Norwegian Safety Investigation Authority

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REPORT Aviation 2021/07

REPORT ON THE AIR ACCIDENT IN FOLLEBU, GAUSDAL MUNICIPALITY, INNLANDET COUNTY, NORWAY ON 1 AUGUST 2019 INVOLVING A HUGHES HELICOPTERS INC. 369D, SE-JVJ, OPERATED BY FIRST EUROPEAN AVIATION COMPANY SP. Z.O.O.

The Norwegian Safety Investigation Authority (NSIA) 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 NSIA's task to apportion blame or liability. Use of this report for any other purpose than for flight safety shall be avoided.

This report has been translated into English and published by the NSIA to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

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REPORT CONCERNING AIR ACCIDENT

Type of aircraft:	Hughes Helicopters Inc. 369D
Nationality and registration:	Swedish, SE-JVJ
Owner:	GCC Capital AB, Sweden
Operator:	First European Aviation Company Sp. z.o.o, Poland
Crew:	Commander and system operator, both uninjured
Passengers:	None
Accident site:	Nordre Fogne farm in Follebu, Gausdal municipality, Innlandet county, Norway (61°15'47.53"N 10°19'56.75"E)
Accident time:	Thursday 1 August 2019 at 1312 hours

All times given in this report are local time (UTC + 2 hours) unless otherwise stated.

NOTIFICATION

On 1 August 2019 at 1336 hours, a police superintendent for Innlandet police district notified the Norwegian Safety Investigation Authority (NSIA) duty officer of a helicopter crash near Lillehammer. He also said that the emergency services were on their way to the accident site and that neither of the two on board had serious injuries. The Joint Rescue Coordination Center of Southern Norway called at 1340 hours and provided further information. They stated that signals from helicopter emergency locator transmitter had been received at 1315 hours and that the accident site was a field near Øverbygdsvegen road in Follebu in Gausdal municipality. The NSIA decided to launch an investigation and, on the same evening, two accident investigators set off for the accident site.

In accordance with ICAO Annex 13, "Aircraft Accident and Incident Investigation", the NSIA notified the authorities in the state of manufacture, USA (National Transportation Safety Board, NTSB), the state of registration, Sweden (The Swedish Accident Investigation Authority, SHK) and the state of operator, Poland (State Commission of Aircraft Accident Investigation, SCAAI). USA, Sweden and Poland all appointed accredited representatives who assisted the NSIA in their investigation.

SUMMARY

The helicopter, SE-JVJ, was mapping distribution lines for the electricity grid company Eidsiva Nett[1], using laser scanning and aerial photography. Approximately 52 minutes into the flight the commander became aware of abnormal vibrations in the helicopter. The vibrations increased in intensity and were accompanied by a metallic sound. Consequently, the commander decided to find a landing site to check the helicopter. Just before landing, at an altitude of 2 – 3 meters, the helicopter lost all its power to the rotor system. The helicopter hit the ground causing the right skid

[1] Eidsiva Nett is constructing, operating, maintaining and upgrading a 22 000-kilometer power grid in Hedmark and Oppland, (now Innlandet) county. Source https://www.eidsivanett.no. On 1 January 2020, Eidsiva Nett merged with Hafslund Nett and formed a new company, Elvia.

to collapse. The tail touched the ground and the main rotor blades hit the ground, whirling up earth on the right-hand side. The crew were unharmed, but the helicopter was severely damaged.

The loss of power was caused by a fracture in the main gearbox input pinion. The pinion fracture was caused by fatigue. However, it has not been possible to determine what caused the fatigue. Regardless of the cause, the NSIA is of the opinion that some of the maintenance work on the main gearbox had not been performed in accordance with the expected standard. Moreover, the NSIA finds that the continuing airworthiness management and the submitted maintenance documentation were inadequate.

The NSIA has not issued any safety recommendations in connection with this investigation.

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 The helicopter, SE-JVJ, was mapping distribution lines for the electricity grid company Eidsiva Nett, using laser scanning and aerial photography. The helicopter crew consisted of a Swedish commander, sitting in the left-hand seat, and a Polish system operator, sitting in the right-hand seat.[2]

1.1.2 The accident flight was the crew's second flight that day. The objective of the first flight was to inspect power lines, starting at Hamar and landing at Mesnali. The first flight lasted 2 hours and 32 minutes. At Mesnali, the crew had a 30-minute break, before they refueled and took off again at 1219 hours. The plan was to inspect a new power line and then return to Hamar. According to the commander, the conditions were perfect for power line inspections, with calm winds and a clear sky. The flights were planned and conducted using an iPad with the flight planner software Sky Demon.

