



**Australian Government**

**Australian Transport Safety Bureau**

**ATSB TRANSPORT SAFETY INVESTIGATION REPORT**

Aviation Occurrence Investigation – 200700357

Final

**Engine failure – 28 km WSW of Warialda NSW**

**2 February 2007**

**VH-HRT Bell Helicopter Company 407**





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### Acknowledgements

Figure 7 & 8 courtesy Rolls Royce Corporation.

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### Abstract

On 2 February 2007, at about 1530 Eastern Daylight-saving Time, a Bell Helicopter 407 (407) emergency medical helicopter with a pilot, a crewman, a doctor and a paramedic on board departed Tamworth, NSW enroute to a car accident. At about 1610, the pilot broadcast on both the area and common traffic advisory frequency (CTAF) radio frequencies that they were inbound to Warialda at 28 km south-west and on descent from 6,500 ft [above mean sea level].

The pilot later reported that soon after the broadcast, the engine chip detector advisory capsule illuminated on the master caution panel. He reported that approximately 5 seconds later, he heard a loud noise and the helicopter developed a severe high frequency vibration with a complete loss of engine power. The pilot then broadcast a distress advisory on the area frequency with position, altitude, passenger information and the problem. During the subsequent autorotation emergency landing, the helicopter landed heavily and rolled onto its side. None of the occupants were injured, but the helicopter was seriously damaged.

The investigation determined that the engine sustained an in-flight catastrophic failure of the engine gearbox. The gearbox failure was due to the fracture and separation of a section of the helical torque-meter gear, which resulted in the complete loss of engine power.

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# THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external bodies.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the Transport Safety Investigation Act 2003 and Regulations and, where applicable, relevant international agreements.

## **Purpose of safety investigations**

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

## **Developing safety action**

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

**About ATSB investigation reports:** How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site [www.atsb.gov.au](http://www.atsb.gov.au).

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# FACTUAL INFORMATION

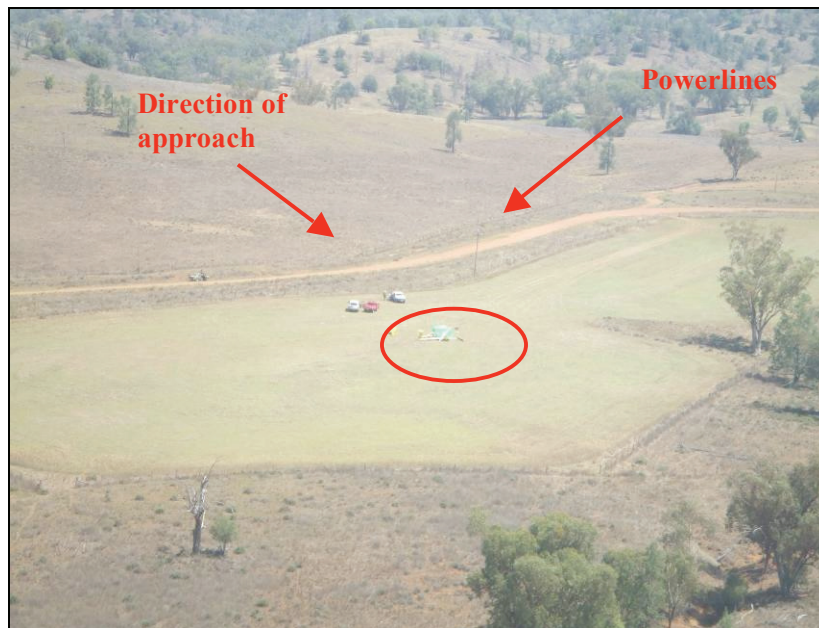
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## History of flight

On 2 February 2007, at about 1530 Eastern Daylight-saving Time<sup>1</sup>, a Bell Helicopter 407 (407) emergency medical helicopter, with a pilot, a crewman, a doctor and a paramedic on board, departed Tamworth, NSW enroute to a car accident. At about 1610, the pilot used the helicopter's radio to broadcast on both the area frequency and common traffic advisory frequency (CTAF) that they were inbound to Warialda at 28 km south-west and on descent from 6,500 ft [above mean sea level (AMSL)].

The pilot later reported that soon after the broadcast, the engine chip detector advisory capsule illuminated on the master caution panel<sup>2</sup> and that approximately 5 seconds later, he heard a loud noise and the helicopter developed a severe high frequency vibration with a complete loss of engine power. The pilot broadcast a distress advisory on the area frequency with position, altitude, passenger information and the nature of the problem. He then informed all occupants that they would have to complete an autorotation emergency landing.

**Figure 1: Helicopter emergency landing site**



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- 1 The 24-hour clock is used in this report to describe the local time of day, Eastern Daylight-saving Time (EST), as particular events occurred. Eastern Daylight-saving Time was Coordinated Universal Time (UTC) + 11 hours.
  - 2 The engine chip detector advisory was a device, often a permanent magnet, for gathering every chip, usually from the lubrication oil. When a metal chip was collected, the circuit was made continuous and an advisory capsule on the master caution panel illuminated indicating metal contamination in the system.

During the emergency landing, the helicopter sustained major damage. The occupants exited the helicopter and were uninjured. The elevation at the site of the emergency landing was about 1,100 ft AMSL (Figure 1).

The pilot later reported that when he checked the engine instruments following the loud noise he noted:

- 0 % engine torque
- 505° C measured gas temperature (MGT)
- 62.9 % engine gas producer speed (N1)<sup>3</sup>.

