 m) above sea level. The wind at the accident site was generally described as light, with one witness assessing it as an easterly of about four knots. People who attended the accident site observed the smoke from the fire to be either going "straight up" or drifting slightly.

3.3.2. Witnesses said a light shower had passed over the forest about midday, but this had quickly cleared. A rainfall recorder located at the Glenbervie Forest office recorded no rain between midday and the time of the accident.

3.4. Wreckage and impact information

3.4.1. The wreckage of the helicopter was found near the base of a large tree that had numerous broken branches. Parts of the landing skids, the tail rotor assembly and the carbon-fibre spray booms had broken off as the helicopter fell through the trees in a northerly direction. The

[5] Cloud is measured using oktas or eighths. Broken is 5-7 oktas.

damage to the helicopter and adjacent foliage indicated that it had struck the ground with a high rate of descent and a low forward speed.

3.4.2. The fire was intense enough to melt aluminium components, including the main rotor gearbox casing. The fire also melted other aluminium components in the fuselage and consumed the fibreglass cabin structure. The tail boom, tail rotor, main rotor blades and mast head were unburnt. Due to the effect of the fire, the pre-impact integrity of the flight and engine control systems and many components could not be determined. The fire had not spread beyond the main wreckage.

3.4.3. The tail, including the horizontal and vertical stabilisers and the complete tail rotor assembly, had detached from the tail boom. Significant crushing damage was found on the leading edge of the horizontal stabiliser that, along with some trapped tree foliage and wood splinters, indicated the stabiliser had struck trees.

3.4.4. The main rotor blades had remained attached to the hub and were not damaged by the fire. Outboard sections of both blades had separated and were found nearby. The damage to the leading edges of both blades, together with small pieces of wood embedded in the blades, indicated that the main rotor blades were turning when the blades struck the trees. There was no evidence of the main rotor blades having struck the tail boom or the cabin.

3.4.5. Figure 3 shows the items comprising the rotor head. Both teeter stops were crushed to varying degrees of damage. Both pitch links[6] remained attached to the upper swashplate.[7] However, both had disconnected from their respective main rotor blades. The pitch link for blade serial number (S/N) 3325 had broken at the upper rod-end thread. The pitch link for blade S/N 3347 was complete, but the attachment bolt that connected it to the pitch horn was missing and was never found. The bolt hole for the pitch link attachment to the swashplate was elongated in an upward direction.

[6] A link between the upper rotating half of the swashplate and a main rotor blade that enables the pilot to change the pitch angle of the blade.
[7] A component that transfers the pilot's cyclic and collective control inputs to the main rotor through two pitch links.

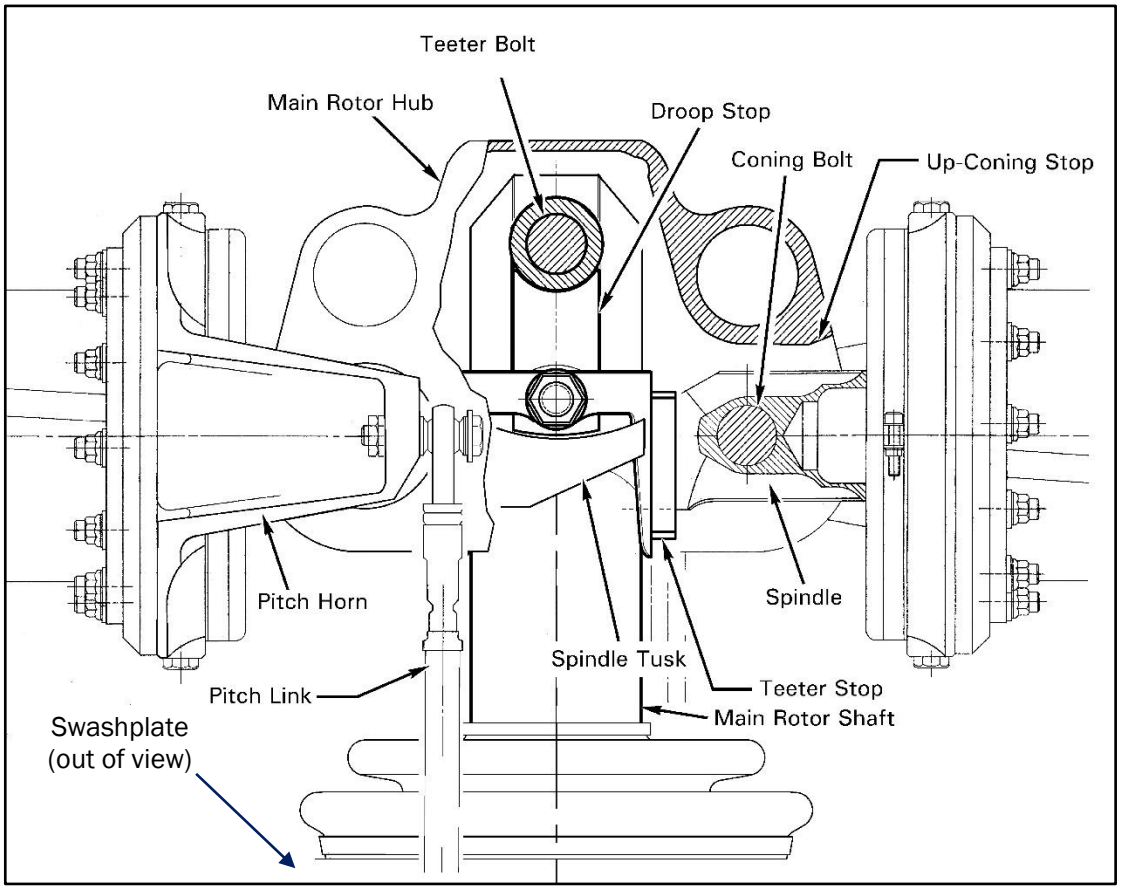

Figure 3
Robinson main rotor head

(source: Robinson Helicopter Company)

