Report 08-002, Eurocopter AS355 F1, ZK-IAV, spherical thrust bearing failure, and subsequent severe vibration and forced landing, Mount Victoria, Wellington, 13 April 2008

Report 08-002

Eurocopter AS355 F1

ZK-IAV

spherical thrust bearing failure and subsequent severe vibration and forced landing

Mount Victoria, Wellington

13 April 2008

Abstract

At 1112 on Sunday 13 April 2008, ZK-IAV, a Eurocopter AS355 helicopter, departed from Wellington International Airport on a visual flight rules flight to Marlborough Sounds, with the pilot and one passenger on board.

Two minutes after departure, one of the 3 main rotor blade spherical thrust bearings attached to the rotor head failed. The failure caused a significant main rotor loss of balance and track, which resulted in severe vibration and limited the pilot's ability to control the helicopter. Despite the vibration and limited control, the pilot completed a successful emergency landing in a nearby sports field with no injuries.

The bearing failed because of internal corrosion and de-bonding of its elastomer segment, which was probably a result of some undetected surface damage to the elastomer surface.

Safety issues identified included the old age of the bearings, the adequacy of inspections and the bearings continued use without a specified calendar life. Safety recommendations were made to the Director of Civil Aviation to address these safety issues.

ZK-IAV after landing near Mount Victoria, Wellington

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Abbreviations

CAA	Civil Aviation Authority
UTC	coordinated universal time

Data Summary

Aircraft registration:	ZK-IAV
Type and serial number:	Eurocopter AS355 F1; 5041
Number and type of engines:	2 Rolls Royce (Allison) 250-C20F gas turbines
Year of manufacture:	1981
Operator:	private
Date and time:	13 April 2008, 1114[1]
Location:	Mount Victoria, Wellington latitude: 41° 17´ south longitude: 174° 47´ east
Type of flight:	private
Persons on board:	crew: one passengers: one
Injuries:	crew: nil passengers: nil
Nature of damage:	substantial
Pilot's licence:	commercial pilot licence (helicopter and aeroplane)
Pilot's age:	46
Pilot's total flying experience:	3050 hours (150 hours on type)
Investigator-in-charge:	K A Mathews

[1] Times in this report are New Zealand Standard Time (UTC + 12 hours) and are expressed in the 24-hour mode.

Factual Information

1.1 History of the flight

1.1.1 At 1112 on Sunday 13 April 2008, ZK-IAV, a Eurocopter AS355 F1 light twin-engine helicopter, took off from Wellington International Airport in fine conditions and a light wind, on a private visual flight rules flight to Marlborough Sounds. On board were the pilot flying from the front right seat and a passenger in the front left seat.

1.1.2 The helicopter departed normally, but 2 minutes later at 1400 feet and 90 knots indicated airspeed the pilot heard a "bang" and felt a significant vibration. Thinking he may have had a bird strike, he immediately reduced power by lowering the collective lever and began to reduce speed. A few seconds later he heard a second, louder "bang" and the vibration became severe. The pilot said the helicopter pitched up and rolled rapidly to the right and that he applied full left cyclic stick control to limit the roll.

1.1.3 The pilot contacted Wellington Tower and requested an urgent return to the airport. In the meantime he manipulated the helicopter controls in an attempt to control the turn, but was unable to fly level without the helicopter turning right, so he further reduced the collective lever, which reduced the amount of right roll, and the helicopter began descending.

1.1.4 The helicopter entered a steady descending right turn with severe vibration. The pilot described the controls as being heavy with a lot of feedback and vibration felt through them. The pilot and the passenger said the instrument console was shaking violently and that it was impossible to read any gauges.

1.1.5 The pilot said he reduced the collective lever further and was able to stop the helicopter turning as it neared Mount Victoria, but realised that the descent rate would prevent him reaching the airport about a mile away. When he raised the collective lever to reduce the descent, the helicopter controls again became heavy and the helicopter rolled to the right.

1.1.6 The pilot saw to his right an open flat field near Mount Victoria, so he lowered the collective lever completely and elected to do an emergency run-on landing on the field. He made a distress (Mayday) call to Wellington Tower and advised the controller of his intentions.

1.1.7 The pilot instructed the passenger to adopt the brace position for the landing by grasping her ankles. As the helicopter neared the field, the pilot flared it and ran it on in a level attitude, where it came to rest after about 35 metres.