The pilot reported that during the engine failure, he had attempted unsuccessfully to maintain the engine and Nr<sup>4</sup> at 100 %. The other occupants also noted that the Full Authority Digital Engine Control had illuminated two faults on the enunciator panel.

The pilot stated that during the approach to land, the helicopter's altitude was excessive for the approach profile and that he manoeuvred the helicopter to the right to 'lose some height'. At the time, the helicopter was flying at about 70 KIAS<sup>5</sup> and that all seemed well. Upon getting closer to the chosen landing area, he noticed overhead powerlines in the corner of the landing area and manoeuvred to clear the wires. While crossing the wires, the Nr decreased as a result of the need to increase main rotor blade pitch by using the collective control. He then nosed the helicopter over to increase forward airspeed, which was 40 KIAS. He then raised the nose of the helicopter and increased collective control slightly to cushion the impact with the ground. Reportedly, the tail 'stinger'<sup>6</sup> of the helicopter impacted the terrain first and then the rear skid tubes of the landing gear. The helicopter slid across the ground for about 15 m before the landing gear collapsed and it nosed over and rolled onto its right side.

## Pilot informaton

The pilot held a Commercial Pilot (helicopter) Licence and had approximately 9,500 hours total flying experience, with 410 hours time on type and 56 hours on type in the last 90 days. The pilot reported that his last proficiency check was a base check completed with the operator's chief pilot on 19 January 2007. The check included several auto-rotation emergency landings.

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3 N1 is a measurement of engine gas producer speed in RPM with 100 % representing 51,000 RPM.

4 Nr is a measurement of helicopter main-rotor RPM.

5 Knots indicated airspeed.

6 A portion of the bottom of the vertical fin.

## Weather information

The pilot reported the weather in the area as: temperature 28 ° C, wind speed 10 kts (18.5 km/h)<sup>7</sup> from the south-east and no cloud. A routine weather observation for the area for 1500 hours was:

- temperature 32.9 ° C
- wind speed 17 km/h from the south-south-east
- relative humidity 28 %
- CAVOK<sup>8</sup>
- QNH 1014.5 hPA.

Using this weather information, the investigation calculated the density altitude at the emergency landing site at the time of the occurrence to be approximately 3,500 ft.

## Helicopter weight and performance information

The helicopter's certificated maximum take-off weight was 2,382 kg. The operator reported that the helicopter departed Tamworth with 850 lbs (386 kg) of fuel with an estimated take-off weight of 2,289.5 kg. The pilot reported that the fuel usage of the helicopter until the time of the occurrence was 200 lbs (91 kg).

The investigation estimated the weight of the helicopter at the time of the occurrence as about 2,198 kg.

An autorotation glide distance chart for the 407 noted:

Autorotational descent performance is a function of airspeed and is essentially unaffected by density altitude and gross weight.

The chart indicated that the minimum rate of descent airspeed was 55 KIAS and the maximum glide distance airspeed was 80 KIAS.

## Wreckage examination

The helicopter, serial number 53042, was taken to an authorised repair facility for further examination. At the time of the occurrence, the helicopter had completed 3,203.0 hours total time since new (TTSN). The front passenger's windscreen was broken and the landing gear was destroyed. The main rotor and tail rotor blades had sustained significant impact damage. The main rotor head assembly, main rotor transmission, tail rotor gearbox and all main and tail rotor drive components were removed for sudden stoppage inspection<sup>9</sup>. The helicopter tail boom and horizontal stabilisers were impact damaged and the tail section had separated from the helicopter (Figure 2).

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7 Kilometres per hour.

8 When the following conditions are observed or forecast to occur simultaneously; visibility of 10 km or more, no cloud below 5,000 ft, no cumulonimbus, and no significant weather.

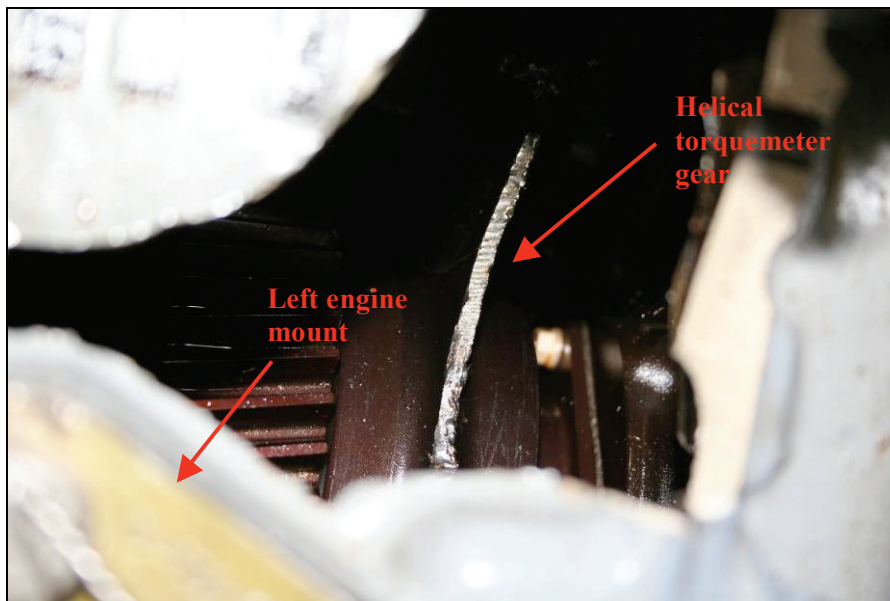
9 Sudden stoppage of a dynamic component normally requires special inspection of the components using non-destructive testing and often results in unserviceability of the component.

