aibn Accident Investigation Board Norway

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REPORT SL 2018/04

SUMMARY REPORT ON THE AIR ACCIDENT NEAR TURØY, ØYGARDEN MUNICIPALITY, HORDALAND COUNTY, NORWAY 29 APRIL 2016 WITH AIRBUS HELICOPTERS EC 225 LP, LN-OJF, OPERATED BY CHC HELIKOPTER SERVICE AS

The Accident Investigation Board has compiled this report for the sole purpose of improving flight safety. The object of any investigation is to identify faults or discrepancies which may endanger flight safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for flight safety shall be avoided.

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This is a summary report of the AIBN's official final investigation report.

Only the official final accident report describes the AIBN's investigation and the findings completely. The final report is available on www.aibn.no

Photos: AIBN and Trond Isaksen/OSL

THE ACCIDENT WITH LN-OJF

On 29 April 2016 at 1155 (local time) the main rotor suddenly detached from a helicopter with registration LN-OJF, an Airbus Helicopters EC 225 LP Super Puma, operated by CHC Helikopter Service AS. The helicopter transported oil workers for Statoil ASA[1] and was en route from the Gullfaks B platform in the North Sea to Bergen Airport Flesland. The flight was normal and the crew received no warnings before the main rotor separated from the helicopter.

From 2,000 ft altitude, the helicopter impacted a small island near Turøy, northwest of Bergen. Wreckage parts were spread over a large area of about 180,000 m^2 both at land and in the sea (see Figure 1). The main rotor landed about 550 meters north of the crash site (see Figure 2). The impact forces destroyed the helicopter, before most of the wreckage continued into the sea (see Figure 3). Fuel from the helicopter ignited and caused a fire onshore.

All 13 persons on board perished instantly when the helicopter hit the island. Although several emergency service units were at the site within a short time, any lifesaving activity was futile.

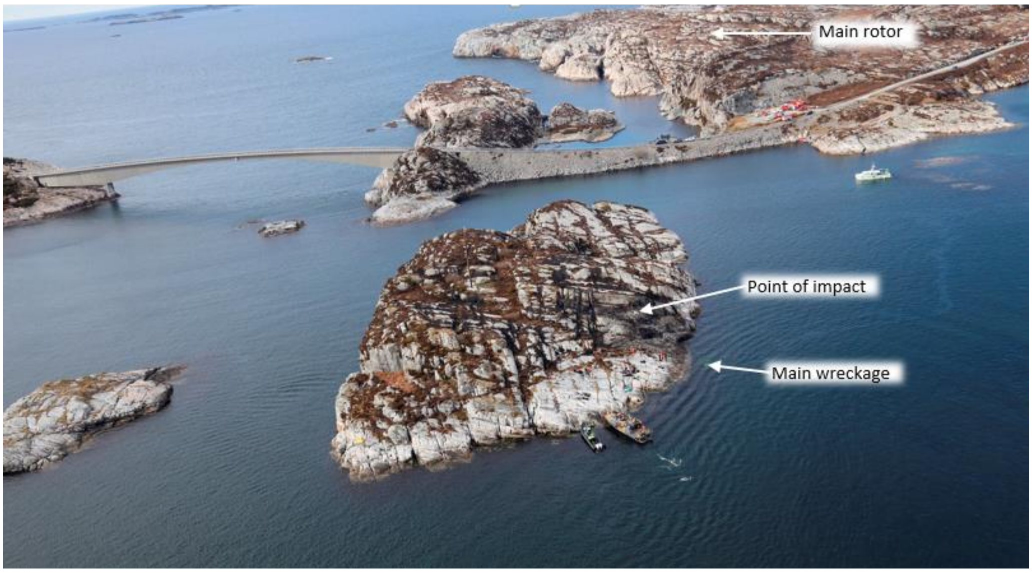

Figure 1: Photo of the accident area taken at 1500 hours 29 April 2016. View from south. Photo: Kripos

Figure 2: The main rotor as found on the island Storskora. Photo: AIBN

Figure 3: The main wreckage during recovery. The tail boom at the lower right. Photo: AIBN

[1] Statoil ASA is a Norwegian multinational energy company with headquarters in Stavanger, Norway. The company was renamed Equinor ASA on 15 May 2018.