1.1.8 The pilot said the helicopter was still shaking severely after it came to a stop, so he instructed the passenger to vacate the helicopter immediately and to shelter behind a nearby rock. The pilot then shut down both engines and applied the rotor brake, bringing the rotor to a stop. He noted that the emergency locator transmitter light on the console was on, so he turned it off. The pilot then called Wellington Tower and advised that he was safely on the ground and no one was injured.

1.2 Pilot information

1.2.1 The pilot held a commercial pilot licence (helicopter and aeroplane) with a class 1 medical certificate valid until July 2008. He had a current biennial flight review, was rated on the Eurocopter AS355 and had flown 150 hours on type. He had flown 1050 hours in helicopters and approximately 2000 hours in aeroplanes.

1.3 Damage to the helicopter

1.3.1 An examination of the helicopter found that the rubberised elastomer portion of one of its 3 main rotor spherical thrust bearings had separated during the flight and dislodged between the starflex hub and its rotor blade sleeve (see Figure 1). The dislodged portion was approximately 4 centimetres thick, which allowed its main rotor blade to move outboard a corresponding distance, which created a large rotor imbalance and out-of-track situation. The failed bearing elastomer jammed between the sleeve and starflex hub and restricted cyclic pitch control of that blade.

1.3.2 The helicopter sustained substantial vibration damage to many of its components, which required replacement, repair or overhaul. The estimated repair costs were in the order of $1 million.