**Figure 2: Wreckage examination**



The helicopter was powered by a single Rolls-Royce Corporation model 250-C47B turboshaft engine, part number 23063393, serial number CAG-47048. Initial examination of the engine gearbox case revealed a 5 cm diameter hole in the case above the left side engine mounting pad. A section of the separated portion of the gearbox case was found on the engine deck, along with bearing material. The internal gear train components were visible through the hole, and it appeared that the helical torquemeter gearshaft (helical torquemeter gear) had fractured (Figure 3).

**Figure 3: Engine gearbox cover damage**



The engine and electronic engine control unit (EEC) were removed from the helicopter and sent to an authorised repair facility for further examination under the supervision of the Australian Transport Safety Bureau (ATSB).

## Engine and engine gearbox history

At the time of the occurrence, the Rolls-Royce model 250-C47B engine, serial number CAE-847049 had accumulated 3,203.0 hours TTSN. The engine was the original engine installed in the helicopter when it was manufactured. The last inspection of the engine occurred on 4 December 2006, at 3,146.4 hours TTSN when a 150/300-hourly inspection was completed. That inspection included cleaning and inspection of the fuel nozzle. The following significant maintenance to the engine assembly was documented in the helicopter's records (Table 1).

**Table 1: Significant engine maintenance**

Date	Hours TTSN	Work completed
1 August 2006	2,995.7	The engine was removed and reinstalled after the compressor scroll was replaced due to a bleed valve stud shearing.
20 April 2006	2,875.6	The compressor section was repaired following foreign object damage.
25 January 2005	2,459.5	The turbine section was removed to incorporate Commercial Engine Bulletin (CEB) A73-6050 and A72-6037.
2 December 2002	1,794.7	The engine was removed and disassembled for inspection of the compressor, gearbox modifications and turbine overhaul.

The gearbox modifications on 2 December 2002 were completed by a Civil Aviation Safety Authority (CASA) authorised engine repair facility. Examination of the worksheets for the modifications to the gearbox documented that the gearbox was disassembled and partially stripped to remove and replace the number-3 and number-4 bearings, cleaned and inspected and then reassembled. There was no 'rework' of the bearing bores<sup>10</sup> completed at that time nor was there any record of the bearing bores being reworked in the documentation for the gearbox<sup>11</sup>.

The replacement of the bearings was in conjunction with the requirements of CEB A 72-6006 revision 4 bearing replacement and CEB 72-6028 revision 1 T.M ring rework (blend ends). Additionally, the repair facilities worksheets for the engine noted that a serviceability check of the gearbox was completed on 13 April 2006 during repairs to the compressor section. At the time of the occurrence, the gearbox had accumulated 1,408.3 operating hours since the repair.

The repair facilities' controlled-copy 'build' worksheets for the engine gearbox included documentation of revisions to the worksheets to incorporate new information and procedures regarding the process. A revision dated 27 August 2004 noted 'gearbox alignment checks' as a requirement<sup>12</sup>. The engine gearbox had not been disassembled after this revision by the repair facility.

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10 Reworking a bearing bore could include increasing the diameter or installing a sleeve to decrease the diameter of the bore.

11 Rework of a bearing bore had the potential to affect the alignment of the bearing, resulting in a subsequent misalignment of any gears associated with that bearing.

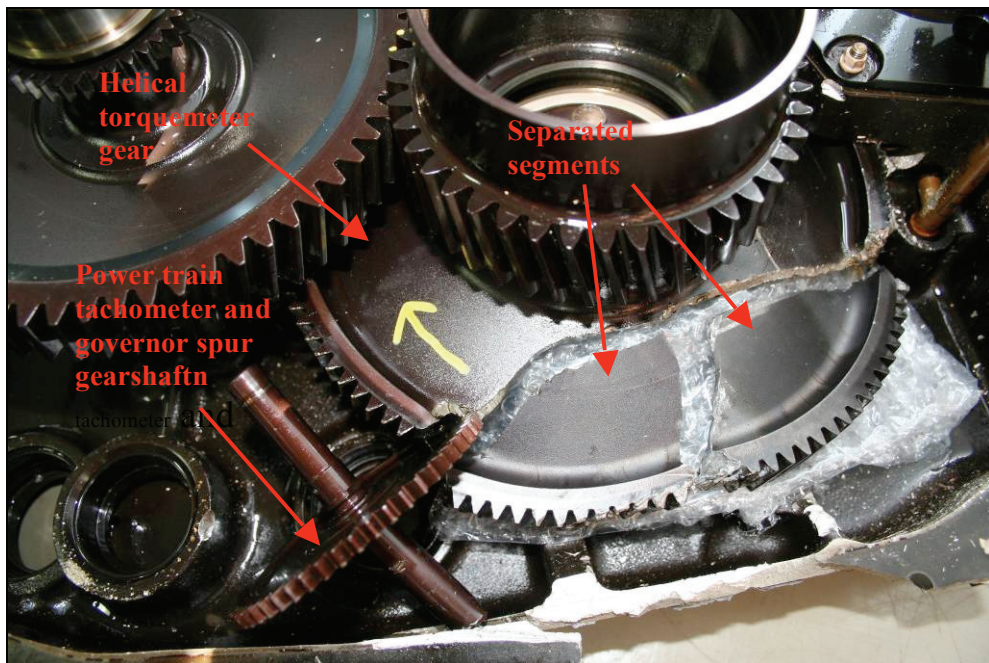
12 See **Engine advisories** for further information