1.1.3 The final flight proceeded as normal for approximately 52 minutes. Then, the commander became aware of an abnormal vibration in the helicopter. Initially, he noticed the vibrations in the seat, and asked the system operator if he could feel them too, which he did not. The vibrations increased gradually, and about 10 seconds after the commander first noticed the vibrations, they were confirmed by the system operator. The vibrations increased in intensity and approximately 20 – 30 seconds later, the commander heard a metallic sound, which, like the vibrations, was becoming louder. The commander said it sounded like it was coming from a bearing that was about to fail. A while later, the system operator also heard the sound, and could feel the vibrations when pressing his back against the seat and his feet to the floor. He felt the strongest vibrations in the floor.

1.1.4 None of the instruments displayed fault indications. At the time, the crew did not perceive the situation as threatening, but the commander nevertheless decided to land the helicopter in order to check it. He circled two farms while taking his bearings. He chose a grassy field northwest of Nordre Fogne farm as the landing site and initiated a slow approach (see figures 1 and 2). When the helicopter reached hovering altitude (2 – 3 meters above the field) the commander was still in doubt as to whether the vibration and sound were signs of a serious problem. He continued at the same altitude, and made a slight turn flying across the field with the purpose of landing the helicopter closer to

[2]As opposed to most other helicopter models, this model is operated from the left-hand seat.

Øverbygdsvegen road. Suddenly, both the vibration and the sound increased significantly, and, at the same time, the torque meter displayed unstable values.

1.1.5 The commander decided to land the helicopter immediately. As he stopped at an approximate altitude of 3 meters and was about to lower the collective, the crew heard a loud bang. Both the commander and the system operator have stated that the bang seemed to come from somewhere behind them. The commander felt he lost control of the helicopter. The helicopter rotated approx. 60 – 70° to the left while losing altitude. It hit the ground causing the right skid to collapse. The tail touched the ground and the main rotor blades hit the ground, whirling up earth on the right-hand side. The crew experienced being flung both to the left and to the right. The accident occurred about a minute after the power line inspection was aborted.

1.1.6 The commander managed to stop the engine by cutting the fuel supply before the crew evacuated the helicopter. They contacted the owner and the operator and informed them of the crash and of the fact that they seemed to be uninjured. The system operator activated the helicopter emergency locator transmitter.[3] According to the Rescue Coordination Center, the transmitter was activated at 1315 hours, three minutes after the crash.

1.1.7 Shortly afterwards, the farmer who owned the field and his son drove down to the helicopter. They have stated that they had observed the helicopter as it passed over the farm, and that they later heard a loud bang.

1.1.8 The emergency services arrived quickly at the accident site, and took the two crew members to the hospital at Lillehammer for a check-up. At the hospital, it was confirmed that they had not sustained any injuries.

[3] The transmitter signals were received by the Swedish rescue coordination center, who then notified the Joint Rescue Coordination Center Southern Norway (JRCC) at Sola.

Figure 1: The area where SE-JVJ conducted the power line inspection for Eidsiva Nett. The power line route that was inspected can be seen in the center of the map, north of the Nordre Fogne farm in Follebu in Gausdal municipality. The crash site is indicated by a red star. Map: © Norwegian Mapping Authority