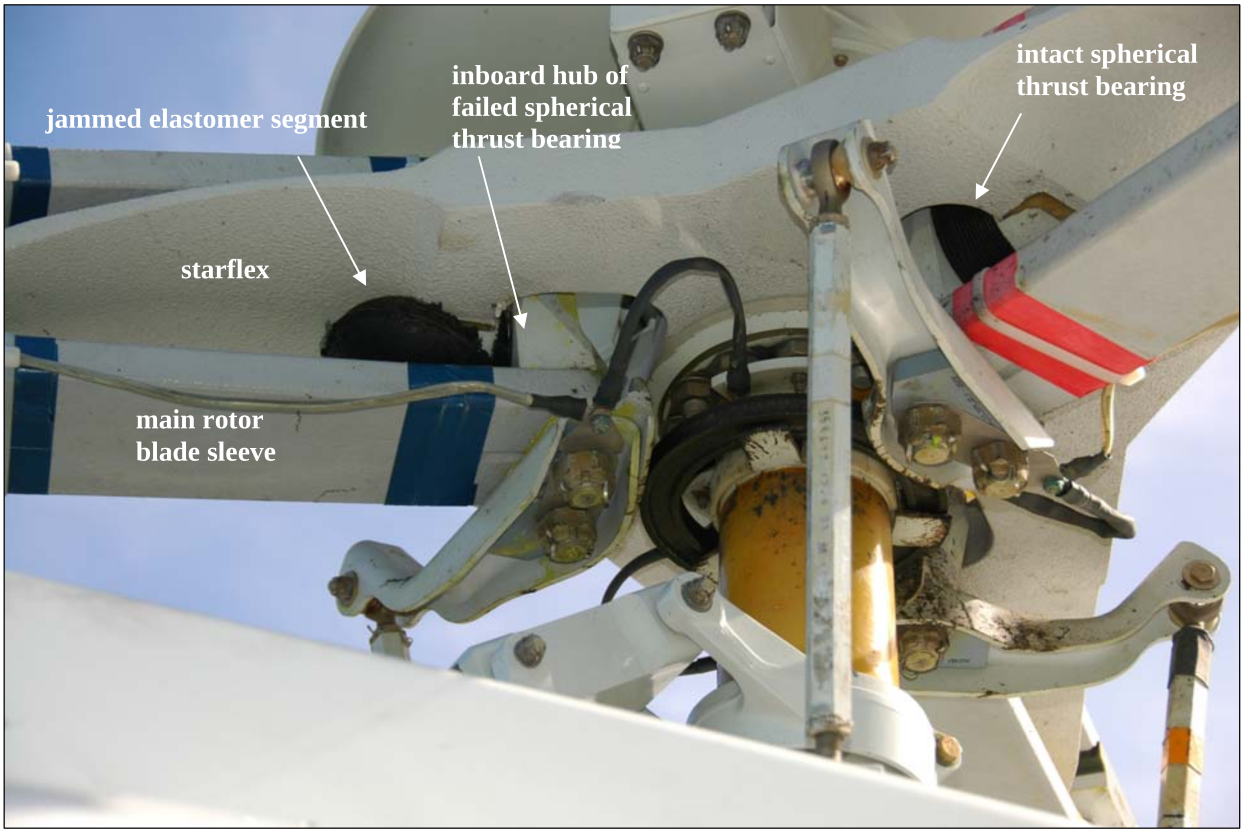


Figure 1
Rotor head assembly

1.4 Helicopter information

1.4.1 ZK-IAV was a Eurocopter AS355 F1, serial number 5041, light twin-engine utility helicopter manufactured in France in 1981 as an AS355 E model. The engines fitted were 2 Rolls Royce (Allison) 250-C20F gas turbines. At the time of the accident the helicopter had flown a total of 204.9 hours.

1.4.2 The helicopter had been owned privately in the United States since new, but had flown 57.4 hours only before being stored in Florida and Canada for 25 years. The helicopter was imported to New Zealand in 2006.

1.4.3 The pilot purchased the helicopter after it entered New Zealand, and in January 2007 a helicopter maintenance organisation in South Island received it in a partially assembled state. The organisation carried out extensive maintenance and component replacement work on the airframe, engines and avionics to upgrade the helicopter from an AS355 E to the AS355 F1 variant. Included in the work was the fitment of a new main rotor mast assembly, a new main rotor starflex hub and new main rotor blades.

1.4.4 The main rotor head contained 3 spherical thrust bearings, each with an elastomer (rubberised) centre that attached to the rotor hub (see Figures 2 and 3). Hydraulic control inputs were applied to each main rotor blade via the respective blade sleeve and spherical thrust bearings, which were flexible in torsion, flapping and drag, but rigid in compression.

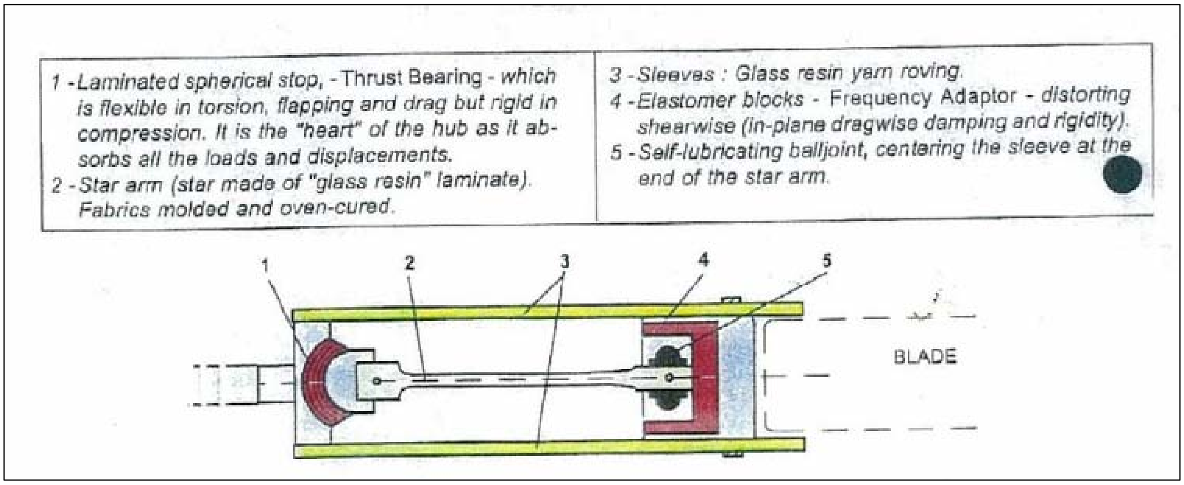


Figure 2
Cross-section of some components of the main rotor head (courtesy Eurocopter)

1.4.5 The 3 main rotor spherical thrust bearings, part number 704A33-633-030, serial numbers 154389, 154574 and 154637, that had been fitted to ZK-IAV since new were not replaced during the refurbishment because they reportedly met the service requirements. The bearings had rubberised elastomer centre sections laminated with stainless steel reinforcing discs, sandwiched between aluminium alloy attachment ends. The bearings had a finite life of 1200 flying hours for the metal components, but the elastomer portion was an on-condition[2] item. The bearings had no calendar life. They had a 60-month shelf storage life, but could be put back into storage or service if they passed inspection by the helicopter manufacturer. The shelf life was imposed as a means of control by checking that the storage environment itself or the packaging over time had not brought about any degradation. Items in storage were not subject to the routine inspection environment that was required when installed on a helicopter.