3.4.6. The helicopter was normally flown from the right seat. The loader did not think that the cyclic stick extension had been installed at the start of the day. However, an examination of the wreckage revealed that the cyclic stick[8] extension for use by the left-seat occupant was installed at the time of the accident (see Figure 4). However, the left-side dual tail rotor pedals and collective lever[9] were not installed.

[8] A control that changes the pitch angle of the main rotor blades at the same point of their rotation cycle, which causes the rotor disc to tilt in the direction in which the pilot has put the cyclic stick. The helicopter then moves in that direction. Normally held in a pilot's right hand.

[9] Tail rotor pedals are used to adjust the pitch of the tail rotor blades to counter the torque effect of the main rotor and control a helicopter's heading and balance. The collective lever is a control held in a pilot's left hand, which changes the pitch angle of the main rotor blades by the same amount and at the same time, which changes the total rotor thrust, usually to effect a climb or descent.

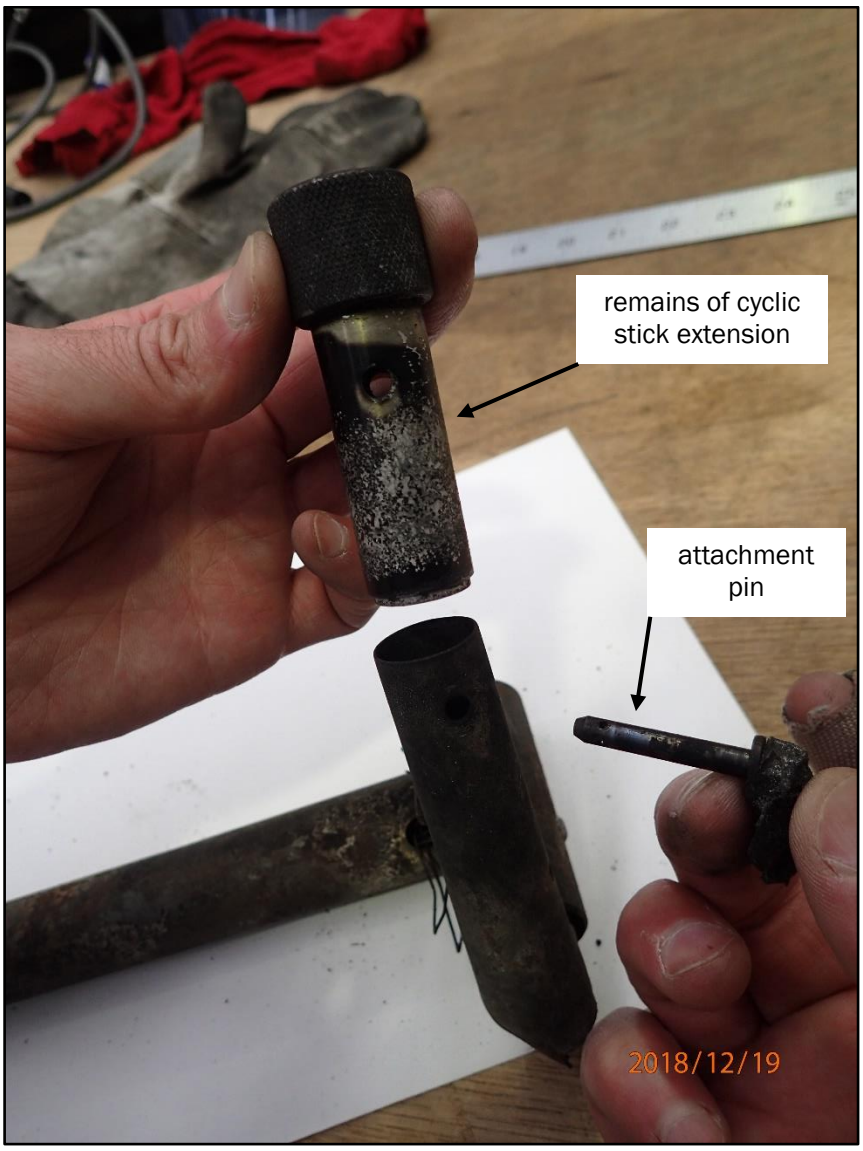

Figure 4
Cyclic stick extension

3.5. Aircraft information

3.5.1. The Robinson R44 model of helicopter was first produced in 1992. It is a four-seat light helicopter, powered by a single, normally aspirated piston engine[10] with later versions equipped with hydraulically assisted flight controls.

3.5.2. The helicopter had been imported new into New Zealand in October 2013, issued with a certificate of airworthiness in the standard category and registered as ZK-HTH. The certificate was non-terminating provided the helicopter was maintained and operated in accordance with the prescribed documents. The certificate had been re-issued on 25 September 2015 to permit the helicopter to be used in the 'restricted category' for agricultural operations.