THE HELICOPTER

Figure 4: The accident helicopter LN-OJF. Photo: CHC Helikopter Service

LN-OJF was manufactured in 2009 by Airbus Helicopters (see Figure 4). It was a twin-engine, medium-size utility helicopter configured for 2 crew and 19 passengers. The Super Puma model EC 225 LP is a development of the previous AS 332 L2. The main rotor gearbox (MGB) is near identical for the two helicopter types.

The MGB is installed on the transmission deck/cabin ceiling. It reduces the engine input shaft speed from 23,000 revolutions per minute (rpm) to 265/275 rpm for the main rotor. The MGB is also a structural part of the main rotor attachment. The epicyclic module (see Figure 5) of the MGB consists of two stages. Each stage has eight planet gears attached to a carrier. The planet gears rotate inside a common fixed ring gear.

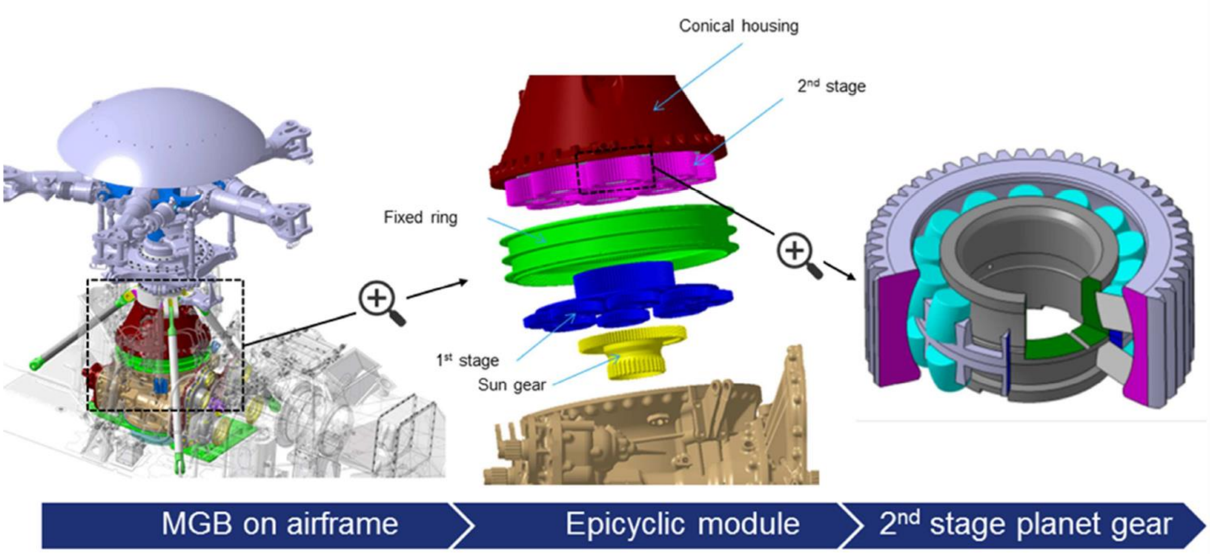

Figure 5: Illustration of the MGB installation, exploded view of epicyclic module and one second stage planet gear. Source: Airbus Helicopters

Each planet gear consists of an inner race, two rows of rollers, two cages and the gear wheel. Each planet gear is 'self aligning' by the use of spherical outer races and barrel shaped bearing rollers. The outer bearing race is an integrated part of the gear wheel made from carburized 16NCD13 steel (see Figure 9).

The planet gears cannot be inspected visually without a complete disassembly of the epicyclic module and the disassembly of gear and bearing.

THE INVESTIGATION

The Accident Investigation Board Norway (AIBN) has undertaken an extensive and complex investigation into the accident in accordance with national legislation, including Regulation (EU) No. 996/2010, and the requirements in International Civil Aviation Organization (ICAO) Annex 13. The investigation has involved close collaboration with the operator, the helicopter manufacturer, the European Aviation Safety Agency (EASA), the Civil Aviation Authorities in Norway (CAA-N) and the UK (CAA-UK) and other safety investigation authorities[2].

The AIBN's investigation has consisted of the following:

- Search and retrieval of wreckage parts at land and in the sea.
- Detailed examination of the wreckage.
- Readout and interpretation of recorded information.
- Detailed metallurgical examination of the MGB.
- Review of LN-OJF maintenance history.
- Study of the development, design and manufacturing process of the planet gears.
- Review of the Super Puma AS 332 L2 and EC 225 LP helicopters' in-service experience, including a similar accident to an AS 332 L2 in 2009 (*G-REDL*).
- Review of certification requirements and the process when the EC 225 LP was type accepted in 2004.