## Disassembly and examination of the engine

The engine was disassembled and examined with the assistance of a representative of the engine manufacturer. Disassembly of the compressor and turbine sections of the engine were unremarkable. Disassembly of the engine gearbox confirmed that a catastrophic failure of the helical torquemeter gear (Figure 4) had caused severe internal damage to the gearbox that included:

- metal contamination of the gearbox, gearbox chip detectors and engine oil sump
- damage to the power train tachometer and governor spur gearshaft<sup>13</sup> and bearing
- damage to teeth of the turbine shaft to pinion gear coupling
- damage to the power turbine shaft to pinion gear coupling
- shearing of the turbine to compressor driveshaft
- damage to several ancillary gears
- shearing of the engine 28 volts direct current permanent magnetic alternator driveshaft.

**Figure 4: Separated segments of the helical gear<sup>14</sup>**



The damage was indicative of a sudden stoppage during operation.

## Component examination

The helical torquemeter gear, part number 6893673, had no retirement life assigned and was maintained in an 'on condition' basis.

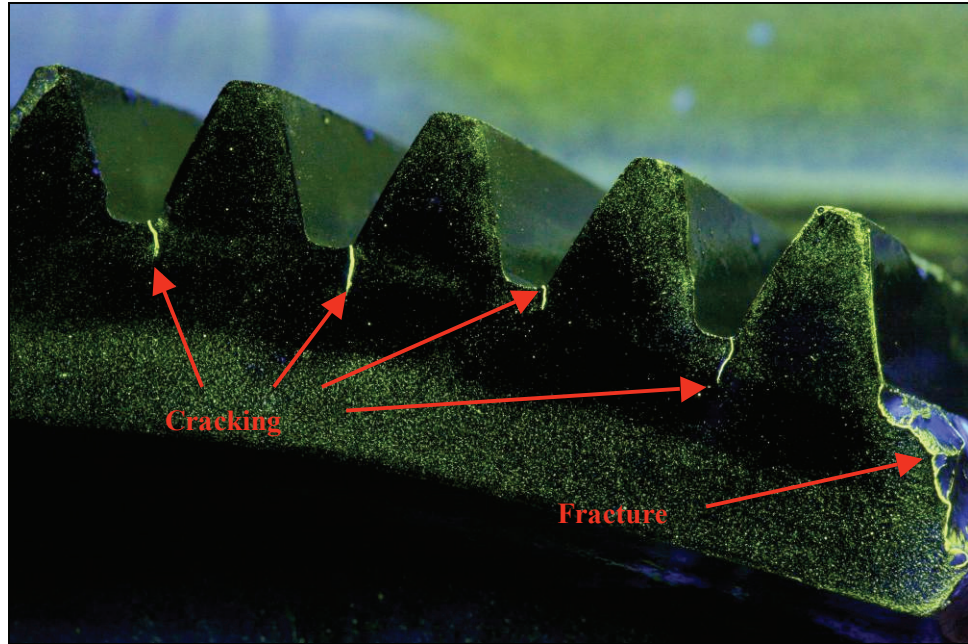
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<sup>13</sup> Supplied N2 or power turbine speed (RPM) information.

<sup>14</sup> Segments not 'as found' - for examination purposes only - direction of gear rotation marked on gear in yellow.

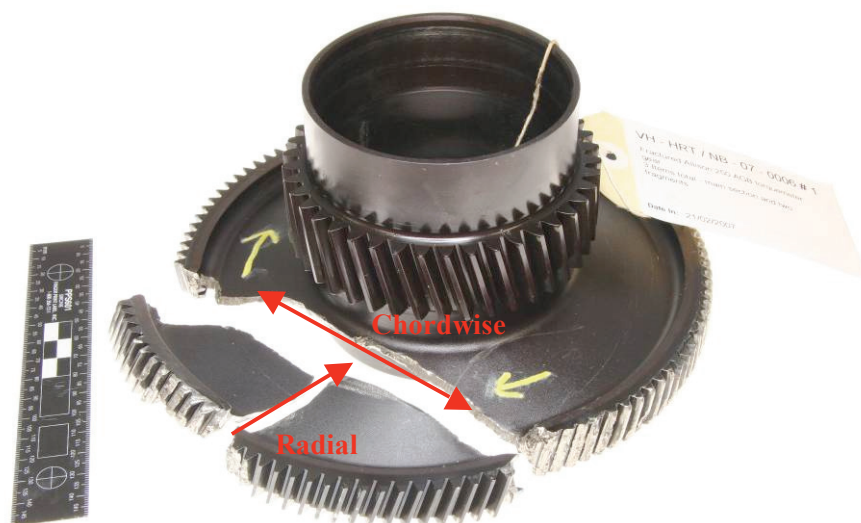
The components from the gearbox were initially examined by the ATSB. Fracture surface appearance suggested the failure had developed from the radial and chordwise growth of fatigue cracking from an origin at the root region of a rim gear tooth. Evidence of localised gear tooth spalling and uneven surface contact patterns were also observed, suggesting a possible misalignment condition (uneven loading) between the helical torque meter gear and the N1 input spur adapter gearshaft. Magnetic particle inspection showed evidence of cracking at the roots of several other gear teeth adjacent to the location of the fracture (Figure 5).