3.5.3. According to the operator's documentation, the helicopter had been maintained in accordance with the Robinson maintenance schedule. The last annual review of airworthiness had been completed on 28 July 2016 and the last 100-hour check completed on 5 October 2016. The helicopter had flown 42 hours since the 100-hour check and accrued a total of 743 flight hours.

[10] Non supercharged or turbocharged.

3.5.4. The technical log that was used to record daily flight hours and any new technical defects was destroyed in the fire. However, the operator and the loader, who held a commercial pilot licence and occasionally flew the helicopter, both said that the helicopter had been flying well. They were not aware of any recent defects that might have affected the airworthiness of the helicopter.

Weight and balance

3.5.5. The weight and balance at the time of the accident were calculated using an assumed fuel load of 60 litres. The assumption was based on the pilot having landed with minimum fuel[11] after completing the earlier spraying in Mokau Forest, adding 60 litres from three jerry cans that were carried on the support truck, and then flying for 20 minutes to Glenbervie Forest. A further 10 minutes of flying was allowed for the survey before the accident. The weight of the two occupants was obtained from medical records.

3.5.6. The weight of the helicopter, including the spray equipment, was estimated to have been 1,026 kilograms (kg), 108 kg less than the maximum allowable weight of 1,134 kg. The longitudinal centre of gravity was estimated to have been 92.82 inches (2.358 m) from the datum[12], which was within the range of 92 inches (2.337 m) to 101.7 inches (2.58 m) allowed for the estimated weight.

Tests and research

3.5.7. An expert metallurgist examined the two pitch links from the main rotor assembly. The pitch link for blade S/N 3325 had broken at the threaded portion immediately below the spherical bearing (see Figure 5), through which a bolt attached the link to the pitch horn. The mode of failure was determined by the metallurgist to be overload. Robinson advised that the mode of failure and location were typical of those seen in other accidents where a severe bending motion had been applied to the pitch links.

[11] Minimum fuel was taken to be 35 litres, which is sufficient for 30 minutes of flying.
[12] The datum is the reference point about which centre of gravity calculations are performed. For the R44 helicopter, the datum is 100 inches (2.5 m) forward of the main rotor shaft centreline.

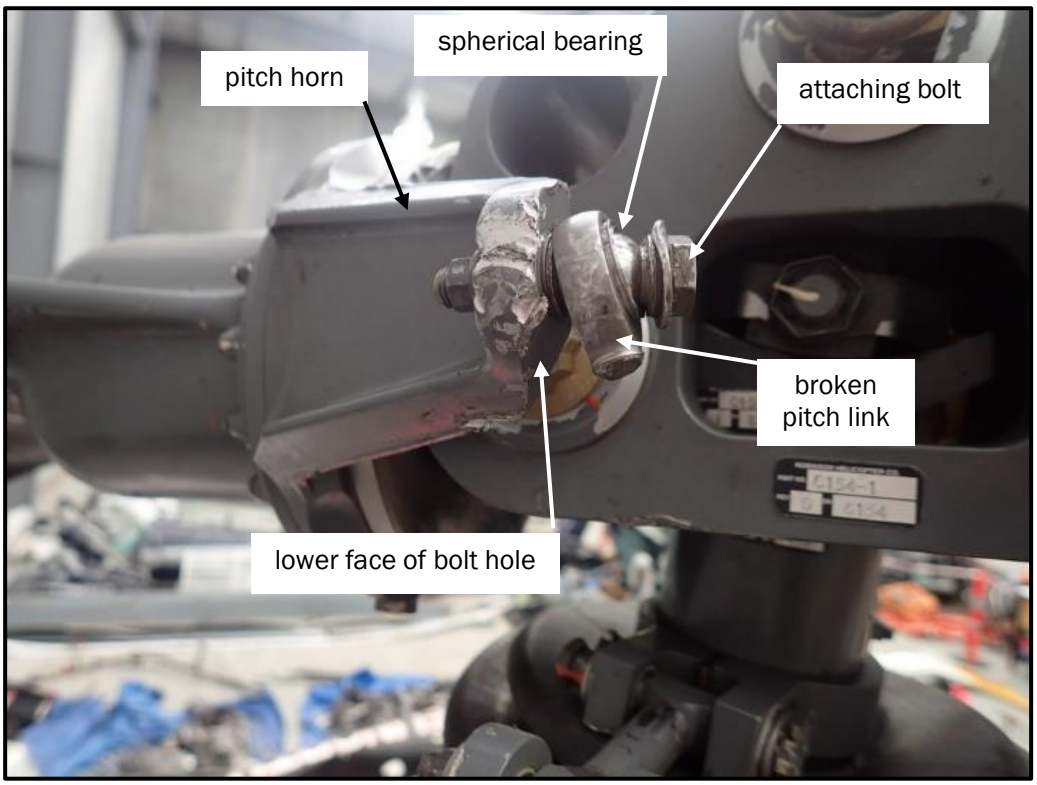

Figure 5
Broken pitch link for blade S/N 3325

3.5.8. The bolt that attached the pitch link to the pitch horn of the other blade, S/N 3347, was missing. The pitch link itself displayed no obvious damage. The metallurgist examined this pitch link and the bolt hole in the associated pitch horn. The report stated, in part:

- the face of the bolt hole closest to the pitch link displayed markings indicating that the paint coating layers were not concentric around the bolt hole. This implies that the spacer may not have been flush against the bare metal when the fastener was fully assembled
- the lower edge of the bolt hole was noticeably deformed in one corner, presumably from the bolt at some point. Burnishing (rubbing) was noted on the bore of the bolt hole below this area of deformation
- the nut face of the bolt hole was bright, surrounded by dark sealing compound. The machined seat underneath the washer displayed machining marks that would be expected from original manufacture. This is a strong indicator that there was no movement of, or wear from, the washer under the nut
- impact marks were visible on the body of the pitch horn above the bolt hole that faces the pitch link. The appearance was that of gouging by a harder material with an irregular profile. Repeating markings within the gouges were measured at a spacing of between 0.48 and 0.51 millimetres. This is approximately half the pitch of the fastener, a 5/16”-24 UNF bolt.[13] A pitch of 24 threads per inch is approximately 1.06 millimetres. It is possible, but not conclusive, that these marks were made by the start of the thread of the bolt
- on the nut side face of the bolt hole, only minor scoring was visible, diametrically opposite the deformation on the opposite face. The scoring was the result of something hard scoring a small ‘U’ shaped scratch or groove as it went down and up the bore of the bolt hole while twisting.

3.5.9. The metallurgist’s report concluded that the amount of damage on the pitch horn and the lack of damage to the pitch link “strongly suggests that there was no impact force[s] transmitted to or through the pitch link at the time of the final impact of the aircraft – it is feasible that the

[13] UNF (Unified National Fine thread) is a standard bolt category.

pitch link was not attached to the pitch horn at the time of final impact". The metallurgist later confirmed that the "final impact" was the helicopter striking the ground.

3.5.10. Impact marks on the lower face of the pitch horn matched the dimensions of the pitch link upper locking nut (see Figure 6). The impact marks could only have been made when the main rotor blade was at an extremely high pitch angle, measured to be about 31°. The normal maximum blade pitch angle achievable with the collective lever fully raised is 19.9°.

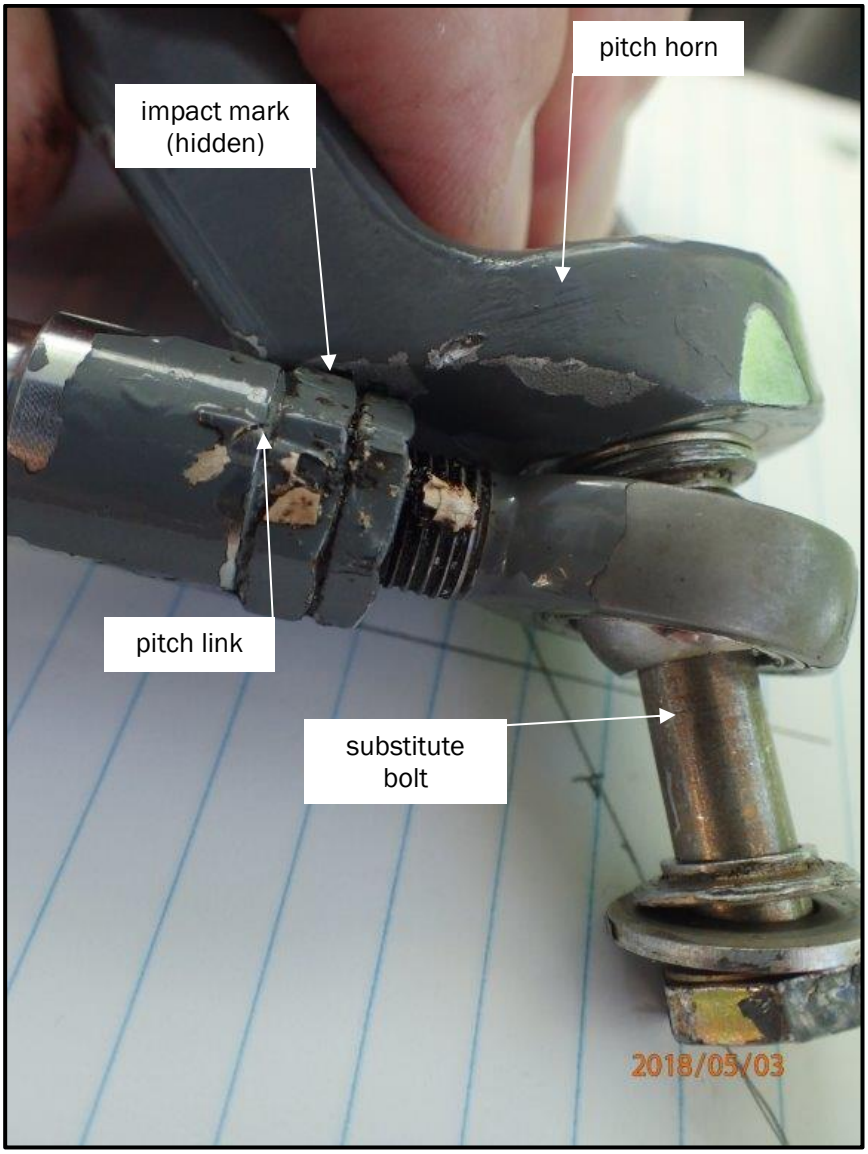

Figure 6
Pitch horn and link for blade S/N 3347

3.5.11. Robinson reviewed the metallurgist's report and examined the pitch horn, swashplate and connecting pitch link. It commented that the observed damage could occur only if the pitch link was attached to both components. Further, Robinson commented that aerodynamic forces alone could not force the blade to such a high (31°) pitch angle.