1.4.6 The spherical thrust bearings when fitted to the helicopter were subject to daily inspection by any person qualified to maintain the helicopter or by a suitably trained pilot. The flight manual said that no elastomer faults, de-bonding, scratches, blisters, extrusions or cracks were permissible. Should the daily inspection reveal any anomalies with the bearings, a maintenance engineer was to inspect them against the maintenance manual requirements before the helicopter could be flown. The bearings were also subject to inspections during routine scheduled maintenance checks. The maintenance manual detailed the inspection requirements for the bearings, and was prescriptive in outlining the conditions for rejection of the on-condition elastomer section of the bearings.

1.4.7 The maintenance organisation's engineer had assessed the spherical thrust bearings and said he had had no reason to reject them, but believed he had advised the pilot to replace them as a precaution. The pilot said he was sure the engineer had not advised him to replace the bearings and believed they had been replaced during the work on the rotor head.

[2] A situation of condition monitoring, whereby a component can remain in service indefinitely as long as it meets the ongoing inspection requirements.

Figure 3
An intact spherical thrust bearing

1.4.8 To complete its assembly and inspections and to prepare it for the issue of an airworthiness certificate, a second maintenance organisation in North Island received the helicopter in a partially assembled state in June 2007. The certificate was issued on 20 June 2007. Following this, the first 100-hour check of the helicopter was due at 157.4 hours or 18 June 2008, whichever occurred first.

1.4.9 In July 2007 when the helicopter was operating in South Island, the pilot had a third maintenance organisation investigate a main rotor vibration. The fault-finding process included inspecting the spherical thrust bearings, which were signed off in the logbook as being serviceable. The organisation found that one of the 4 main transmission suspension bars had broken, and rectified the vibration by fitting 4 new suspension bars to the transmission. The main rotor system was then tracked and balanced and found to be within normal limits.

1.4.10 In December 2007, at 153.1 hours, a fourth maintenance organisation gave ZK-IAV its first 100-hour check since the issue of its airworthiness certificate. At the time of the accident the helicopter had flown 51.8 hours since the check, leaving 48.2 hours remaining. The engineer who carried out the previous check had since left the organisation and was working overseas at the time of the accident. He said he remembered the helicopter and said there was no apparent damage or defects with the bearings during that 100-hour check.

1.4.11 The pilot during his type conversion training in New Zealand was shown how to inspect the spherical thrust bearings. He said he completed a detailed inspection of the helicopter at the end of each flight, as well as inspections before each flight. He did not recall noticing any defect with the bearings, including during his pre-flight inspection the day of the accident.

1.4.12 The spherical thrust bearings were described by the helicopter manufacturer as the "heart" of the main rotor head system, and any failure could be catastrophic. The bearings fitted to ZK-IAV were manufactured between 1977 and 1989 and were no longer available. In 1987 part number 704A33-633-109 bearings were introduced as a replacement for the earlier bearings, and in 1989 part number 704A33-633-156 bearings were introduced. Both bearings were manufactured until 1995, after which part numbers LB4 1231-1 and 57910700 bearings were introduced. The helicopter manufacturer advised that because the bearings were strategic components it had 2 separate companies manufacture them to ensure supply.

1.4.13 All spherical thrust bearings manufactured after the 704A33-633-030 part number series fitted to ZK-IAV had the finite life increased from 1200 hours to 6400 hours on the metal components, but the elastomer portion remained an on-condition item. The later bearings also had a 60-month shelf life and no calendar life.

1.4.14 The helicopter manufacturer said that the spherical thrust bearings had been progressively updated over the years to: increase the service life of the metal reinforcements; increase the reliability of the elastomer section to the level of the metal components' service life; and increase the temperature operating range.

