

# Investigation Report

## Identification

Type of Occurrence:	Accident
Date:	26 June 2016
Location:	Near Hofgeismar
Aircraft:	Helicopter
Manufacturer / Model:	Bell Helicopter Textron / Bell 407
Injuries to Persons:	None
Damage:	Aircraft severely damaged
Other Damage:	None
State File Number:	BFU16-0848-3X

## Factual Information

### History of the Flight

At the day of the accident the pilot had planned to conduct a ferry flight from Assen, the Netherlands, to Ingolstadt-Manching Airport. A refuelling stop at Kassel-Calden Airfield (EDVK) was planned.

According to his statement, the pilot had already established radio contact with Kassel Tower and passed the mandatory reporting point November 1 when, at about

1605 hrs<sup>1</sup>, he noticed slight torque fluctuations in the control pedals and a decrease of the main rotor rpm (NR) to about 94%.

The pilot reacted to the loss of power with an autorotation and turned to an emergency landing area, which he deemed suitable. Shortly before the flare he noticed a power line and pulled the helicopter over it.

While skidding with reduced rotor rpm and giving backward control inputs in an attempt to avoid the helicopter toppling forward the main rotor slashed through the tail boom. The helicopter was severely damaged.

After the helicopter had come to a stop the pilot noticed that the engine was still running with reduced thrust and the main rotor was still powered. He manually shut down the engine. He radioed Kassel Tower informing them about the accident and left the helicopter uninjured.

## Personnel Information

The 56-year-old pilot held a Commercial Helicopter Pilot's Licence (CPL(H)) issued in accordance with Part FCL. The licence listed the ratings as Pilot in Command (PIC) for Bell206, Bell427 and Bell407. He held a class 1 medical certificate in accordance with Part MED without restrictions; valid until 30 September 2016.

According to his own statement, he had a total flying experience of more than 5,000 hours, of which about 2,500 hours were flown on Bell 407.

## Aircraft Information

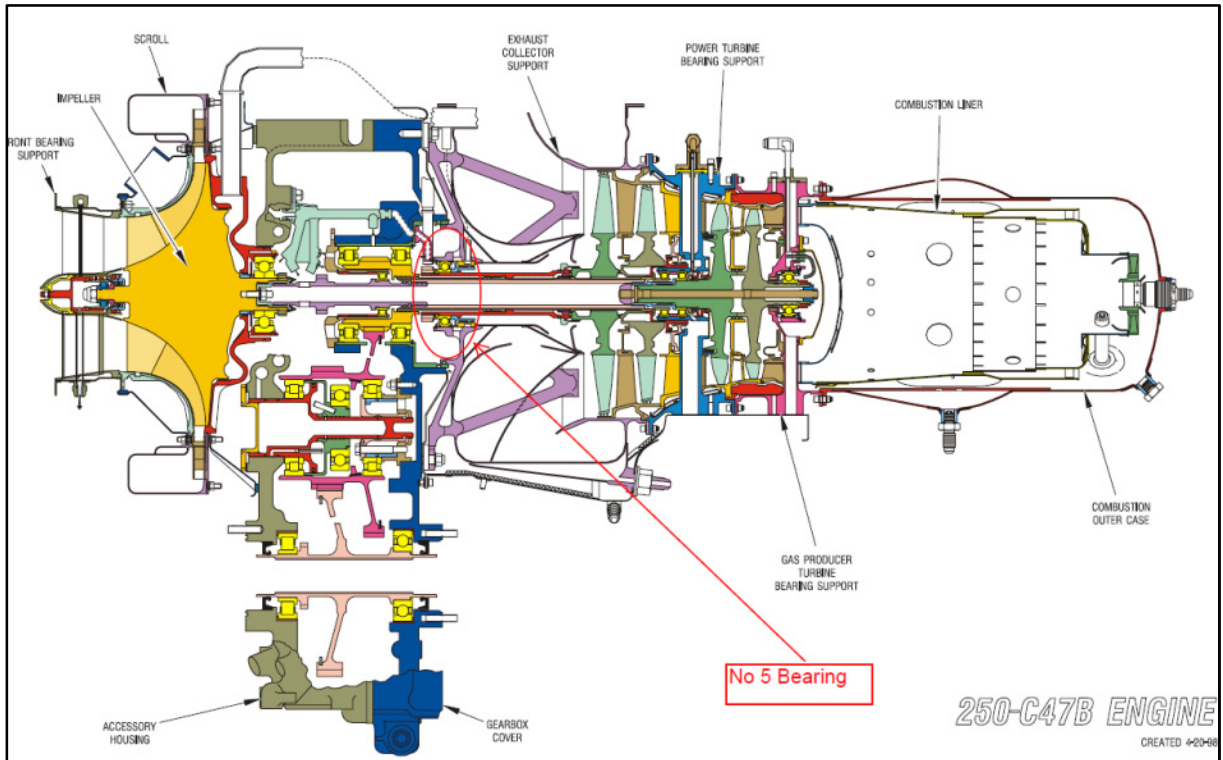
The Bell Helicopter Textron Bell 407 is equipped with seven seats. It has skids, a four-blade main rotor and a tail rotor for anti-torque. Maximum take-off mass is 2,268 kg. The helicopter is equipped with a Rolls-Royce M250-C47B jet engine and a Full Authority Digital Engine Control (FADEC/ECU). In 1996 the helicopter type was certificated in accordance with FAR Part 27.