**Figure 5: Cracking at the roots of gear teeth**



In order to enlist specialist opinion, the removed components were sent to the engine manufacturer for further examination under the supervision of the US Federal Aviation Administration (FAA). That examination confirmed radial growth of fatigue cracking from an origin at the root region of a rim gear tooth and subsequent chordwise growth at the flange (Figure 6).

**Figure 6: Helical torquemeter gear examination**



That examination confirmed that:

- the case hardness, core hardness, microstructure and chemistry of the helical torquemeter conformed to the requirements of engineering drawings
- the effective case depth at the tooth root conformed to the requirements of engineering drawings
- the dampening ring groove width and depth dimensions met the minimum engineering drawing requirements
- the measured tooth root radii on three consecutive teeth were less than the minimum engineering drawing requirement of 0.021 inch (0.015 to 0.016 inch on the driven side and 0.018 to 0.019 inch on the coast side)
- the oil delivery tube showed no evidence of blockage or obstruction
- the damage to the other components examined was considered secondary.

## **Helical torquemeter gear and system description**

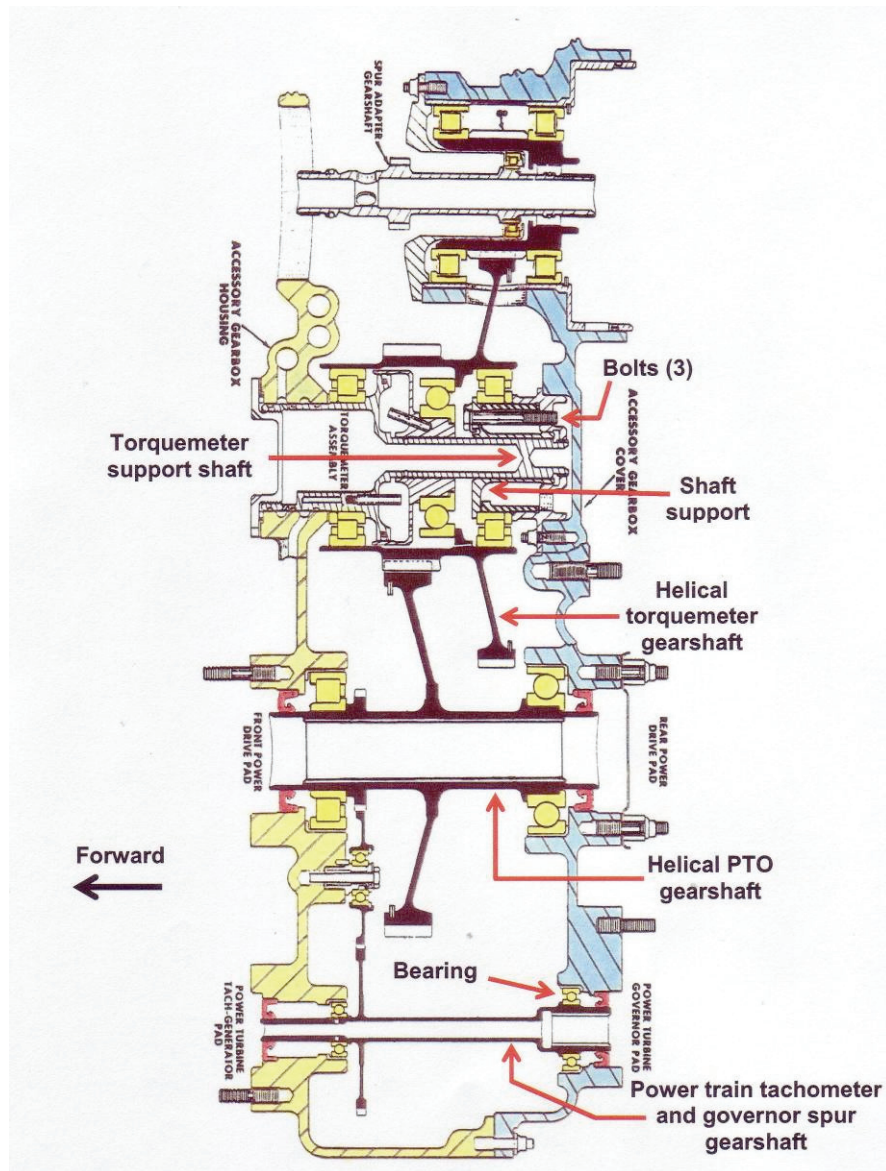
The engine gearbox assembly consisted of a gearbox housing, gearbox cover, gas producer (N1)<sup>15</sup> gear train, power turbine (N2)<sup>16</sup> gear train, oil pump assembly, oil filter assembly and the necessary oil tubes to provide pressure and scavenge oil as required by the lubrication system. Some of the gears in the gearbox, including the helical torquemeter gear, were compound gear assemblies. A compound gear assembly consisted of one gearshaft with two gears on it (Figure 7).

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<sup>15</sup> N1 was a measurement of engine gas producer speed in RPM.

<sup>16</sup> N2 was a measurement of engine power turbine speed in RPM.

Figure 7: Schematic of engine gearbox gears



The helical torquemeter gear was a 42-tooth gear, which rotated at 10,026 RPM at 100 % N1 within the gearbox. It drove the helical power take-off gearshaft, which delivered power to the output pads located on the front and rear of the gearbox. The front output pads delivered power to the input of the main transmission assembly and the rear output pad to the tail rotor driveshaft.