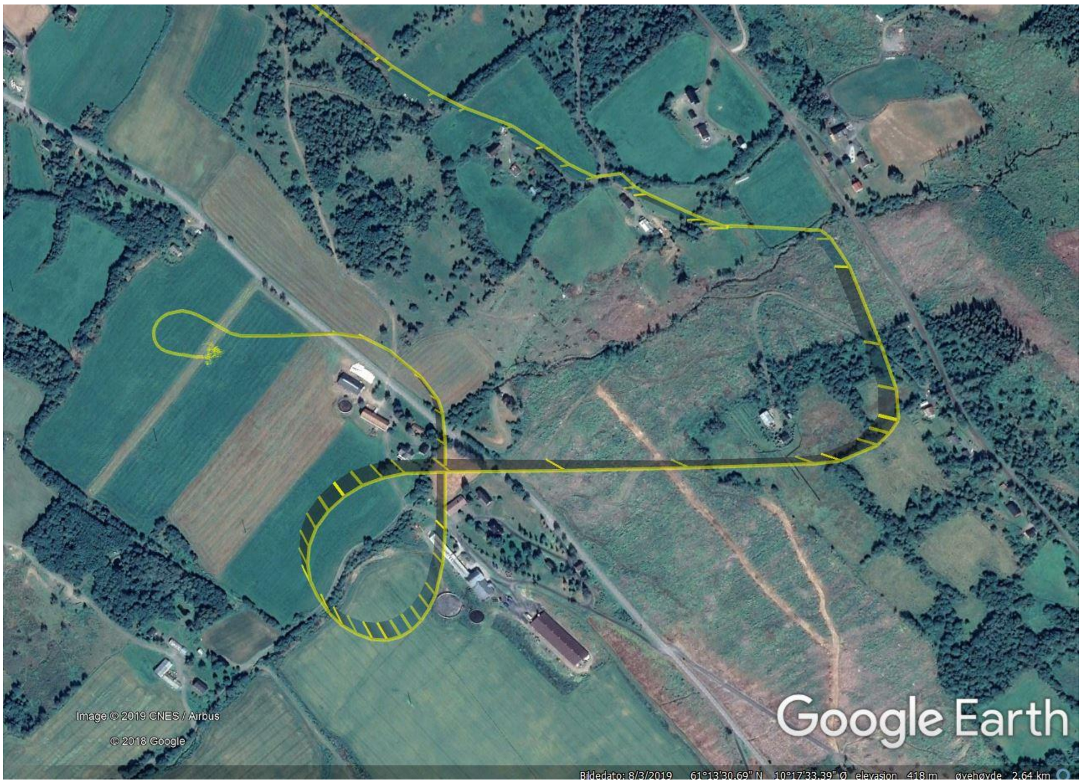

Figure 2: Flightpath Source: Flight data from Sky Demon imported into Google Earth

Figure 3: SE-JVJ facing southwest. To the left in the photo, there are visible traces of the main rotor blades striking the ground. Photo: NSIA

1.2 Injuries to persons

Table 1: Injuries to persons

Injuries	Crew	Passengers	Other
Fatal			
Serious			
Minor/none	2		

1.3 Damage to aircraft

The aircraft was substantially damaged. See Chapter 1.12.2 for more information.

1.4 Other damage

The fuel tank was punctured and spilled an unknown quantity of fuel at the accident site. Some of the grass was also flattened and destroyed upon impact and during the subsequent removal of the helicopter.

1.5 Personnel information

1.5.1 The commander

The commander was 32 years old and a Swedish national. He had operated helicopters since 2011 and had held a Commercial Pilot License for helicopters (CPL(H)) since 2013. The commander held a valid Class 1 medical certificate. He was working as a freelance helicopter pilot and was hired on a four-months' contract for the Swedish company Visimind AB. The commander has stated that he felt rested and fit for flight.

Table 2: Flying experience commander

Flying experience	All types	On type
Last 24 hours	2:30	2:30
Last 90 days	121:06	121:06
Total	907:30	244:30

1.5.2 The system operator

The system operator was 23 years old and a Polish national. He was employed by the Polish subsidiary Visimind Ltd. Sp. z.o.o as an operator of the laser and photo equipment that was used during power line inspections with helicopters. He had been on several flights with the commander previously. The system operator has stated that he felt rested and fit for flight.

1.6 Aircraft information

1.6.1 General

Hughes Helicopters Inc. 369D is a light single engine helicopter seating one pilot and four passengers. The helicopter is also referred to as McDonnell Douglas MD 500D.

Serial number:	1127D
Year of manufacture:	1982
Total accumulated flight time:	5,329.6 hours
Engine:	Rolls-Royce 250-C20F (formerly Allison) turbine engine with 420 hp output
Main gearbox, part number:	369D25100-505
Main gearbox, serial number:	0693
Main gearbox, total operating time:	3,749.5 hours
Rotor diameter:	8.05 meters
Maximum take-off weight:	1,360 kg (3,000 lb)
ARC valid until:	26 May, 2020

SE-JVJ was formerly registered in the Italian register as I-ANBE. On 27 February 2017, the helicopter was transferred to the Swedish register as SE-JVJ.

1.6.2 Checklists

SE-JVJ was equipped with a checklist including an emergency checklist. The checklist states the following with regard to vibrations:

ABNORMAL VIBRATIONS
- sudden, unusual or excessive vibrations occurring during flight. - LAND AS SOON AS POSSIBLE
No further flights should be attempted until the cause of the vibration has been identified and corrected.

1.6.3 The main gearbox

1.6.3.1 The function of the main gearbox is to transmit power from the engine, and gear down the engine's output rotational speed to the desired rotational speed for the main rotor and tail rotor respectively (see Figure 4). The power-on limits for the engine output driveshaft[4] speed are 6,136 – 6,196 rpm with corresponding main rotor speeds of 487 – 492 rpm and tail rotor driveshaft speeds of 2,120 – 2,142 rpm. The tail rotor driveshaft speed reduction takes place in one step, and the main rotor speed reduction in two steps as shown in Figure 5.