FINDINGS FROM THE INVESTIGATION

The accident sequence

The helicopter flew level at 140 kt at 2,000 ft when one of the eight second stage planet gears fractured and caused an abrupt seizure of the second stage epicyclic gears. The seizure of the second stage epicyclic gears caused a rupture of the epicyclic ring gear and shattering of the conical housing. This led to a loss of structural integrity in the upper section of the MGB and allowed uncontrolled forceful movement of the main rotor. The forces pulled apart all three suspension bars and the main rotor separated from the helicopter.

The AIBN has excluded any connections between the crew handling and the accident.

The metallurgical examination

Two recovered segments of the fractured second stage planet gear make up approximately half of a gear (see Figure 6). Detailed metallurgical examinations carried out at QinetiQ, Farnborough in UK, found that the gear had fractured due to fatigue.

The fatigue fracture initiated from a surface micro-pit in the upper outer race of the bearing (inside the second stage planet gear), propagating subsurface while producing a limited quantity of particles from spalling, before turning towards the gear teeth and fracturing the rim of the gear. Four spalls

[2] The Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) in France, the Air Accidents Investigation Branch in the UK (AAIB) and the Bundesstelle für Flugunfalluntersuchung (BFU) in Germany.

were observed on the bearing outer upper race centred along the line with maximum contact pressure (see Figure 7).

It is probable that the failure was initiated by debris caught within the bearing and scratching one or more rollers. This probably caused a band of local work hardening and associated micro-pitting at the outer race.

Figure 6: The two segments of the fractured second stage planet gear. The fatigue fracture through the rim (through-thickness fracture) started in the outer upper race of the planet gear wheel, where the red arrow is pointing. Photo: AIBN/NDL

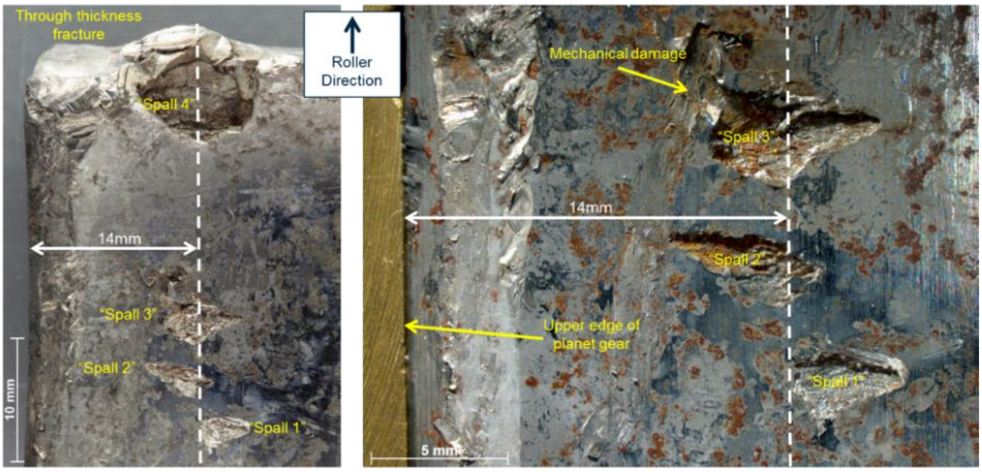

Figure 7: Spalls 1, 2, 3 and 4 together with the max Hertzian stress line. Photo: AIBN/QinetiQ

The AIBN concludes that the fatigue fracture in the second stage planet gear initiated from a surface micro-pit, and were neither a consequence of a mechanical failure or misalignment of another component, nor due to material unconformity. It has not been possible to determine a conclusive propagation rate or a time for the fatigue crack development, but it must have developed within a maximum of 260 flight hours since the gearbox was inspected and repaired at Airbus Helicopters.

No warnings of the impending failure

The EC 225 LP was provided with a chip detection system in accordance with the certification requirements. The chip detectors (marked in yellow in Figure 8) were designed to catch and retain particles of magnetic material (spalling) for example shed from the gears or their bearings. Three of the chip detectors were to display to flight crew through a warning circuit when debris was captured.

However, no chip warning was given to the flight crew of LN-OJF before the MGB failure, and no magnetic material was found on the chip detectors during maintenance checks performed by the helicopter operator in accordance with the requirements.