3.5.12. The engine was subjected to a full examination or teardown[14] by a licensed aircraft maintenance engineer who was very familiar with the type of engine. The examination was supervised by a Commission investigator and the Lycoming Engines field representative for New Zealand. The maintenance records for the engine were found to be complete and accurate.

[14] A disassembly of an engine down to its individual components.

3.5.13. The aircraft maintenance engineer provided a report that concluded that, apart from fire and impact damage, 'no evidence was found of any pre-impact defect that would have affected the engine's ability to produce power. Accident fire damage precluded a detailed investigation of the engine components'.

3.5.14. The Commission received information that there may have been a problem with the helicopter's sprag clutch.[15] The sprag clutch was examined by a different aircraft maintenance engineer,[16] who found that it was of the correct type and had been maintained in accordance with the manufacturer's instructions.

3.5.15. The sprag clutch had significant heat (fire) damage. There was no oil inside the unit, but no evidence of oil leakage. The clutch was 'notchy' under freewheel rotation and the sprags had locked under drive rotation. The sprags displayed normal wear and tear for the age of the clutch, and no excessive wear on the sprag 'windows' was found. See section 4.3 for further comment on the sprag clutch.

3.6. Personnel information

3.6.1. The pilot had started helicopter flight training in July 2006 and been issued with a private pilot licence in April 2007. The pilot had qualified on the Robinson R44 in September 2007 and been issued with a commercial pilot licence in February 2011.

3.6.2. The pilot had obtained a chemical rating in October 2007 and a helicopter Grade 2 agricultural rating in August 2011. Both ratings had been revalidated and were current at the time of the accident. The pilot's last flight crew competency check and agricultural competency check were recorded as having been satisfactorily completed on 19 September 2016.

3.6.3. The pilot held a current Class 1 medical certificate issued on 18 April 2016. The certificate contained no conditions, restrictions or endorsements. A review of the pilot's medical records identified no health concerns.

3.6.4. The pilot had been rested and apparently in good health before the accident.

Medical and pathological information

3.6.5. Both occupants sustained fatal injuries. The toxicology results for the pilot and contractor were negative for any performance-impairing substances.

3.7. Organisation and management information

3.7.1. The pilot, who was the former owner of the company, flew under the operator's air operator certificate. The operator provided the company management and oversight, while the pilot was responsible for the day-to-day operations. The helicopter was maintained by a contracted maintenance organisation based at Ardmore Aerodrome.

3.8. Recorders

3.8.1. The helicopter was fitted with equipment that recorded the flight path of the helicopter using global positioning system (GPS) information. The recorded information included the flights on the day of the accident. The data showed that the helicopter was flown between about 100 feet and 150 feet (30-45 m) above the terrain during the survey and spraying flights (see Figure 7).

3.8.2. The last recorded position of the helicopter was about 0.9 km south of the accident site. The data for the final portion of the flight had not been saved from the data buffer to the

[15] A component that transmits engine power to the main and tail rotors, and disengages (freewheels) when the engine ceases driving.
[16] The aircraft maintenance engineer who performed the examination was very experienced with sprag clutch maintenance, having maintained most of the Robinson R44 sprag clutches in New Zealand.

permanent memory so was not able to be recovered.[17] The ELT started transmitting about 40 seconds after the last recorded GPS position report.

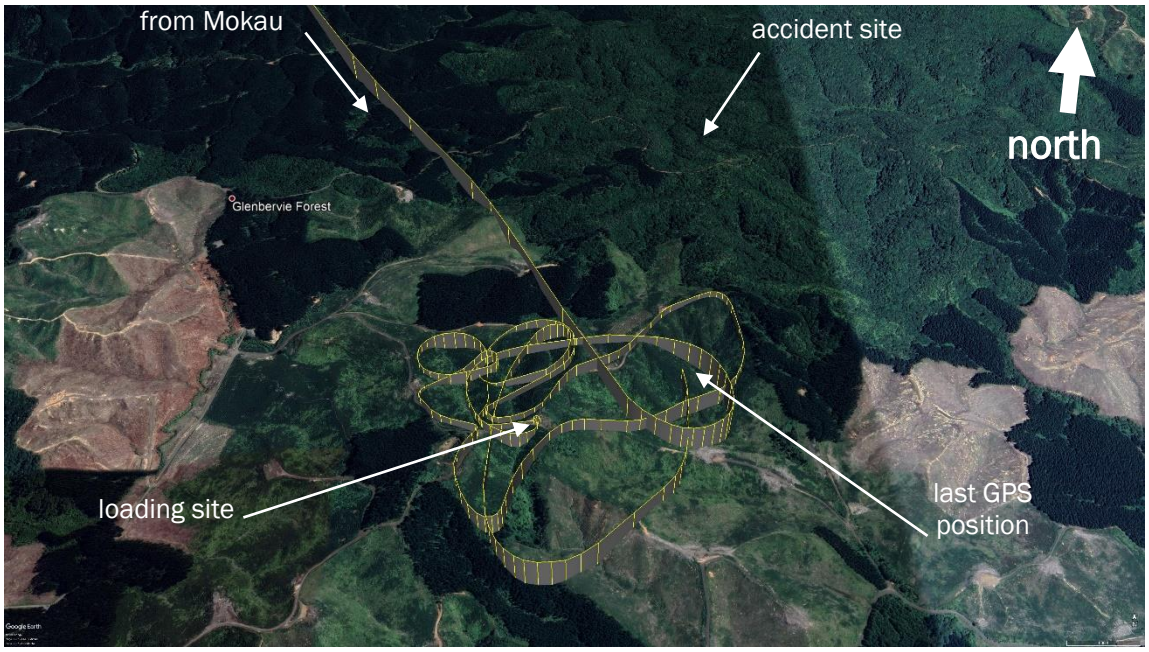

Figure 7
GPS track

3.9. Survival

3.9.1. The helicopter's ELT transmitted a brief distress signal at 1258, which was detected by satellite and transmitted to RCCNZ at 1309. No positional information was transmitted and no further transmissions were received.