1.6.3.2 The main gearbox input pinion, (part number 369D25121-11) is made of 9310 steel[5]. The part's drawings specify that the surface roughness in the fillet area between the driveshaft and the pinion (where the cracks occurred) can be maximum 63 RMS. In the bearing journal area adjacent to the fillet area, the surface roughness can be maximum 32 RMS.

1.6.3.3 The bore inside the pinion had originally been plugged using a natural cork plug (part number 23425-100). This cork plug had been replaced by a synthetic filler material on newer pinions (see Figure 5).

1.6.3.4 The main gearbox has a separate oil system with a pressure pump and an external oil cooler. A fan run by a belt on the driveshaft between the engine and the main gearbox blows air through the oil cooler.

1.6.3.5 When asked by the NSIA, MD Helicopters stated that they were not aware of any previous cases where the main gearbox input pinion had fractured. They also stated that the adjustment of the engine's position in relation to the main gearbox is less critical for the input pinion. If the engine position is not properly adjusted, other components than the main gearbox will be overloaded.

[4]Connected to the main gearbox input pinion (the part that failed).
[5]According to AMS 6265 (steel alloy with chrome, nickel and molybdenum)

Figure 4: The main gearbox before it was disassembled at MD Helicopters in Arizona. Photo: NSIA

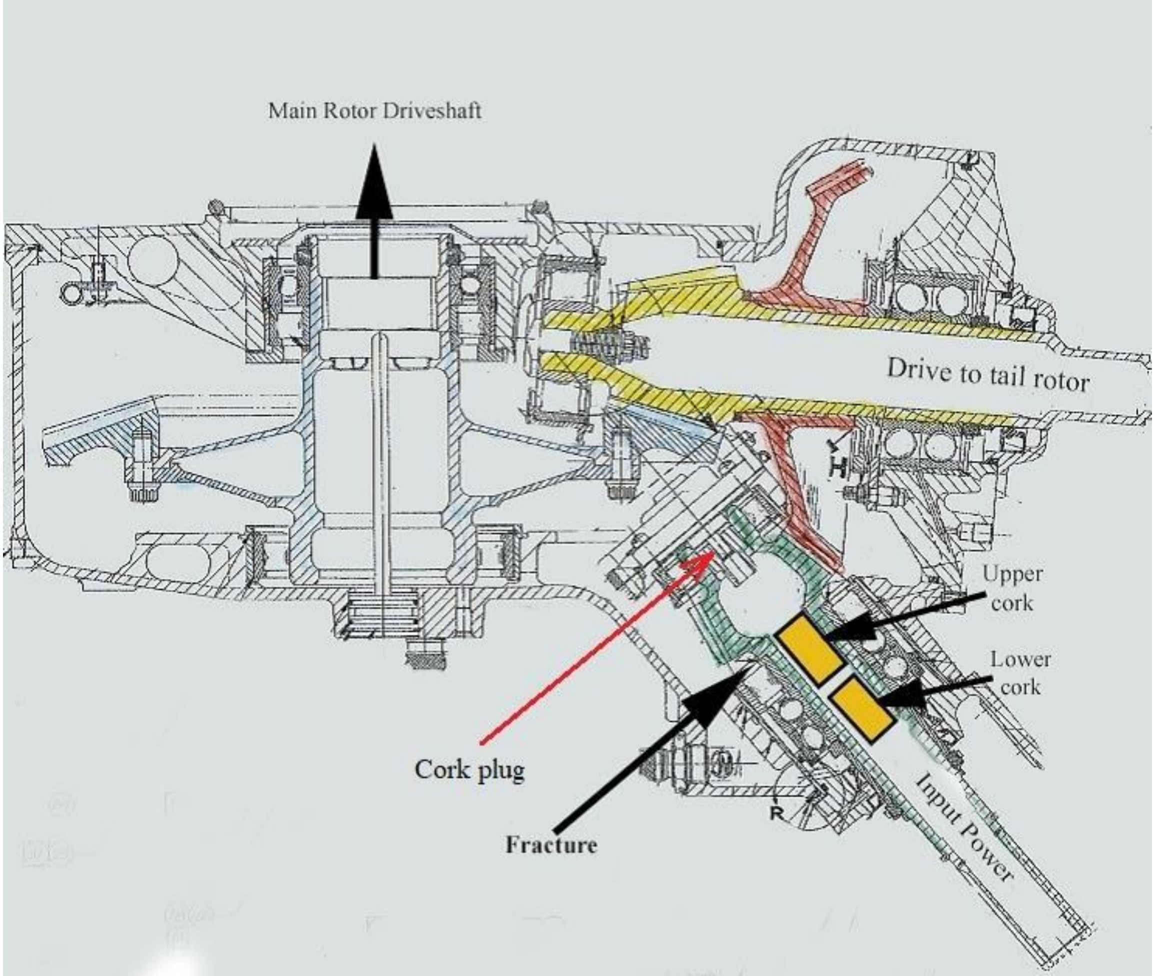

Figure 5: Drawing showing the main gearbox structure. The input pinion is shown in green. The black arrows show the fracture and the two irregular wine corks. The red arrow points to the bore inside the pinion that had originally been plugged using a natural cork plug. Source: MD Helicopters

1.6.4 Maintenance

1.6.4.1 The NSIA did not find it fruitful to search the helicopter's maintenance documentation for the period prior to the installation of the main gearbox in I-ANBE in April 1996. There is nothing in the available documentation indicating that the main gearbox was subject to accidents or incidents during the period from 1996 until the crash on 1 August 2019.

1.6.4.2 A review of the available maintenance documentation shows the following:

- On 12 March 1996, the main gearbox in question (S/N 0693) was removed from a helicopter with the registration I-COLA. The main gearbox was then inspected, with a time since overhaul (TSO) of 1,382:36 hours. The main gearbox's total time was not given.

- On 12 March 1996, the main gearbox (S/N 0693) was installed in I-ANBE. The helicopter's total time was 2,962.36 hours. The main gearbox's time since overhaul (TSO) was 1,382:36 hours.

- On 16 June 2004, the helicopter's total time was 3,769:35 hours. According to the documentation, the helicopter maintenance was performed by March Helicopters Ltd. UK.

- On 12 June 2005, the helicopter's total time was 3,808 hours. At that time, Kent Helicopters Ltd. in England conducted a combined 100-hours/annual inspection. The main gearbox oil and filter were changed and replenished with new Mobil 254 oil.