Since 1962 the two-shaft Rolls-Royce M250 engine (former Allison M250) is a widespread engine, which different manufacturers install mostly in single and twin-engine helicopter types. The engine manufacturer stated that more than 31,000 engines were produced; of which presently about 16,000 are in civil and military use. The manufacturer estimates the total operating time of the entire fleet of

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<sup>1</sup> All times local, unless otherwise stated.

approximately 244 million flight hours. The M250-C47 is presently the strongest variant of the M250 engine family. Since 1999 approximately 1,800 of these engines have been produced.



Engine structure and position of the No 5 bearing

Source: Rolls-Royce

The accident helicopter was built in 2004 and had the manufacturer's serial number 53605. The Luftfahrt-Bundesamt (German civil aviation authority, LBA) issued the certificate of registration. The last Airworthiness Review Certificate (ARC) was issued on 27 May 2016. At the time of the accident, the helicopter had a total of approximately 1,341 operating hours.

The Rolls-Royce M250-C47B engine with the manufacturer's serial number CAE 847657 had a total operating time of approximately 1,341 hours. On 8 April 2016 the last 150 and 300 hours check had been documented at an operating time of 1,263 hours.

Component	Serial Number	Part Number	TSO	Total Time
Engine	CAE 847657	23063392	New	1341.3
Gearbox	CAG 47657	23063393	New	1341.3
Compressor	CAC 44787	23065593	New	5806.4
Turbine	CAT 44956	23063354	New	1341.3
HMU	JGALM0905	23078029	New	1341.3
ECU	JG6ALK0268	23072790	New	2869.6
Fuel Nozzle	VN1AAP0928	23077067	New	1341.3
Bleed Valve	FF288944	23073353	New	1341.3

Operating times of the engine components

Source: Rolls-Royce

According to the operator and the responsible Part-145 maintenance organisation there had been no engine chip indication warnings since 2013. Back then the No 2 bearing had been damaged and been replaced together with the entire compressor unit.

The helicopter flight manual Section 3 EMERGENCY/MALFUNCTION PROCEDURES recommends the following actions:

PANEL WORDING	FAULT CONDITION	CORRECTIVE ACTION
RPM (with low RPM audio)	NR below 95%.	Reduce collective and ensure throttle is in FLY detent position. Light will extinguish and audio will cease when NR increases above 95%.
FADEC DEGRADED (In-flight)	FADEC ECU operation is degraded which may result in NR droop, NR lag, or reduced maximum power capability.	Remain in AUTO mode. Fly helicopter smoothly and nonaggressively. Land as soon as practical.
FADEC FAULT	PMA and or MGT, NP or NG automatic limiting circuit(s) not functional.	Remain in AUTO mode. Land as soon as practical. Applicable maintenance action required prior to next flight.
ENGINE CHIP	Ferrous particles in engine oil.	Land as soon as possible.

## Meteorological Information

According to the aviation routine weather report (METAR) of Kassel-Calden Airfield (EDKV) of 1550 hrs the following weather conditions prevailed: ground visibility of more than 10 km, scattered clouds (SCT) at 4,700 ft, wind from 200°, variable 170° to 240°, temperature 20°C, dewpoint 8°C. Barometric air pressure (QNH) was 1,017 hPa.