1.5 Tests and research

1.5.1 Information from the aircraft manufacturer, overseas investigation agencies and the New Zealand Civil Aviation Authority (CAA) showed 4 other cases of spherical thrust bearing failure on AS355 and AS350 helicopters.

1.5.2 All failures involved the part number 704A33-633-156 bearing, which had been manufactured to allow very low ambient temperature operations. One failure occurred in Austria in August 1991, one in Guyana in January 1993 and one in Canada in August 1994. In each of these 3 cases the investigations revealed that the bearings had been operated in an unserviceable condition before failure, and they had been used in hot ambient conditions for which their reliability was lower.

1.5.3 The one case known to have occurred in New Zealand involved an AS355 helicopter about December 1997 or early 1998 in South Island, but it was not notified to the CAA.

1.5.4 Discussion with a New Zealand helicopter organisation that operated a large number of the same types of helicopter in New Zealand and overseas, revealed that it had not had any failures of the bearings. The organisation said that proper examination should reveal any developing defects.

1.5.5 Initial examination of the failed spherical thrust bearing from ZK-IAV, serial number 154389, showed corrosion around at least one of the stainless steel reinforcing laminates where the bearing had separated, plus internal de-bonding around the area of corrosion.

1.5.6 To determine the cause of the failure, all 3 spherical thrust bearings from ZK-IAV were examined by a specialist organisation using visual and microscopic means, including scanning electron microscopy and energy-dispersive X-ray for chemical analysis. The organisation sent a sample of the elastomer (rubber) from the failed bearing to a separate specialist organisation for analysis.

1.5.7 From the examinations of the spherical thrust bearings, the specialists' main observations are summarised below:

- the failed spherical thrust bearing had a relatively large area of corrosion pitting between its aluminium alloy block and elastomer segment, and a larger area of smooth separation. The combined areas were about half of the area of the elastomer segment

- the bonding of the elastomer between most laminations and the condition of the elastomer were considered sound, but there was considerable de-bonding in the corroded region and the central region, and on the top lamination (see Figure 4)

- significant corrosion and de-bonding had occurred in region c (see Figures 4 and 5) on a laminate. The cause was not considered to be related to the age of the material because evidence of age-related de-bonding would have been more widespread

- there was no obvious deterioration of the elastomer rubber itself, which was described as being in sound condition. Although it is rarely possible after such a failure to state that a nick, cut or tear brought it about, some form of earlier mechanical damage to the exposed elastomer surface was considered most likely to have been instrumental in the failure

- a fracture on the top stainless steel lamination suggested that rapid progressive tearing had taken place

- the materials and the condition of the aluminium alloy blocks and stainless steel laminates were consistent with materials to be used in the bearings. No material imperfections were observed

- the elastomer around the narrow perimeter between the laminations, where it was not bonded, exhibited cracking and pilling (the formation of small pieces of partly detached rubber)

- no evidence of de-bonding was seen in the 2 non-failed bearings.

1.5.8 The main conclusions drawn by the specialists are summarised below:

- the spherical thrust bearing failed because of initial de-bonding that allowed corrosion to occur. This in turn probably encouraged further de-bonding that allowed relative movement between 2 regions of the top lamination, which then led to its failure

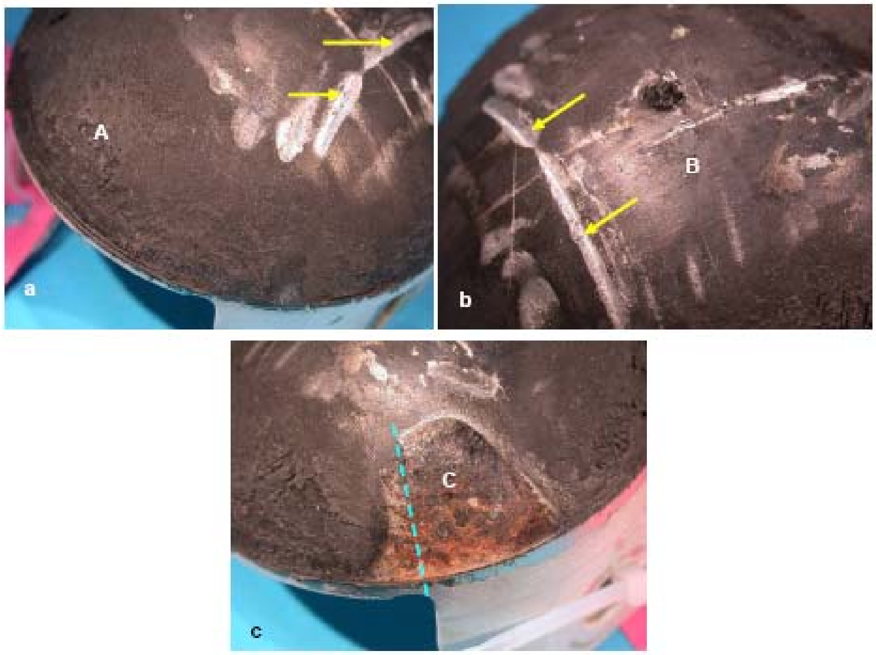
- the final failure of the bearing was from de-bonding and overload of the top lamination