- Between July 2009 and April 2012, some maintenance was carried out in Milan by the French organization Copter & Boat's Dream.

- On 22 June 2012, the helicopter's total time was 4,053.0 hours. According to the documentation, maintenance of the helicopter was performed in Italy by Malmskog Aerocenter AB.

- On 27 May 2016, the helicopter's total time was 4,125.8 hours. The documentation states that the helicopter maintenance was performed by Helicraft Nordflyg Service AB.

- On 8 February 2019, the helicopter's total time was 5,124.8 hours. As part of the maintenance, the oil and filter on the main gearbox were replaced. New Mobil AGL oil was added. This was the last documented maintenance performed on the main gearbox. The maintenance was performed by First European Aviation Company Sp. z.o.o, Poland.

- The engine was replaced on 12 May 2019. The helicopter total time was 5,124.8 hours and 9,046 cycles[6]. The installed engine with part number 6887190 and serial number CAE 820223 had recently been overhauled and had an engine total time of 14,619:46 hours. The maintenance was performed by First European Aviation Company Sp. z.o.o, Poland.

- On 28 June 2019, the helicopter total time was 5,266:53 hours and 9,133 cycles. Along with other maintenance, a 100-hour inspection was carried out at that time. The maintenance was performed by First European Aviation Company Sp. z.o.o, Poland.

1.6.4.3 It has not been possible to retrieve much of the older maintenance documentation for the helicopter components. Among others, the NSIA contacted the Italian accident investigation authority, but was unable to obtain maintenance documentation from the period when maintenance of the main gearbox was conducted in Italy. Thus, it has been impossible to determine who carried out modification AD 87-18-12 (see section 1.16.2.3) and when the modification took place. Nor has it been possible to determine whether the main gearbox has been disassembled on other occasions than during the modification.

1.6.5 Continuing Airworthiness

1.6.5.1 First European Aviation Company is a commercial helicopter operator with a duty to adhere to an approved maintenance program. In this case, the helicopter was registered in Sweden and under the authority of the Swedish Transport Agency (Transportstyrelsen). The maintenance program, approved by the Swedish Transport Agency, is based on maintenance requirements and recommendations from the helicopter manufacturer. The

[6]Number of take-offs/landings

manufacturer requirements (section 04-00-00, Airworthiness Limitations) have been approved by international authorities, including the US Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA).

1.6.5.2 According to the helicopter manufacturer's recommendations in section 05-00-00, the main gearbox should be overhauled after a flight time of 3,000 hours. However, the overhaul interval can be extended to a flight time of 4,000 hours if only Mobil AGL gear oil has been used, and/or the use of cargo hook totals less than 750 flight hours during the overhaul period. For the gearbox in question other types of gear oil was also used (see 1.6.4.2).