3.9.2. RCCNZ alerted the operator, which in turn contacted the loader, who reported that the helicopter was overdue from the survey flight. The operator reported that information to RCCNZ, which dispatched the nearest search and rescue helicopter from Whāngārei, 15 km to the south. A ground search was also commenced by the loader and two forestry managers.

3.9.3. After approximately 20 minutes, both the search helicopter and the ground searchers saw smoke rising from the dense bush. The helicopter crew found the crashed helicopter, but as the helicopter did not have a winch, a paramedic could not be lowered to the site. The helicopter returned to base and was replaced by a helicopter that was equipped with a winch, but which had been undergoing servicing when the initial call-out was received.

3.9.4. The ground searchers had arrived at a forestry loading site above the crash site as the first search helicopter departed, and proceeded to locate the accident helicopter.

3.9.5. The second search and rescue helicopter returned at 1457 and a paramedic confirmed the occupants were deceased.

[17] The delay in writing to the permanent memory was normal for the model of GPS installed.

4. Analysis

4.1. Introduction

4.1.1. The accident occurred during a routine survey flight of forestry land that the pilot was about to spray. The weather was suitable for the planned task with little or no wind present. The pilot was not engaged in spraying at the time.

4.1.2. The accident site was about one kilometre to the north of the planned spraying area. Why the helicopter flew beyond the planned area could not be determined. The damage to the helicopter caused by the impact and post-accident fire masked much of the evidence, and as there were no witnesses to the accident and there were no on-board flight data recorders installed, the Commission has been unable to determine conclusively the factors that contributed to the crash.

4.1.3. Previously, on 27 July 2016, the Commission had recommended that the Secretary for Transport promote the installation of on-board recorders in certain classes of helicopter, including Robinson helicopters, to address the continued lack of reliable evidence for some accidents.[18] At the time of writing this report, the recommendation remained open but other parties were working to address this issue.

4.1.4. The following analysis describes the circumstances of the accident and discusses potential scenarios.

4.2. Initial observations

4.2.1. The accident site was in dense bush on a moderate downslope, about 150 m past a ridgeline the helicopter had just flown over. There was a road running along the ridgeline that offered a potential landing site for the helicopter in the event of an emergency.

4.2.2. Based on GPS data and the activation of the ELT, and allowing for timing and position inaccuracies, it was calculated that the helicopter had an average groundspeed of 45-53 knots (83-98 km per hour) between the last GPS position report and the accident site. This was based on flying a straight line between the two points. Therefore, if there had been any deviation along the way the average speed would have been higher.

4.2.3. There is evidence that after the helicopter crossed the ridgeline it struck the treetop canopy, in particular the large tree referred to in section 3.2. After striking the large tree the helicopter descended through the bush at a descent angle of about 50°. It could not be determined whether the helicopter striking the tree canopy initiated, or was a consequence of, the accident sequence.

4.2.4. The damage to the trees and main rotor blades showed that the main rotor was still turning when the helicopter entered the bush. However, there was insufficient evidence to determine whether the main rotor speed was in the normal operating range, and whether the rotor was being driven by the engine or aerodynamic forces alone.[19] The wreckage was confined to a small area, which indicated that the helicopter was being flown at low speed[20] when it struck the trees.

[18] Transport Accident Investigation Commission Report AO-2015-002: Mast bump and in-flight break-up, Robinson R44, ZK-IPY, Lochy River near Queenstown on 19 February 2015 – Recommendations 014/16 and 015/16.
[19] Should an engine fail a main rotor can continue to rotate under aerodynamic forces. In a descent these forces can be strong enough to maintain normal rotor operating speeds.
[20] Less than 80 knots (150 km per hour), its maximum permitted speed with the spray equipment fitted.

4.3. Possible scenarios either ruled out or considered unlikely

Engine or power defect

4.3.1. It was very unlikely that an engine or power defect was the cause of the accident. A detailed examination of the engine found no evidence of pre-impact mechanical failure that might have contributed to a power loss.

4.3.2. Robinson and the engineer who examined the sprag clutch were aware of instances of sprag clutches disengaging in flight, without any fault being found with the clutch. A slipping clutch would normally show excessive wear on the sprags, or possibly evidence of severe heat stress.

4.3.3. The sprag clutch from the helicopter was damaged in the fire, masking possible evidence of internal heat stress. Nevertheless, the wear on the sprags was consistent with the time in service. The absence of oil within the unit was almost certainly a result of the intense fire. The clutch had last been serviced about three and a half months before the accident on 13 July 2016, at which time the oil was replaced. Had no oil been added the clutch would have shown evidence of this and most likely would have failed earlier. An in-flight failure of the sprag clutch would likely have led to the engine disconnecting from the main rotor transmission.