- the bearing materials were considered to have been fit for their intended purpose

- no evidence of fatigue was found

- there was no evidence that the initial de-bonding was from deterioration of the elastomer itself

- the 2 non-failed bearings showed no evidence of de-bonding or other damage of any significance. However, there was evidence of some surface degradation of the elastomer (see Figure 6).



The convex surface of the Stop, showing (a) a large smooth area with very little rubber, (b) an area exhibiting no rubber and some corrosion product and (c) remnant rubber still adhered to the Stop.

Scratches on the Stop (right) matched with the two laminations on the Laminated Portion (left). Yellow arrows indicate the gap in the two laminations due to the missing piece of top lamination.

Figure 4
Area of corrosion and de-lamination

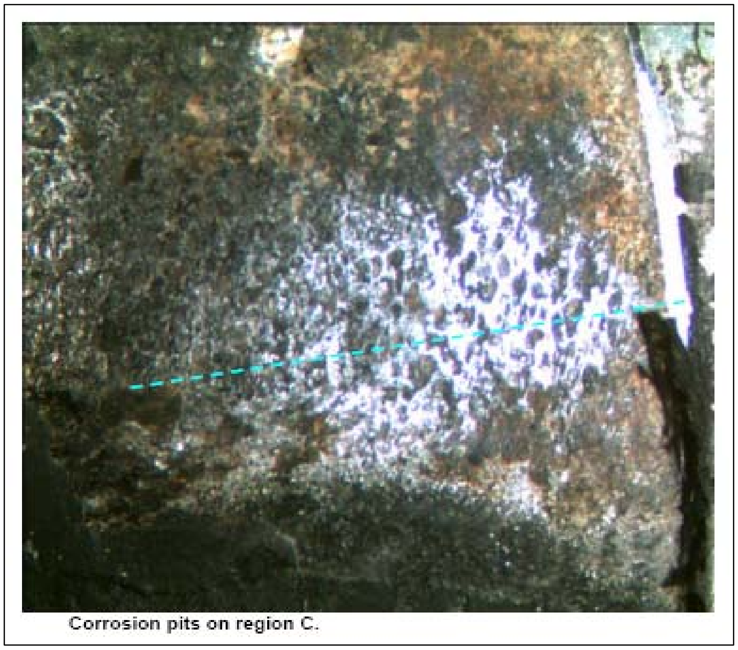


Figure 5
Area of corrosion

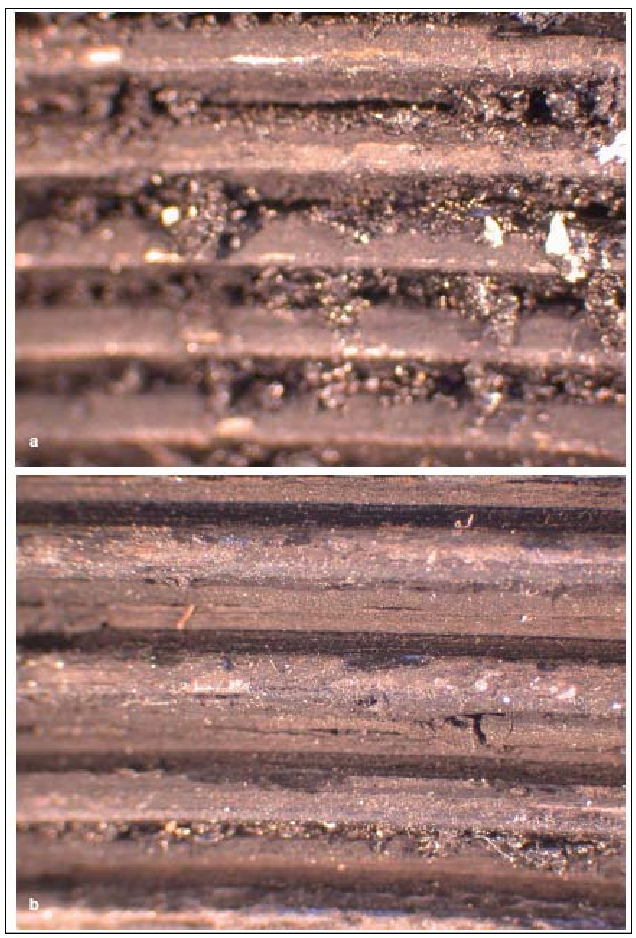


Figure 6
Elastomer surface condition of a non-failed bearing

2 Analysis

2.1 The AS355 accident helicopter type and the AS350 type that has a similar rotor head arrangement are common helicopters operated in all types of commercial and non-commercial operations in New Zealand and overseas. Because of this the Commission was concerned that the failure could have had wide safety implications.

2.2 ZK-IAV had no known defects and the pilot said he completed a pre-flight inspection, including an examination of its rotor head, before the helicopter departed in fine weather on a private flight with the pilot and one passenger on board.

2.3 A few minutes after departure, as the pilot prepared to level the helicopter at a cruising altitude of 1500 feet, one of the 3 main rotor head spherical thrust bearings failed suddenly. A severe vibration developed as the associated main rotor blade moved outboard about 4 centimetres, which created a substantial loss of balance and out-of-track situation with the other 2 blades. Control inputs to the blade were also restricted, which limited the pilot's ability to control the helicopter.

2.4 The pilot did not know the cause of the vibration and control difficulty, but knew that it was control related because of the un-commanded right turn. He took the immediate recovery action of reducing power, slowing the helicopter then attempting to control the turn and descent. After realising that the helicopter would not make it back to Wellington International Airport he took the best option available to him and, despite the difficulty in controlling the helicopter, successfully completed an emergency landing on the nearest field.