## Radio Communications

Radio transmissions between the pilot and Kassel Tower were recorded. The BFU received transcripts of the recorded radio communications.

## Flight Recorder

The helicopter was not equipped with a Flight Data Recorder (FDR) or a Cockpit Voice Recorder (CVR). There were no legal requirements for such equipment to be fitted.

The engine was equipped with Full Authority Digital Engine Control (FADEC/ECU). In case of threshold value violation the ECU records numerous engine parameters. Analysis of the ECU showed no parameters had been recorded. The engine manufacturer assumed that due to the swift reaction of the pilot the respective threshold values were not exceeded. As part of the investigation the engine was disassembled, which revealed a damaged N2 sensor. N2 sensor failure is not classified as "hard fault" and therefore does not trigger engine parameter recording.

The radar trace of the flight path was recorded. The radar recording was available to the BFU for evaluation.

## Wreckage and Impact Information

The accident site was located between the townships Friedrichsdorf and Hofgeismar approximately in the middle of a slightly downward sloping grain field. The helicopter stood upright at the end of skid marks, which were about 24 m long, pointing to about 30°.



Overview accident site

Source: BFU

All four main rotor blades and the rotor head were damaged. The tail boom had been severed abeam of the horizontal stabilizer. The outer vertical fins had been severed above the horizontal stabilizer. The vertical fin together with the tail rotor including the fractured tail rotor gear box were found in the field south-east of the helicopter. The aft crosstubes of the skids were bent outwards.



Damaged tail of the helicopter

Source: BFU

At the instrument panel the warning lights FADEC FAULT, FADEC DEGRADED and ENGINE CHIP were illuminated. According to the fuel indicator 286 LBS fuel were in the tanks. Neither fuel nor lubricants were leaking.

After the helicopter had been salvaged the engine was examined in the presence of an expert of the engine manufacturer. It was determined that the engine was still mounted correctly and did not show any external damage. All air pressure, oil, and fuel pipes seemed to be undamaged and without leakages. The compressor did not show any foreign object damages. The N1 and N2 power train could manually be turned and power transmission was possible. In the N2 power train strong friction and grinding noises were observed. The examination of the two chip detectors revealed numerous metal chips. The bypass-pop-out of the oil filter at the engine had also been triggered.



Metal chips in the engine oil circulation

Source: BFU

The FADEC was still installed correctly, did not show any external damages, and the electrical connections were intact.

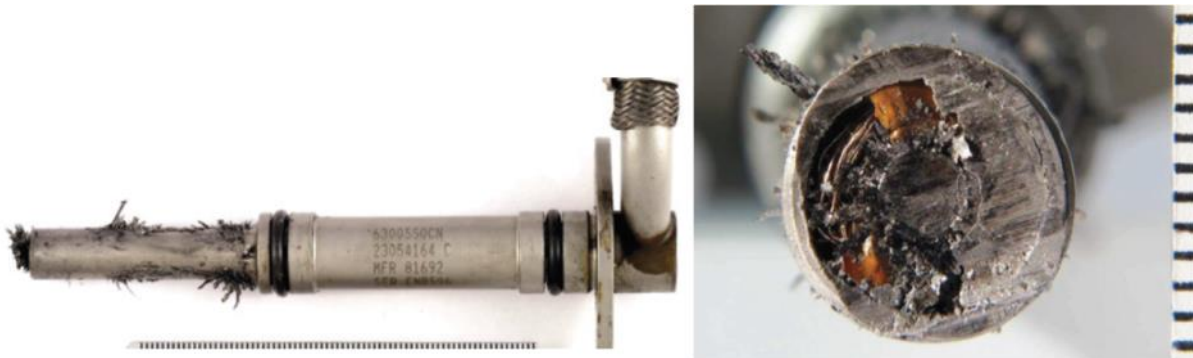
The engine was shipped to the engine manufacturer in the USA for further examination under supervision of the National Transportation Safety Board (NTSB).

The examination at the engine manufacturer occurred on 11 November 2016. The engine disassembly showed damage of the No 5 bearing (Version Part Number 6871505, operating time of about 1,341 hours and 1,479 cycles) and a damaged N2 sensor.