1.6.5.3 First European Aviation Company had implemented a maintenance program (FEAC/MP/MDHI369 rev #7) that had been approved by the Swedish Transport Agency.

1.6.5.4 In their approved maintenance program, First European Aviation Company set the main gearbox maintenance interval at 4,000 hours, referring to section 04-00-00. However, the reference should have been to the helicopter manufacturer's recommendation in section 05-10-00, which also stipulates an oil type requirement.

1.6.5.5 In its continuing airworthiness documentation (CAMO status), First European Aviation Company specifies that the main gearbox should be overhauled after 3,000 hours. In the same list, the operating time of the main gearbox was set at 0 hours and the helicopter's flight hours at 2,590.6 hours when the main gearbox was installed on 13 April 1994. This information does not corresponds to any other available documentation.

1.6.6 Equipment on board the helicopter

1.6.6.1 The helicopter had equipment for mapping and documenting power lines. The equipment consisted of laser and camera equipment attached to a permanently mounted rig under the helicopter. The rig was secured by bolts to the helicopter belly and left skid. The seats in the rear had been removed and replaced by several computers. The computers were connected to the external laser and photo equipment via several cables that ran through a hole in the left passenger door. All equipment received power from the helicopter power supply system. The system operator sat in the right front seat and operated the system via a screen in front of him. The owner of the equipment was the Polish company Visimind Ltd. Sp. z.o.o.

1.6.6.2 The system was installed in the helicopter based on a Supplemental Type Certificate – STC) no. 10057706 from the European Aviation Safety Agency (EASA). The installation was developed by SAAB AB, Nyköping, Sweden and comprised the *Data Acquisition Module – Hardware (DAM-H), Vision Mount Module Installation.*

1.6.6.3 The NSIA removed and weighed the equipment. The total mass of the equipment was 105 kg.[7]

[7]The computer equipment in the rear compartment: 30.6 kg, external bracket including 7 cameras and 1 laser: 59 kg, as well as 15.4 kg of cables. Total 105 kg.

1.6.7 Mass and balance

1.6.7.1 The helicopter operator First European Aviation Company has provided the following data for the helicopter (with full fuel tanks):

Helicopter empty mass	1,639.5 lb
Removed flight controls right side	-11.3 lb
Pilot	185.0 lb
System operator	185.0 lb
Mapping equipment inside the cabin	91.7 lb
Mapping equipment installed under the belly	181.0 lb
Equipment in the rear compartment	60.0 lb
Fuel main tank (62.1 US gallons)	423.0 lb
Fuel aux tank (20 US gallons)	143.0 lb
Total mass	2,896.9 lb

1.6.7.2 As mentioned in section 1.6.6.3 the equipment in the helicopter weighed 105 kg. This corresponds to 231.5 lb. The helicopter operator has stated that the mapping equipment should weigh 272.7 lb. This means that the equipment was 41.2 lb lighter than reported. Consequently, the mass is as follows:

Total mass (according to the helicopter operator)	2,896.9 lb
Difference in mapping equipment mass	-41.2 lb
Mass at departure from Mesnali	2,855.7 lb

1.6.7.3 The maximum take-off mass is 3,000 lb. The calculation shows that the helicopter operated within the maximum permitted mass during the whole flight.

1.6.7.4 Data provided by the helicopter operator First European Aviation Company show that the helicopter balance was within its limitations.

1.7 Meteorological information

1.7.1 There was hardly any wind. Visibility: More than 10 km. High clouds. Temperature: 15 °C. QNH: 1 019 hPa.

1.7.2 It was daylight and the commander said the weather conditions were perfect for power line inspections.

1.8 Aids to navigation

The commander used an iPad with the navigation application Sky Demon.

1.9 Communications

The commander did not have contact with Norway Control.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

Not mandatory and not installed.

1.12 Wreckage and impact information

1.12.1 The accident site

The accident took place in a field with tall grass belonging to Nordre Fogne farm, Øverbygdsvegen, Follebu in Gausdal municipality. The helicopter ended up in a position pointing north approx. 200 meters below Øverbygdsvegen road (see Figure 2). The inclination of the field was 10.5°. The crash site is located at 395 meters (1,300 ft) above sea level.

1.12.2 The helicopter wreckage

1.12.2.1 The aircraft was significantly damaged. Upon impact with the ground, the right skid broke and the rig with the mapping equipment that was attached to the helicopter was pressed upward, damaging the helicopter belly. Among other damage, the equipment punctured a fuel tank. Furthermore, all main rotor blades hit the ground and were damaged.