2.5 The pilot and passenger were fortunate that a suitable landing site was readily available, because continued flight with such a high vibration level could have led to an in-flight break-up of the helicopter.

2.6 The unusual history of the helicopter saw it enter New Zealand with very low flying hours for its age. Consequently it needed to have various inspections and a number of its components replaced before it could be issued with an airworthiness certificate and be allowed to fly. These were completed, but the original spherical thrust bearings remained on the helicopter because they were still within their service limits and reportedly met the inspection criteria.

2.7 The evidence from specialist examination showed that the failed spherical thrust bearing had an area of significant pre-existing internal de-bonding and corrosion within the elastomer segment. This had degraded the elastomer strength and properties to such a degree that it came apart during the flight. Although the reason for the onset of the degradation of the elastomer could not be determined, the specialists considered that the most likely cause was some form of earlier mechanical surface cut or tear or surface de-bonding that allowed the elements to enter, causing further corrosion and de-bonding. When this would have occurred could not be determined, but it cannot be ruled out that in a salt air environment, such as is common in coastal areas of New Zealand, the degradation might have occurred since the inspection by an engineer 4 months earlier.

2.8 Because the spherical thrust bearings were readily accessible on the helicopter and had been inspected by various qualified engineers and considered serviceable, and regularly by the pilot, it is difficult to imagine that any evident defect would have gone unnoticed. The last known check by an engineer was at the 100-hour servicing 4 months before the failure. Although close examination showed there was some surface degradation of the elastomer in the 2 non-failed bearings after the accident, the likelihood is that the trauma of the accident event brought about that condition. The examinations by the specialists showed that the elastomers were otherwise serviceable with no de-bonding.

2.9 Although the helicopter manufacturer had set no calendar life for the elastomer segment of the spherical thrust bearings, it had set inspection-dependent on-condition requirements. The manufacturer had set a 5-year shelf life for the bearings to be returned for evaluation, as a measure of control to ensure that the storage environment itself or bearing packaging had not brought about any degradation. When fitted to the helicopter the shelf life did not apply because the bearings were under more controlled conditions and rigorous inspection requirements, including when in and coming out of storage.