The No 5 bearing at the time of the engine disassembly

Source: Rolls-Royce



Damages at the N2 Sensor

Source: Rolls-Royce

The engine manufacturer compiled a 45-page Engine Investigation Report (dated 21 March 2017) and a 44-page Materials Evaluation Report (dated 5 April 2017).

In summary, the manufacturer concluded the following:



Source: Rolls-Royce

- *The No. 5 bearing separator fractured into several fragments and the outer diameter surface exhibited rub damage from rubbing against the inner diameter surfaces of the outer ring. Smearing of the fracture surfaces precluded the identification of a fracture mode.*
- *The No. 5 bearing outer ring shoulders exhibited fretting from contact with the four holding rings. The inner diameter of the outer ring exhibited re-deposited material rolled over the full circumference of the forward edge of the raceway. The outer ring shoulders also exhibited rub damage from the separator around the full circumference of the outer ring; the rub damage pattern forward of the raceway was different than the rub damage pattern aft of the raceway. The forward outer ring raceway surface exhibited evidence of thermal distress. The manufactured split in the outer ring exhibited damage consistent with heavy hammering between the two mating surfaces.*
- *The No. 5 bearing inner ring exhibited re-deposited material around the full circumference of the raceway. The forward shoulder of the raceway exhibited a rolled edge continuously for approximately 90° and discontinuously around the rest of the circumference while the aft shoulder exhibited a rolled edge around the full circumference. More material rolled over the aft shoulder of the inner raceway than*

*the forward shoulder. The aft inner ring raceway surface exhibited evidence of thermal distress.*

- All of the No. 5 bearing balls exhibited thermal distress and varying degrees of re-deposited material. Twelve (12) of the nineteen (19) balls were barrel shaped.*
- The No. 5 bearing aft holding rings fractured from fatigue crack initiation and propagation that transitioned to overload. Fatigue initiated on the outer diameter surface and then on the inner diameter surface of aft holding ring A, while fatigue only initiated on the outer diameter surface of aft holding ring B. The No. 5 bearing forward holding rings fractured from overload. The faces of all the holding rings were fretted and worn. The inner diameter surfaces of all the holding rings were not flat, indicating the inner diameter surfaces of the holding rings were not completely flush with the No. 5 bearing outer ring.*
- The No. 5 bearing lost the ability to axially and radially position the power turbine and related shafting due to the failure of the separator and holding rings. The sequence of failure between the separator and the holding rings could not be determined.*
- The compositions of the No. 5 bearing components were consistent with the component definition requirements.*
- The rest of the damage to the received engine components was consistent with secondary damage that would occur after the damage to the No. 5 bearing.*
- No ECU hard faults were recorded during the event which would have triggered the incident recorder. The N2 sensor fault recorded is consistent with the damage discovered resulting from the #5 bearing retaining nut contacted and damaging the N2 speed pick up sensor.*

## Fire

There was no evidence of in-flight fire or fire after the accident.

## Additional Information

Damages on bearings of jet engines due to deterioration, adverse operational conditions, or abnormal loading are not uncommon. In general, the bearing damages are recognised early due to metal chips in the engine oil, residue in the oil filters, and chip warning indications. Excerpt from the Transportation Safety Board of Canada

(TSB) Report Number A10P0388: *Bearings can fail for a variety of reasons, including material defects, improper installation, inadequate or contaminated lubrication, and abnormal loading. Most impending bearing failures, however, are preceded by progressive wear that generates metal debris for a period of time that is long enough to be detected either during routine maintenance (chip detector and oil filter inspections) or during operation (when the engine's magnetic chip detectors accumulate enough debris to illuminate a cockpit warning light). In either case, bearing wear is detected before damage is so extensive that it causes the engine to fail.*

The nominal life span in millions of revolutions, which 90% of a sufficiently large amount of bearings reach or exceed before the first signs of material fatigue occur, is calculated with the  $L_{10}$ -calculation according to ISO 281:2007. The reverse conclusion is that 10% of the bearings may fail before reaching their nominal life span and still meet the quality requirements.

According to the engine manufacturer the design of the No 5 bearing is the same for the entire M250 engine family. The manufacturer did not have any reliable numbers for the commonness of chip detection indication during flight operations due to damages of the No 5 bearing. The sporadic early replacement of the No 5 bearing during scheduled engine overhauls is known. The manufacturer estimates that the mean life span of bearing No 5 is approximately 1,800 operating hours.