1.12.2.2 Upon impact with the ground, the tail boom twisted to the right causing the right-hand fin on the T-tail to come into contact with the ground and bending.

1.12.2.3 The mapping equipment under the helicopter belly was significantly damaged.

Figure 6: The rig with the mapping equipment and wrinkles in the skin on the helicopter's belly. The yellow arrow points towards the twisted tail boom. Photo: NSIA

1.12.2.4 The helicopter was transported to the NSIA's premises at Lillestrøm on the same evening.

1.12.2.5 During the crash, a fuel leakage occurred from the main tank. Some fuel was spilled at the accident site and during the rescue. The rest, 75 liters of Jet A1 fuel, was drained from the main tank after the helicopter arrived at the NSIA's hangar at Lillestrøm. The aux tank was intact and full of fuel. It was emptied the following week. In total 160 liters of fuel were drained.

1.12.2.6 During the initial examinations, it was discovered that the ceiling panel at the rear of the cabin had come loose. After the panel was removed, a part of the main gearbox was found to be fractured (see Figure 7). Some oil had also spilled from the area. Furthermore, the belt that drives the cooling fan had snapped. The main gearbox was consequently removed, put in a sealed container and sent to MD Helicopters in Arizona, USA, for further examination (see Chapter 1.16).

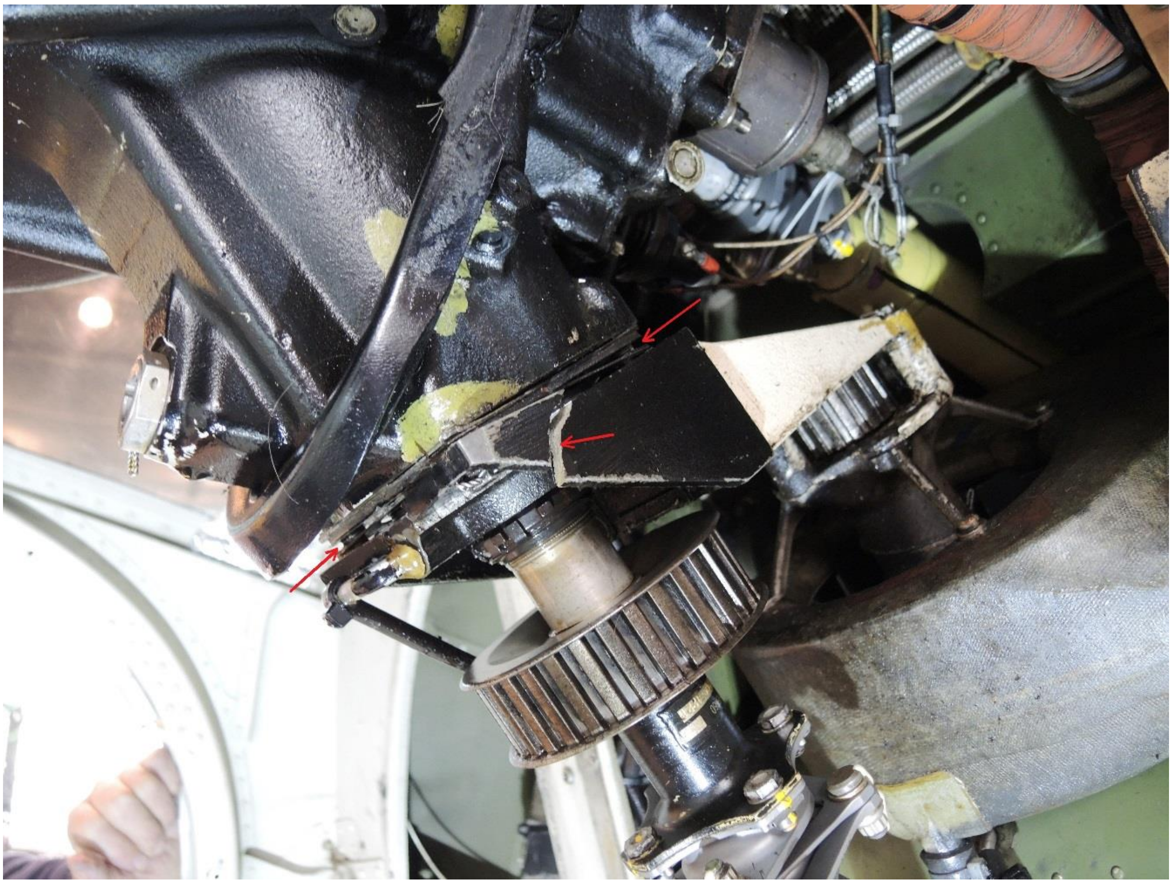

Figure 7: The main gearbox section where the shaft from the engine enters the main gearbox. The cooling fan drive belt has fallen off. The red arrows show a fracture and gaps. Photo: NSIA

1.13 Medical and pathological information

The commander and the system operator were examined at the hospital at Lillehammer on the same evening. Neither had sustained any injuries. The crew took routine alcohol blow tests, which were both negative.