The investigation has revealed that 12 % of total particles could be detected by the chip detection system and there were no requirements for the system's efficiency. Since the cracks in the second stage planet gear propagated while there were limited spalling, the probability of detection was low.

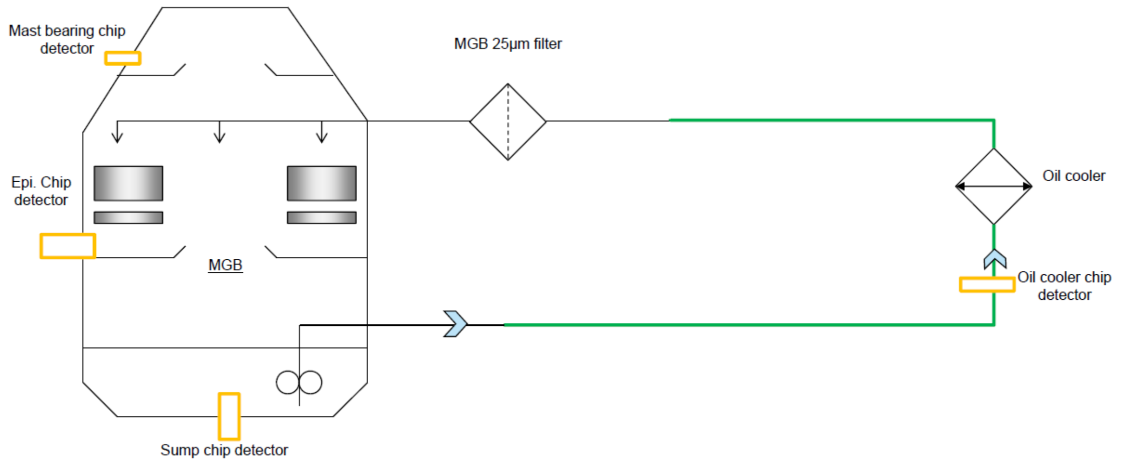

Figure 8: Chip detection system overview. Source: Airbus Helicopters

LN-OJF was also equipped with a Health and Usage Monitoring System (HUMS) designed for monitoring the status of the dynamic components (drivetrain) in the helicopter. Analysis of HUMS-data for LN-OJF does not show evidence of increasing trends or abnormal vibration for any dynamic components monitored by the system. However, the present HUMS has limitations and is unable to detect fatigue fractures in second stage planet gears.

The conclusion is that the failure developed in a manner which was unlikely to be detected by the maintenance procedures and the monitoring systems fitted to LN-OJF at the time of the accident.

Planet gear design

For industrial reasons, there were two suppliers (FAG and NTN-SNR) of second stage planet gear bearings. Because the outer race of the planet gear bearing is an integrated surface of the gear wheel[3], a specific workshare was established between Airbus Helicopters and the bearing manufacturers, see Figure 9.

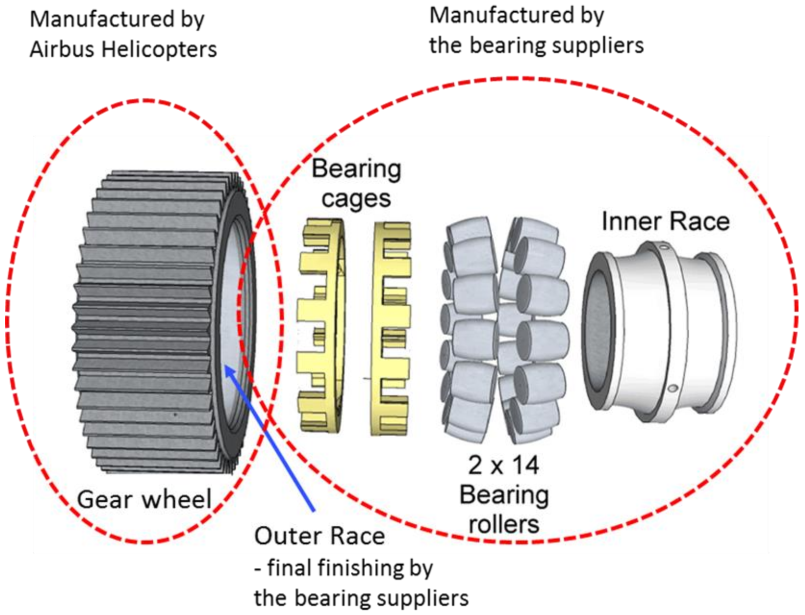

Figure 9: Planet gear configuration and workshare. Source: Adapted from the AAIB / G-REDL report

[3] The planet gear wheel without the bearing, including its rim with teeth, was designed and manufactured by Airbus Helicopters.