## Engine advisories

Commercial engine bulletin (CEB) *A 72-6006 revision 4* outlined the requirement to replace the gearbox non-tabbed outer race number-3 and number-4 bearings with a new bearing, which incorporated a tabbed outer race and an M50-Nil inner race, which featured revised internal geometry. Additionally, the old bearing cage was replaced by a newer cage. The background leading to the issue of the CEB was that the engine manufacturer had discovered two non-tabbed outer race number-3 and number-4 bearings where the inner race had failed due to possible improper fit

between the roller bearing inner race and the pinion gear. The new tabbed outer race bearing alleviated this possibility.

Commercial engine bulletin *72-6028 revision 1* introduced new retaining rings which secured the helical torque meter gear. The change was developed to decrease the wear of the retaining rings where they mount into the retaining ring groove in the gearbox.

Commercial Service Letter (CSL) *6098 revision 1* released 27 August 2004, stated:

Upon receipt of this commercial service letter, anytime the main accessory gearbox is disassembled for any reason to a point where the gears and other internal components are removed, a bore alignment check must be carried out. This is to prevent and alleviate abnormal shafting wear due to misalignment of the bores often associated with older gearbox covers and housings that have experienced overhauls.

The CSL further stated:

The contents of this CSL will be added to each Operation and Maintenance Manual [OMM] during a future revision.

Compliance with CEBs or CSLs was not mandatory and CSL *6098 revision 1* had not been issued at the time of the last maintenance of the engine gearbox.

The engine manufacturer advised the investigation that it had not yet incorporated the bore alignment requirement from the CSL into the OMM because they had not:

- had an opportunity to see if the check did indeed reveal out of alignment bores on older gearbox housings and covers
- gathered sufficient data regarding how many hours at which to require this check.

## **Requirements during gearbox repair**

The engine manufacturer advised that during gearbox overhaul, the non-destructive testing<sup>17</sup> of the helical torque meter gear was required only if the component had accrued more than 3,500 hours TTSN. They also advised that there was no 'adjustment' possible of the helical torque meter gear tooth alignment. During overhaul, a check is made to ensure that the bearing bores' locations (oversize check) were within serviceable limits. If the bore locations were out of limits, they were repaired by an approved repair scheme (typically a spraybronze repair) to restore the locating bores to specification. The gearbox bearing bores in the VH-HRT gearbox had not been repaired at any time in the life of the gearbox. Because of the extensive damage to the gearbox, a bore alignment check could not be completed as part of the investigation.

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<sup>17</sup> Methods of testing structures for integrity, especially absence of manufacturing flaws or cracks that do not impair serviceability or future life.

Included in the engine manufacturers OMM was a requirement to inspect the gearshaft drive splines and gear teeth whenever the gearbox was opened for any reason. That inspection included:

A visual check for wear on the gear teeth should be performed. If visual wear other than polishing of the teeth at their contact surface is present, it should be checked using a 0.020 in. (0.5 mm) radius scribe. Chipping of the gear teeth, or localized pitting, spalling or step wear which can be felt with the scribe is reason for rejecting and replacing the gear.

An examination of the repair facility documentation dated 14 November 2002<sup>18</sup> regarding the repair to install the modifications to the gearbox, involved in this occurrence, did not specifically annotate that such an examination was completed. The documentation did include a general statement that all work was completed in accordance with the engine manufacturer's latest instructions.

## **Electronic engine control unit (ECU) information**

Data from the ECU was downloaded by a representative from the engine manufacturer under the supervision of the ATSB. The downloaded information included:

- a previously recorded engine torque exceedance<sup>19</sup>
- an Nr range fault logged on the ECU memory
- a 28 volt direct current alternator fault logged on the ECU memory about 2 seconds prior to the engine failure
- normal engine parameters at the time of the engine failure
- reduced engine parameter values, as would be expected, following the engine failure.

## **Previous occurrences**

The model 250-C30 series engine was similar in design to the model 250-C47B series engine and the part number 6893673 helical torque meter gear was used in both models.

The engine manufacturer provided the ATSB with information on previous failures of the part number 6893673 helical torque meter gear. Included in the information were reports of three helical torque meter gears (model 250-C47B engines) that had been submitted to the engine manufacturer with:

- wear and pitting on two gears with 400 and 1,834 hours TTSN respectively, with both exhibiting overheat indications and no teeth cracking
- spalling on one gear with 146 hours TTSN and no teeth cracking.