A total of nine power loss incidents due to a damaged No 5 bearing are known. Of these nine, six had been caused by lack of oil supply of the bearing. In the three remaining cases (including the engine involved) the cause was unknown.

In 2016 the New Zealand civil aviation authority (CAA NZ) published the Continuing Airworthiness Notice (CAN)- 72-001 Revision 1 "Rolls-Royce 250 Series #5 Engine Bearing P/N M250-10106" due to several damaged No 5 engine bearings:

*This CAN alerts operators/maintainers of seven failures of P/N M250-10106 reported to the CAA. The majority failed bearings were found during maintenance actions due to post chip light illumination during flight operations. Investigation revealed outer race spalling. The bearing S/N range appear not to be from a specific batch, and the lowest time defective bearing only has 300 hours TTIS, and the highest 1200 hours TTIS.*

After the CAA NZ had received information of six other bearing damages, on 13 April 2016 it published the Airworthiness Directive DCA/AL250/58 "No. 5 Engine Bearing with P/N M250-10106 – Replacement".

An enquiry with several German maintenance organisations specialising in helicopters did not reveal any similar damages of No 5 bearings in Germany.

Over the years different part numbers (6871505, M250-10106, M250-10795) were available and had been installed in engines. According to the manufacturer there should not be any difference between the part numbers 6871505 and M250-10106 only the supplier is different. In 2016 the bearings with the part number M250-10795 were introduced. These bearings have reinforced holding wires. Currently it is the only one in production.

## Analysis

In the control zone of Kassel-Calden Airfield shortly before a planned refuelling stop a sudden engine power loss occurred, which caused the pilot to initiate an immediate autorotation. The emergency landing occurred with about 10 kt tail wind on a slightly downward sloping field. Due to the high vegetation the helicopter was abruptly decelerated and threatened to topple forward. The pilot reacted by pulling the stick, which caused the main rotor to slash through the helicopter's tail boom. The helicopter came to rest upright and was severely damaged.

The pilot held the licences and ratings required by aeronautical regulations. Due to his total flying experience and his experience on type (Bell 407) the pilot must be considered as very experienced. This, in combination with the electronic engine control, explains why no parameters were exceeded during the emergency landing, which would have caused the ECU to record the engine parameters.

The weather conditions did not restrict the ferry flight in accordance with visual flight rules and had no influence on the course of events, except for the wind direction.

According to the documents provided helicopter and engine had been continuously maintained pursuant to aeronautical regulations. The maintenance documentation does not list any engine chip indications. Centre of gravity and take-off mass were within the prescribed limits.

The examination of the engine at the manufacturer's in the USA showed that the No 5 bearing was the cause for the power loss which was recognised by the pilot, the

metal chips in the engine oil, and the illumination of the engine chip warning light. In addition, a damaged N2 sensor was determined as cause for the illuminated FADEC warning lights. Due to numerous different damages including fatigue fractures at the two aft holding wires and redeposited material it was not possible to determine an unambiguous cause for the damage in spite of extensive examination of the bearing. Based on the damage the experts could not understand why there was no previous engine chip indication during flight operations.

The manufacturer has data on individual damages of the No 5 bearing of the M250 engine family. The manufacturer is of the opinion that based on the number of engines, the high number of operating hours, the generally timely warning through metal chips in the engine oil, and the L<sub>10</sub> bearing life span, there is no safety deficit. The BFU agrees with this opinion because German maintenance organisations specialising in helicopters are also not aware of similar damages of No 5 bearings up to now.

Based on the determination of the examination of the engine involved and the experiences the manufacturer has gained through other occurrences caused by No 5 bearing damages a landing as soon as possible of the comparatively light helicopter with reduced thrust should have been possible.

## Conclusions

The accident was caused by engine bearing damage, which resulted in power loss, in combination with an emergency landing with forward speed at a field with high vegetation.

The cause for the bearing damage could not be determined.

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Field Investigation:	Uwe Werner
Assistance:	Thomas Karge
Braunschweig	2. November 2017

This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (*Flugunfall-Untersuchungs-Gesetz - FIUUG*) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

## Published by:

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