There were slight dimensional differences between the two bearing designs, and consequently differences in performance and load carrying capabilities. Both fulfilled specifications set by Airbus Helicopters. On LN-OJF, all the second stage planet gear bearings were manufactured by FAG.

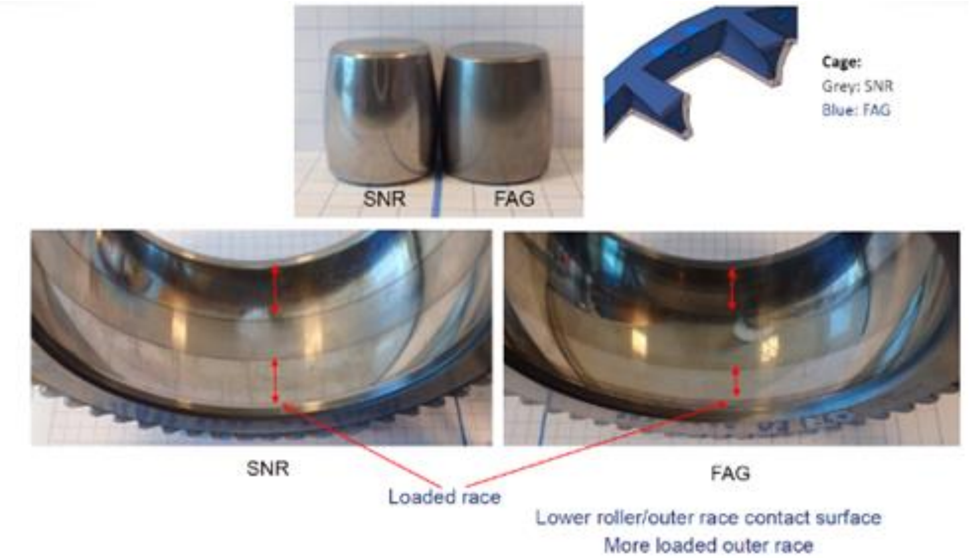

Figure 10: Geometry differences on outer race. Source: Airbus Helicopters

Maintenance history

All maintenance activities were performed by a certified organisation (see Figure 11) and there was no evidence indicating that maintenance actions by the helicopter operator have contributed to this accident. The MGB from LN-OJF was during operation or maintenance not subject to any event that can explain contamination from foreign objects (FOD).

The MGB had been involved in an accident during transport on a truck in Australia in 2015 (see Figure 12). The MGB was subsequently inspected, repaired and released for flight by Airbus Helicopters. The MGB was then installed on LN-OJF in January 2016, 260 flight hours prior to the accident.

However, the AIBN has found no physical evidence that could connect the ground transport accident in Australia to the subsequent fatigue cracks in the subject planet gear.

Figure 11: The CHC Helikopter Service maintenance hangar in Bergen. Photo: CHC Helicopter Service

Figure 12: The MGB in the transport container after the transport accident in Australia in 2015. Photo: Airbus Helicopters

The G-REDL accident

The accident has clear similarities to an Airbus Helicopters AS 332 L2 accident off the coast of Scotland in 2009 (*G-REDL*) where all 16 persons on board perished. This accident was also identified to be the result of fatigue fracture in a second stage planet gear.

In the G-REDL accident, the origin of the crack was in a section of the failed gear which was not recovered (*Missing Part* in Figure 13). Consequently the precise origin and nature of the fracture could not be determined. However, the G-REDL stress model prediction of crack growth (to the left in Figure 13), appears to be very similar to the crack propagation underneath the depth of the carburized layer in the retrieved second stage planet gear segment from LN-OJF (to the right in Figure 13).