4.3.4. A total or near-total loss of power would have required the pilot to enter autorotation in order to preserve the main rotor revolutions per minute. As the helicopter approached the ground, the pilot would have needed to complete a flare manoeuvre to reduce forward and vertical speeds as much as possible to cushion the landing. The lower and faster the helicopter, the more exaggerated would be the flare. However, the height and speed of the helicopter are unknown, and the damage to the trees and helicopter provides no conclusive determination of how the helicopter approached the tree canopy.

Medical condition

4.3.5. It was very unlikely that a loss of control occurred because of a medical event affecting the pilot or the contractor. There was nothing in the medical history of either, or revealed in the post-mortem examinations, to suggest that possibility.

Fuel system defect

4.3.6. There were an estimated 60 litres of fuel on board when the helicopter crashed. A small trace of dirt and a small amount of water were found in one of the containers used to refuel the helicopter. The damage sustained in the post-accident fire prevented an examination of the helicopter's fuel system. Therefore, the possibility of a fuel-related engine problem could not be excluded.

Bird strike

4.3.7. The possibility of a bird strike could not be excluded. There was no evidence of a strike on the main rotor blades, but if there had been a strike on the front of the cabin the evidence would have been destroyed in the fire.

4.4. Missing pitch link bolt

4.4.1. It was highly unusual to find the attachment bolt missing from the upper end of the pitch link. Robinson commented that it had seen this only once before, after a "controlled flight into terrain" accident. Robinson had also supported two National Transportation Safety Board investigations where the lower pitch link attachment had released.[21] In each case the helicopter was having work done at the rotor head immediately before the accident flight.[22] The loss of the pitch link and control rod attachments resulted in severe mast bumping (see section 4.6). In one case the main rotor severed the tail boom, while in the other the main

[21] Robinson R44, N3101H, Miami, Florida, 3 April 2013 and Robinson R44, N3234U, North Salt Lake, Utah, 2 December 2014.
[22] Email from Robinson, 1 May 2018.

rotor assembly separated. Both helicopters fell vertically to the ground. The present accident did not have these characteristics apart from a degree of mast bumping, which is observed on nearly all occasions when the main rotors hit a solid object during an accident sequence.

4.4.2. An examination of the maintenance records identified that the most recent work undertaken in the area of the main rotor head had been in September 2015, more than one year earlier, when the helicopter was being prepared for agricultural work. Main rotor blade S/N 3347, which was associated with the pitch link that had the missing bolt, had been removed to facilitate the replacement of a spindle boot that was leaking lubricant. This task had required the pitch link to be disconnected, then reconnected after the blade was refitted.

4.4.3. It was very unlikely that the pitch link attachment bolt had been installed incorrectly after that maintenance, for the following reasons:

- records indicated that the maintenance personnel involved had referenced the approved Robinson maintenance procedure during the work
- according to the signed job cards, two additional engineers had checked the re-attachment of the main rotor blade and pitch link
- following the spindle boot replacement, the helicopter had flown 576 hours over 13 months without any recorded problems with the main rotor head
- during those 13 months the rotor head had been subjected to regular inspections, including six 100-hour inspections and daily inspections before each flight.

4.4.4. It was virtually certain that the pitch link attachment bolt for blade S/N 3347 broke and was lost as a consequence of the impact sequence, rather than being the cause of the accident. If the bolt had become loose before impact with the bush, there would very likely have been more evidence of fretting or wear around the upper attachment bolt hole. If the bolt had come completely out before the accident, the blade pitch would have been uncontrollable. The blade would almost certainly have moved to a very high (positive or negative) pitch angle. Because the main rotor's rotational speed was more than six revolutions per second, a blade with uncontrollable pitch could have struck the fuselage within a fraction of a second and that would very likely have been followed by an in-flight break-up. There was no in-flight break-up in this accident.

4.4.5. The blade pitch was calculated to have reached 31° while the pitch link was still attached (see section 3.5). Robinson said that aerodynamic forces alone could not have driven the blade to such a high angle. Therefore it was virtually certain that the blade reached that angle as a result of impact forces from the main rotor striking the trees while rotating, and that the pitch link attachment bolt then broke and was lost.

4.4.6. In the opinion of the metallurgist who examined the associated pitch horn, the non-concentric coating layers or painting around the bolt hole had the potential to cause a misalignment of the bolt and, with a soft polymer coating, relax the bolt's loading and reduce its effective fatigue strength. However, "a loss of pre-load would be associated with vibration and wear of the connection – this was not seen at the upper, nut side of the fastener". Therefore the possible misalignment almost certainly did not explain why the bolt was missing.

4.5. Mast bumping

4.5.1. Mast bumping is the result of extreme movement of the main rotor hub about the teeter hinge, often initiated by low-G (weightlessness) or a low rotor speed stall. Termed 'teetering', this causes the inboard end of a main rotor blade (the spindle) to contact the main rotor driveshaft (or mast), crushing the teeter stops in the process (see Figure 2). The Robinson main rotor design also allows independent flapping of the blades, which can amplify abnormal rotor movement under some conditions.

4.5.2. In this accident, evidence of the mast bumping included the crushed teeter stops and scoring on the main rotor hub. The pitch link for blade S/N 3325 was broken at the thread just below the eye of the spherical bearing. This type of damage has been observed in numerous

Robinson accidents investigated by the Commission where the main rotor has flapped beyond its design limits. Pitch link failure can also be caused by column buckling[23] or by the lower attachment point moving out of its normal position, thereby applying a bending load to the top of the pitch link, causing it to break just below the spherical bearing.