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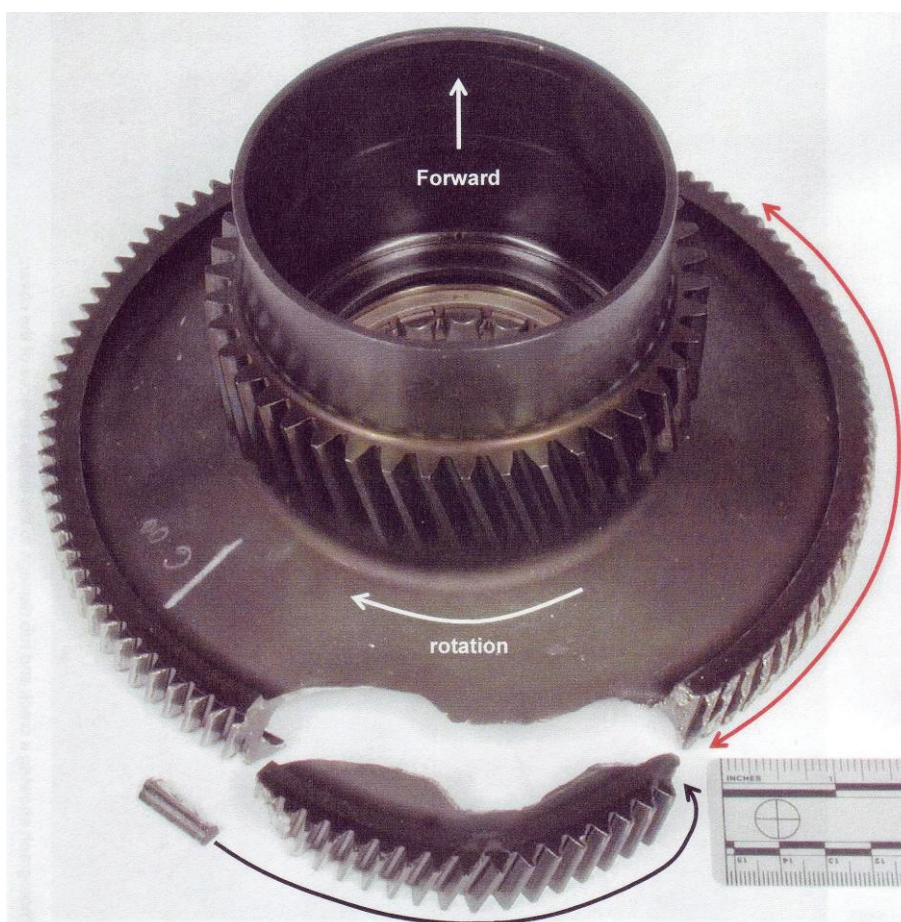
<sup>18</sup> 1,408.3 hours operating hours before the helical torque meter gear failure.

<sup>19</sup> The hours and date of the exceedance were not documented as no time stamp was associated with this event.

The engine manufacturer also advised that on 3 June 2007, a Canadian registered model B407 helicopter (model 250-C47 engine) sustained an in-flight engine failure. The pilot conducted a successful autorotation emergency landing near Goose Bay, Labrador, Canada. The helical torque meter gear in that engine gearbox had also failed.

The ATSB contacted the Transportation Safety Board (TSB) of Canadian regarding the Goose Bay occurrence to understand if there were common factors involved in the events. The failure modes of the helical torque meter gear and damage to ancillary gears in both occurrences appeared to be similar. The failed gear in that occurrence had accumulated 4,476 hours TTSN and one section only had separated. The engine manufacturer later advised the ATSB that they did not consider that the occurrences were related<sup>20</sup> (Figure 8).

**Figure 8: Goose Bay gear**



In 1981, a failure of a model 250-C30 engine helical torque meter gear was also documented. The engine in that occurrence had accumulated 628 hours TTSN.

The following table lists reports of the part number 6893673 helical torque meter gear unserviceabilities as recorded in the FAA Service Difficulty Database from 1998 to present (Table 2).

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<sup>20</sup> For further information refer to the **Engine manufacturer response** section.

**Table 2: FAA Service Difficulty Reports**

<b>Date</b>	<b>Hours at occurrence</b>	<b>Description of event and damage</b>
7 August 1998	1,835	Engine removed for metal contamination. Helical torquemeter gear to pinion gear galling.
30 November 1998	1,995	Engine removed for time change components. Helical torquemeter gear to pinion gear galling.
18 December 1998	496	Engine removed for metal contamination. Helical torquemeter gear spalling.
19 April 2001	Unknown	Engine disassembled for over speed inspection. Helical torquemeter gear improper machining and finish.
29 June 2001	163	Chip detector light illuminated in-flight. Engine removed for metal contamination. Helical torquemeter gear to pinion gear galling.
25 March 2002	1,878	During inspection of components found rough helical torquemeter gear edges at the radius.
5 December 2002	4,781	Chip detector light illuminated in-flight. Engine removed for metal contamination. Helical torquemeter gear to pinion gear galling.

## **Engine manufacturer response**

Following the initial metallurgical examination, the engine manufacturer advised that it had not confirmed the causal factors related to the fatigue fracture of the VH-HRT helical torquemeter gear and had assigned senior engineering personnel to investigate the occurrence further. As a result of the draft report, they provided the

ATSB with a follow up report on the progress of that investigation, including the following comments on the failure of the gear:

The Findings and Safety Actions sections of Report 200700357 suggest that the failure of the subject torquemeter gear was due to wear as a result of misalignment. Based on our metallurgical examination and in-house review by our gear train experts, Rolls-Royce does not conclude that gear tooth wear was a contributing factor to this event. The wear noted on the failed gear in undamaged areas is considered relatively light as there was no discernible wear step on the tooth face and a cross section through a representative tooth showed an unaltered profile. Thus Rolls-Royce engineering does not find evidence on the gear teeth to suggest that a stress concentration from heavy wear was present and contributed to the failure of the gear.

Regarding the suspected failure mode of the gear they commented:

You will find that the report does not specify a root cause for the torquemeter gearshaft failure as the nature of this fracture mechanism has not been documented previously on this part. Thus, our engineering team has begun an extensive stress modelling and analysis project to determine the probable cause of the fracture initiation. The nature of this work will take some time and is therefore not complete at this moment. Once our analysis is complete, we will send the results to ATSB if you desire.