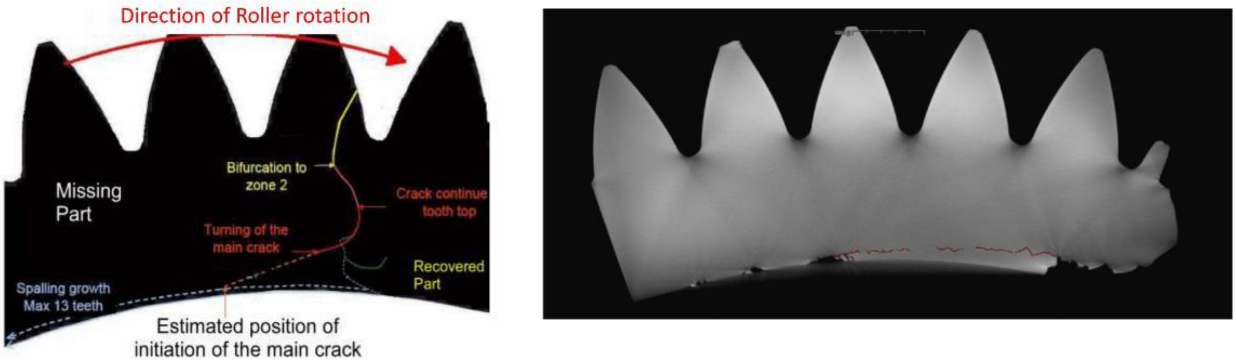

Figure 13: Stress model estimation of crack growth from the G-REDL to the left (Source: Airbus Helicopters) compared with the CT scan from the LN-OJF gear with the crack in red (Photo: CT-scan from AIBN/Southampton University).

Furthermore, in the G-REDL accident, the lack of damage on the recovered areas of the bearing outer race indicated that the initiation was not entirely consistent with the understood characteristics of spalling. Also, all the eight second stage planet gears on G-REDL had bearings supplied by FAG. In contrast to the LN-OJF accident, there was indication of the impending failure of the second stage planet gear in the G-REDL accident; some 36 flight hours prior to the accident, the chip detection system had collected a magnetic particle. Unfortunately, due to misunderstanding or miscommunication between the operator and Airbus Helicopters, the maintenance task was not carried out and the MGB was not opened.

The Air Accidents Investigation Branch in the UK (AAIB) made several safety recommendations following the G-REDL accident, and these are directly relevant to the LN-OJF accident. Airbus Helicopters considered the G-REDL accident as mainly a result of maintenance error and safety measures were introduced to improve the chip detection system. In addition, a ‘G-REDL test programme’ was launched.

The post-investigation actions following the accident with G-REDL were not sufficient to prevent another main rotor loss. The AIBN finds that the actions undertaken by Airbus Helicopters could have been more effective with regards to a possible scenario with limited spalling, assessing the effectiveness of the detection system and reviewing the MGB design features. The AIBN also finds that the oversight of Airbus Helicopters by EASA could have been more effective with regards to implementation of the safety recommendations and the follow-up on the information from the G-REDL accident report.

Certification and design criteria

The observed failure in this accident, i.e. crack initiation and propagation with limited spalling, was not expected or foreseen during design and type certification in 2004. It was assumed that if rolling contact fatigue occurred, spalling would result and be detected prior to gear failure.

The EC 225 LP satisfied the requirements in place at the time of certification. However, the AIBN has found weaknesses in the current EASA Certification Specifications for Large Rotorcraft (CS-29). There are significant lessons to be learned related to MGB design and future certification projects concerning; safety assessment, fatigue evaluation, detection systems and operational reliability.

Continued airworthiness

Less than 10 % of all second stage planet gears in the EC 225 LP and AS 332 L2 helicopters ever reached their intended operational time before being rejected during overhaul inspections or non-scheduled MGB removals due to signs of degradation. Airbus Helicopters did not perform systematic examination and analyses of unserviceable and rejected second stage planet gears in order to understand the full nature of any damage and its effect on continued airworthiness.

Following the accident, Airbus Helicopters' examination of near 500 second stage planet gears removed from service indicate that the epicyclic module planet gears in the AS 332 L2 and EC 225 LP helicopters were frequently damaged by foreign objects debris (FOD). The lack of systematic analysis, led also to a situation where the difference in reliability between the bearings supplied by different vendors was not known until after the LN-OJF accident occurred.

Accident data availability

Considerable time and resources by the AIBN were diverted to request, wait for release acceptance and review of design and certification documents. Because of protection of sensitive proprietary information, the AIBN was offered to study requested design and certification documents at Airbus Helicopter's premises in France. Furthermore, the AIBN had to wait for two to six months before receiving some of the documents from EASA.