4.5.3. The Commission's interim factual report on this accident noted that "it was very unlikely that the helicopter had broken up in flight or that the accident had been caused by mast bumping". After further analysis, the Commission has determined that the helicopter did not break up before entering the trees, and although there were indications of mast bumping this was likely due to the dynamics of the helicopter entering the bush with its main rotors still turning. Consequently, it is likely that the pitch link and pitch link attachment failed as the helicopter descended through the trees. This scenario is consistent with advice from Robinson, which said that evidence of mast bumping has been found in most accidents where helicopters have struck terrain or water with the main rotors turning.

4.5.4. The alternative hypothesis is that the pitch links failed while the helicopter was above the trees. However, if that had been the case the pitch of the main rotor blade would have been uncontrollable and the blade would likely have moved to an extreme angle. There were no creases on the blade to indicate that it had flapped upwards or downwards excessively, and no indication that either blade had struck the fuselage. Therefore it is virtually certain that the pitch link and pitch link attachment failed as the helicopter descended through the trees with its main rotor blades still turning.

4.6. Low-G

4.6.1. A helicopter may encounter a low-G (weightlessness) flight condition in significant turbulence, or if the cyclic stick is moved abruptly forward (called a 'pushover'). The helicopter may respond to that with an uncommanded roll to the right. The R44 Pilot Operating Handbook contained a safety notice describing the condition and the correct recovery technique.[24] The main rotor must first be 'reloaded' by applying a rearward cyclic input before any left cyclic is used to correct the right roll. Should left cyclic be applied first, a mast bump may occur.

4.6.2. There have been two known non-fatal incidents in New Zealand of Robinson R22 helicopters (which have similar main rotor configurations as the R44) entering low-G conditions followed by an uncommanded right roll and a mast bump.[25] In both cases the instructor pilot did not try immediately to counter the right roll, but allowed the helicopter to descend while slowly reloading the main rotor and easing out of the diving turn. The recoveries resulted in a significant loss of altitude. If the pilots involved in those two incidents had had less height in which to recover, the more natural reaction to roll left might have resulted in a more severe mast bump and possibly an in-flight break-up.

4.6.3. The only point on the accident flight where the helicopter might reasonably have entered a significant low-G condition was crossing the ridgeline shortly before the accident site. However, the weather conditions on the day were not conducive to the generating of low-level turbulence. Further, the pilot was an experienced low-level agricultural R44 pilot, and should have been able to manage any potential low-G encounter.

4.7. Cyclic stick extension

4.7.1. The cyclic stick extension for the left seat was found installed. The ground loader recalled that it had not been installed at the beginning of the day, which indicates that it was installed at some time later in the day. It could not be determined why the cyclic extension was installed. Equally, it could not be determined if it had been used by the contractor to manoeuvre the helicopter at any time during the flight.

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[23] Lateral bending or bowing of a column due to a compressive load.
[24] Safety Notice SN-11, Low-G Pushovers – Extremely Dangerous, issued October 1982, revised November 2000.
[25] Robinson R22, ZK-HIE, near New Plymouth, 30 March 2013 (TAIC, 2013), and Robinson R22, ZK-HMW near Ardmore, 19 March 2015.

4.7.2. A person without a current pilot licence must not manipulate the controls of an aircraft unless they are receiving dual instruction from an appropriately qualified flight instructor.[26] The pilot did not hold a flight instructor rating and the operator was not approved to give flight training. The contractor was familiar with flying in the helicopter, therefore it was unlikely that the contractor would have unintentionally interfered with the controls.

4.8. Survivability

4.8.1. The ELT was destroyed by the post-impact fire, which explained why RCCNZ received one emergency transmission only. The Commission has previously commented on the crashworthiness and reliability of ELTs[27] and included that safety issue on its Watchlist. It also made the following recommendation (006/14) on 26 February 2014:

> The Commission recommended that the Director of Civil Aviation 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.

4.8.2. The response by RCCNZ and a local search helicopter was timely. RCCNZ, knowing that the helicopter fitted with a winch was undergoing scheduled maintenance, tasked the next available helicopter to conduct a search. The winch-equipped helicopter was prepared in anticipation of being required to support any rescue efforts. This did not affect the outcome.

[26] Civil Aviation Rule 61.103.

[27] Refer to Commission inquiries 11-003, In-flight break-up, ZK-HMU, Robinson R22, near Mount Aspiring, 27 April 2011 and 13-003 Robinson R66, ZK-IHU, Mast bump and in-flight break-up, Kaweka Range, 9 March 2013.

5. Findings

5.1. The damage to the helicopter sustained in the accident sequence and subsequent fire, and the lack of any other incontrovertible evidence, meant that the cause or causes of the accident could not be determined.

5.2. A bolt that attaches the pitch link to the pitch horn on one of the main rotors was found to be missing. It is virtually certain that the missing bolt came out of position during the impact sequence, meaning it did not contribute to the accident.

5.3. It was not possible to determine why the cyclic extension for the left seat was installed and if it was being used at the time of the accident or at any time during the flight.

6. Safety issues

6.1. No new safety issues were identified.

7. Recommendations

7.1. No new recommendations were identified.

8. Key lesson

8.1. No new lessons were identified.

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