The engine manufacturer will provide the ATSB with a copy of the results of the stress modelling and analysis project report when completed.

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## **ANALYSIS**

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### **Pilot actions**

Following the catastrophic in-flight failure of the engine, the pilot reacted to the engine failure and actioned the appropriate emergency procedures for the situation. The engine failure occurred at an adequate height above the ground that should have enabled the pilot to make a successful autorotation emergency landing with minimal damage to the helicopter. However, the power lines were difficult to see at the time of the engine failure and after noticing the power lines in the area, the pilot had to adjust the helicopter's descent profile to avoid them.

Once he was required to manoeuvre the helicopter to avoid the power lines, the helicopter's forward airspeed decreased below the recommended airspeed (as defined by the helicopter manufacturer as minimum rate of descent airspeed). The result was the hard landing and subsequent damage to the helicopter.

The pilot's previous completion of autorotation emergency landings during his recent proficiency check in January 2007 probably assisted in his conduct of the emergency landing.

### **Engine issues**

#### ***Engine failure event***

The catastrophic internal failure of the engine resulted in complete loss of engine power during the flight. The failure was such that further operation of the engine was not possible. The illumination of the engine chip detector advisory was the only indication of an impending failure and it provided insufficient warning to enable the pilot to land the helicopter prior to the complete engine failure. There were no abnormal vibrations or other indicators of the impending engine failure. There was no evidence to suggest that incorrect operation of the helicopter or engine was contributory to the failure. However, a previous torque exceedance of the engine had been recorded on the electronic engine control unit memory.

Disassembly and examination of the engine confirmed the catastrophic nature of the failure. The damage documented to the power turbine tachometer and governor spur gear shaft and power turbine shaft to pinion gear, as well as damage to other ancillary gears, was the result of the separation and seizing of the helical torquemeter gear.

Evidence of localised gear tooth spalling and uneven surface contact patterns were noted by the Australian Transport Safety Bureau during the examination of the helical torquemeter gear teeth. The engine manufacturer found that the teeth root radii were below the minimum engineering drawing requirements but considered it to be not contributory to the event. The engine manufacturer was unable to establish the initiator of the fatigue cracking of the gear, but has implemented an extensive engineering stress and modelling analysis project.

### ***Engine inspections requirements and effectivity***

All inspections required at the time of the accident were documented as completed during repair and modification of the gearbox. During gearbox modifications, maintenance personnel did not note any helical torque-meter gear tooth alignment or wearing issues. Therefore, it was considered likely that the evidence of localised gear tooth spalling and uneven surface contact patterns of the teeth took place following this maintenance, during the ensuing 1,408.3 hours of operation. The reason for the change in alignment and surface contact pattern could not be conclusively established by the investigation.

There was no retirement life of the helical torque-meter gear and no requirement to conduct non-destructive testing of the gear at any time during the engine repairs or overhauls documented<sup>21</sup>. Even if non-destructive testing had been required or had been conducted, at the time of those repairs or overhauls, it is unlikely that the fatigue cracking as witnessed would have been evident.

At the time of the December 2002 maintenance, there was no requirement in the repair documentation or the engine manufacturer's documentation for a bore alignment check to be completed on the bearing bores during overhaul. Therefore, the investigation considered that it was highly unlikely that one was completed. The engine manufacturer's opinion was that only 'high time'<sup>22</sup> engine gearboxes with in-service repairs to the bearing bores were susceptible to this problem. If an alignment check had been completed, it may have revealed the alignment issues related to the gear teeth surface contact or wear anomalies that were subsequently found.

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21 The helical torque-meter gear had not accumulated 3,500 hours total time since new.

22 Gearboxes with substantial accumulated operating hours.

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## **FINDINGS**

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From the evidence available, the following findings are made with respect to the engine failure of the Bell Helicopter Company 407 helicopter and should not be read as apportioning blame or liability to any particular organisation or individual.

### **Contributing safety factors**

- The helicopter sustained an in-flight catastrophic gearbox failure.

### **Other safety factors**

- The engine manufacturer's Operations and Maintenance Manual did not require a bore alignment check during disassembly of the engine gearbox.
- The US Federal Aviation Administration Service Difficulty Database documented several reports of galling/spalling of the helical torque-meter gear.
- The engine manufacturer had previously documented a failure of a helical torque-meter gear which had indications of gear tooth alignment anomalies.
- The pilot did not initially notice the proximity of the power lines in relation to the selected landing area.
- The pilot's manoeuvring to avoid the powerlines resulted in the helicopter approaching the landing area with less than the optimum knots indicated airspeed.

### **Other key findings**

- The pilot's recent flight training in auto-rotation emergency landings most likely limited the consequences of the hard landing as documented.
- At the time of the occurrence, the helicopter was operating at less than the maximum take-off weight.



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## **SAFETY ACTION**

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The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

### **Engine manufacturer**

#### ***Commercial engine bulletin***

On 17 August 2007, the engine manufacturer released Commercial Engine Bulletin (CEB) 72-6061 which outlined the replacement of several engine gearbox gears with new part number gears, including the helical torque-meter gear. These replacement gears included ‘superfinished<sup>23</sup>’ gear/teeth and silver plating of the gears and a helix lead angle change to account for web deflection under high loads, to improve gear reliability.

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<sup>23</sup> Superfinishing is a mechano-chemical polishing technique for producing ultra-smooth contact surfaces that resist pitting and spalling to a greater extent than conventionally ground gears.