Safety actions following the accident

Within two weeks following the accident, the CAA-N and CAA-UK grounded all AS 332 L2 and EC 225 LP helicopters[4]. One month following the accident, based on the AIBN's third preliminary report with a safety recommendation to EASA, EASA grounded the helicopters[5], while the two CAAs suspended all operations.

On 7 October 2016, EASA lifted the flight prohibition based on an agreement between Airbus Helicopters and EASA. A range of safety measures were mandated; including removal of planet gears with bearings supplied by FAG, reducing service life limit and intensifying maintenance checks. On 20 July 2017, the CAA-N and CAA-UK released the flight ban based on, amongst others, an improved chip detection system.

Two catastrophic events (G-REDL and LN-OJF) and the service experience with many planet gears removed from service after relatively short service exposure, may suggest that the operational loading environment, on both AS 332 L2 and EC 225 LP, is close to the limit of endurance for the design. Although the planet gears still in service seem to be more robust; data, analyses and tests do not conclusively prove that the NTN-SNR bearing will not have the potential to develop subsurface and possible undetectable fatigue cracks from a surface damage.

However, decisions concerning the fleet airworthiness are not within the mandate of the safety investigation authorities. This is the responsibility of the regulatory authorities. As part of the return to service programme it was demonstrated that the probability of such an event is acceptable in terms of continuing airworthiness agreed with the regulator.

[4] Except search and rescue (SAR).
[5] Except SAR, military versions and other State aircraft.

CONCLUSION

The accident was a result of a fatigue fracture in one of the eight second stage planet gears in the epicyclic module of the MGB, a critical part in which cracks initiated from a micro-pit at the bearing outer race and developed subsurface to a catastrophic failure without being detected.

The investigation has shown that the combination of material properties, surface treatment, design, operational loading environment and debris gave rise to a failure mode which was not previously anticipated or assessed.

From this investigation there are significant lessons to be learned related to gearbox design, safety assessment, fatigue evaluation, condition monitoring, certification and the continued airworthiness of the AS 332 L2 and the EC 225 LP helicopters, which also could be valid for other helicopter types.

Based on this investigation, the AIBN issues 12 safety recommendations:

SAFETY RECOMMENDATIONS

The following safety recommendations are made by the Accident Investigation Board Norway[6].

AIBN SR Ref.	*Safety recommendation:*
SL No. 2018/01T	The failure mode, i.e. crack formation subsurface with limited spalling initiated from a surface damage, observed in the LN-OJF accident is currently not fully understood. The investigation has shown that the combination of material properties, surface treatment, design, operational loading environment and debris gave rise to a failure mode that was not previously anticipated or assessed. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) commission research into crack development in high-loaded case-hardened bearings in aircraft applications. An aim of the research should be the prediction of the reduction in service-life and fatigue strength as a consequence of small surface damage such as micro-pits, wear marks and roughness.
SL No. 2018/02T	The MGB, which was later installed in LN-OJF, fell off a truck during transport. It was inspected, repaired and released for flight by Airbus Helicopters without detailed analysis of the potential effects on the critical characteristics of the MGB. The current regulatory framework for large rotorcraft does not make connections between the Instructions for Continued Airworthiness (ICA) and requirements for critical parts subject to an unusual event. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) assess the need to amend the regulatory requirements with regard to procedures or Instructions for Continued Airworthiness (ICA) for critical parts on helicopters to maintain the design integrity after being subjected to any unusual event.
SL No. 2018/03T	Rolling contact fatigue as observed in the LN-OJF accident was not considered during type certification, neither is it directly addressed in the current certification specifications. The Accident Investigation Board Norway recommends that European Aviation Safety Agency (EASA) amend the Acceptable Means of Compliance (AMC) to the Certification Specifications for Large Rotorcraft (CS-29) in order to highlight the importance of different modes of component structural degradation and how these can affect crack initiation and propagation and hence fatigue life.
SL No. 2018/04T	The chip detection system fitted to LN-OJF did not produce any warnings of the impending planet gear catastrophic failure, and the potential of detection was limited. The Certification Specifications for Large Rotorcraft (CS-29) do not specify the chip detection system's functionality and performance. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) revise the Certification Specifications for Large Rotorcraft (CS-29) to introduce requirements for MGB chip detection system performance.

[6] The Accident Investigation Board Norway issues safety recommendations in accordance with Act of 11 June 1993 relating to Aviation § 12-6, cf. Regulation (EU) No. 996/2010 Article 16, 17, 18.