2.10 Because of the old age of the spherical thrust bearings fitted to ZK-IAV, it would have been wise to replace them with later part number bearings, despite their reported serviceable condition. The bearing storage life could also have been used as a measure for replacement, even though they were not in storage or subject to that life when installed on a helicopter, but subject to regular monitoring and other criteria. Elastomer can naturally deteriorate with age, and the bearings were a critical rotor head component, the failure of which could be catastrophic. Even though the specialist examinations did not find any age-related deterioration of the elastomer, the normal pilot and maintenance engineer inspections only looked at the external condition so it was possible that any age-related internal degradation went undetected.

2.11 Under normal or even low utilisation, it would not be expected that the bearings would remain in service for as long a calendar time as they had done on ZK-IAV. The particular part number bearings fitted to ZK-IAV had a finite life (the metal segments) less than a fifth of later model bearings, and would normally have been replaced within a few years of operation. The situation therefore with ZK-IAV was rare, if not unique.

2.12 The large number of helicopters with spherical thrust bearings fitted to the rotor head and flying successfully in all types of operations worldwide, with the low reported failure rate, attested to the durability of the bearing. The 4 known failures were attributed to one particular low-temperature part number bearing over a 7-year period in the 1990s and, apart from the failure with ZK-IAV, there had been no reported in-flight failures of other part number bearings. Additionally, in 3 of the 4 cases the bearings had each been in a known unserviceable condition before the failure.

2.13 The manufacturer had progressively upgraded the spherical thrust bearings over the years to improved versions, and various operators said they had not seen the earlier bearings in service for many years. The operators also noted that proper inspections should have detected any concerns with the bearings ahead of any problems. However, safety recommendations were made to the Director of Civil Aviation to address the potential safety issues with the bearings raised by this report.

3 Findings

Findings are listed in order of development and not in order of priority.

3.1 The in-flight failure of the rotor head spherical thrust bearing from undetected internal de-bonding and corrosion brought about a partial loss of control and severe vibration, which made a successful recovery difficult.

3.2 A successful in-flight recovery was only possible because a suitable emergency landing site was immediately available and the helicopter remained intact. Had a suitable landing site been some distance or time away, a successful recovery would have been unlikely.

3.3 The reason for the onset of the bearing deterioration could not be determined, but some earlier event of surface degradation of the bearing elastomer most likely allowed the degradation to begin.

3.4 There was no evidence that age-related deterioration, or material imperfections, contributed to the failure.

3.5 Although the evidence in this case did not support imposing a calendar life on the bearings, a life should have been imposed as a safety measure on such critical components to overcome any potential age-related deterioration, and to ensure that old components were progressively updated to the latest variants.

3.6 Despite regular inspections, the spherical thrust bearing had remained in service in an undetected unserviceable state for a period of time before its ultimate failure. Therefore either the published inspection procedures or the inspections performed were inadequate to detect an impeding failure.

4 Safety Recommendations

Safety recommendations are listed in order of development and not in order of priority.

4.1 On 20 June 2008 the Commission recommended that the Director of Civil Aviation address the following safety issues:

4.1.1 The spherical thrust bearings remained in service in an unserviceable state despite inspections by various engineers and the pilot over the preceding 18 months. This may indicate that the documented inspection procedures for the bearings are not being followed correctly or that the procedures need to be examined for their adequacy. (021/08)

4.1.2 With no calendar life but an hour and on-condition limit on the bearings only, their service life limits may need to be examined in conjunction with the aircraft manufacturer to determine if they are satisfactory. (022/08)

4.2 On 4 July 2008 the Director of Civil Aviation replied in part:

> The CAA is considering the safety recommendations you have made, and will respond to you soon with respect to the actions we will take. However, we are not able to meet your deadline of 4 July to provide you with a response.
>
> I can advise however, that the CAA accepts the intent of the safety recommendations, as they are worded.

Approved on 18 December 2008 for publication

Hon W P Jeffries
Chief Commissioner

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01-005R	Bell UH-1H Iroquois ZK-HJH, in-flight break-up, Taumarunui, 4 June 2001

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