SL No. 2018/05T	The LN-OJF accident was a result of a fatigue fracture in one of the eight second stage planet gears in the epicyclic module of the MGB, a critical part in which cracks developed subsurface to a catastrophic failure without being detected. It might not be possible to assess the fatigue reliability of internal MGB components, or design a warning system that works with sufficient efficiency and warning time, thus the MGB should be designed fail-safe. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) develop MGB certification specifications for large rotorcraft to introduce a design requirement that no failure of internal MGB components should lead to a catastrophic failure.
SL No. 2018/06T	The investigation into the accident to LN-OJF has revealed that the tests performed during the design and certification of the Airbus Helicopters EC 225 LP were in accordance with applicable regulations. However, with regard to the risks associated with offshore operations, there is a less stringent continued operational reliability test requirement for large rotorcraft compared with the *Extended Operations and All Weather Operations* regime for fixed wing aircraft. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) develop regulations for engine and helicopter operational reliability systems, which could be applied to helicopters which carry out offshore and similar operations to improve safety outcomes.
SL No. 2018/07T	The investigation into the accident to LN-OJF has found that only a few second stage planet gears in Airbus Helicopters EC 225 LP and AS 332 L2 ever reached their intended operational time before being rejected during overhaul inspections or non-scheduled MGB removals. The parts rejected against predefined maintenance criteria were not routinely examined and analysed by Airbus Helicopters. The Accident Investigation Board Norway recommends that European Aviation Safety Agency (EASA) make sure that helicopter manufacturers review their Continuing Airworthiness Programme to ensure that critical components, which are found to be beyond serviceable limits, are examined so that the full nature of any damage and its effect on continued airworthiness is understood, either resulting in changes to the maintenance programme, or design as necessary, or driving a mitigation plan to prevent or minimise such damage in the future.
SL No. 2018/08T	The investigation into the accident to LN-OJF has found that only a few second stage planet gears in Airbus Helicopters EC 225 LP and AS 332 L2 ever reached their intended operational time limit before being rejected during overhaul inspections or non-scheduled MGB removals. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) review and improve the existing provisions and procedures applicable to critical parts on helicopters in order to ensure design assumptions are correct throughout its service life.
SL No. 2018/09T	The investigation into the accident to LN-OJF has demonstrated that a critical structural component could fail totally without any pre-detection by the existing monitoring means. The Accident Investigation Board Norway recommends that the European Aviation Safety Agency (EASA) research methods for improving the

	detection of component degradation in helicopter epicyclic planet gear bearings.
SL No. 2018/10T	During the investigation into the accident to LN-OJF, considerable time and resources by the AIBN has been drawn to request, wait for release acceptance and review of design and certification documents. The Accident Investigation Board Norway recommends that the European Commission (DG MOVE) in collaboration with European Aviation Safety Agency (EASA) evaluates the means for ensuring that investigation authorities have effectively free access to any relevant information or records held by the owner, the certificate holder of the type design, the responsible maintenance organisation, the training organisation, the operator or the manufacturer of the aircraft, the authorities responsible for civil aviation, EASA, ANSPs and airport operators.
SL No. 2018/11T	During the investigation into the accident to LN-OJF, considerable time and resources by the AIBN has been drawn to request, wait for release acceptance and review of design and certification documents. The Accident Investigation Board Norway recommends that the International Civil Aviation Organisation (ICAO) evaluates the means for ensuring that investigation authorities have effectively free access to any relevant information or records held by the owner, the certificate holder of the type design, the responsible maintenance organisation, the training organisation, the operator or the manufacturer of the aircraft, the authorities responsible for civil aviation, certification authorities, ANSPs and airport operators.
SL No. 2018/12T	The LN-OJF accident was a result of a fatigue fracture in one of the eight second stage planet gears in the epicyclic module of the MGB, a critical part in which cracks developed subsurface to a catastrophic failure without being detected. With the knowledge from this investigation, all effort should lead to a robust design in which a single load path should demonstrate compliance to CS 29.601(a), 29.602 and 29.571 without compromising its structural integrity and not only by depending on detection systems or maintenance checks. The Accident Investigation Board Norway recommends that Airbus Helicopters revise the type design to improve the robustness, reliability and safety of the main gearbox in AS 332 L2 and EC 225 LP.

Accident Investigation Board Norway

Lillestrøm, 5 July 2018