1.14 Fire

No fire occurred.

1.15 Survival aspects

Both the commander and the system operator had access to helicopter helmets with earphones. However, the commander did not wear his helmet because the earphones were broken. He therefore wore separate earphones. During the impact, the commander's head struck the left window, but he was not hurt.

1.16 Tests and research

1.16.1 Preliminary investigations

1.16.1.1 Before the main gearbox was removed, the two magnetic chip detectors were inspected. Both detectors were covered by metal chips, in particular the plug by the shaft input (see Figure 8). The magnetic chip plug at the bottom of the gearbox had fewer metal chips. When measured, the magnetic chip plug had the following values:

- Magnetic chip plug by the input shaft: 650 Ohm[8]
- The magnetic chip plug at the bottom of the gearbox: 100 Ohm

As the crew had stated that they did not see any warning lights, the NSIA decided to check if the warning system was functioning. The helicopter battery switch was switched on, and when the cables to the magnetic chip detectors short-circuited against the helicopter fuselage, the warning light in the cockpit activated (M/R XMSN CHIPS).

Figure 8: The magnetic chip plug from the main gearbox shaft input area. Photo: NSIA

1.16.1.2 After an unknown quantity of oil had spilled from the main gearbox, 2 deciliters of clear, reddish oil was drained out.

1.16.2 Examination of the main gearbox at MD Helicopters in Arizona, USA

1.16.2.1 Led by the NSIA, the main gearbox was examined more closely at the manufacturer MD Helicopter's premises. Present during the investigation were representatives from MD Helicopters, as well as representatives from the US FAA. The FAA participated on behalf of the NTSB.

1.16.2.2 During the disassembly, it soon emerged that the input pinion (with part number 369D25121-11 and serial number 57152-0093) had split at the section between the bearings and the pinion itself. A fracture that had developed in that region could lead to oil spilling from the gearbox and out through the hollow input pinion. The fracture surface was analyzed in more detail at external metallurgical laboratories, first in the USA (see chapter 1.16.3) and subsequently in Norway (see chapter 1.16.4).

[8]Ohm is a unit used to measure electrical resistance.

Figure 9: The split input pinion with the pinion section to the left and the shaft section to the right. Photo: NSIA

1.16.2.3 During disassembly, the following was pointed out in particular:

- The gearbox was relatively clean with few metal chips or other contamination inside.

- The gearbox had been opened after manufacture. E.g., the modification AD 87-18-12 had been completed by replacing the bevel drive gear in the last step with an improved version. This entailed that the gearbox changed identity from a 369D25100-503, becoming a -505 gearbox. In that connection, the data plate was also replaced.

- The shims that adjust the pressure on the main bearings were too thick. This meant that the bearings were loose and had rotated inside their housing. Moreover, one of the bearings had not been fastened with *Locktite* (glue) in accordance with the instructions.

- A bushing surrounding the bearings on the input pinion had been installed in a 90° incorrect position. This meant that the oil could not drain freely from the bearing area. Consequently, the oil would collect in the bearing and spill over the edge once the bearing region was full. This, in turn, reduced the oil flow past the magnetic chip plug.

- Several shafts had longitudinal scratches indicating the presence of contamination on the shafts when the bearings were pressed into place. This also applied to the input pinion. However, none of the scratches reached the fracture area on the shaft (see Figure 10).

- The natural cork plug at the end of the input pinion (see section 1.6.3.2 and Figure 5) was found to be in good condition (not leaking).

- It was discovered that the bore inside the input pinion also had been blocked by a cork-like material (see Figure 11).

Figure 10: Examples of scratches where the bearings sat on the pinion driving the tail rotor. Photo: NSIA

1.16.3 Examination of the input pinion at SEMTEC Laboratories in Phoenix, USA

1.16.3.1 After MD Helicopters had disassembled the main gearbox, the two parts of the input pinion were examined closer at SEMEC Laboratories. The same representatives that were present at the MD Helicopters examination also took part during this examination. It was initially confirmed that there were three unapproved pieces of something looking very much like wine corks inside the hollow pinion. These were removed and are from now on referred to as wine corks (see Figure 5 and Figure 12).

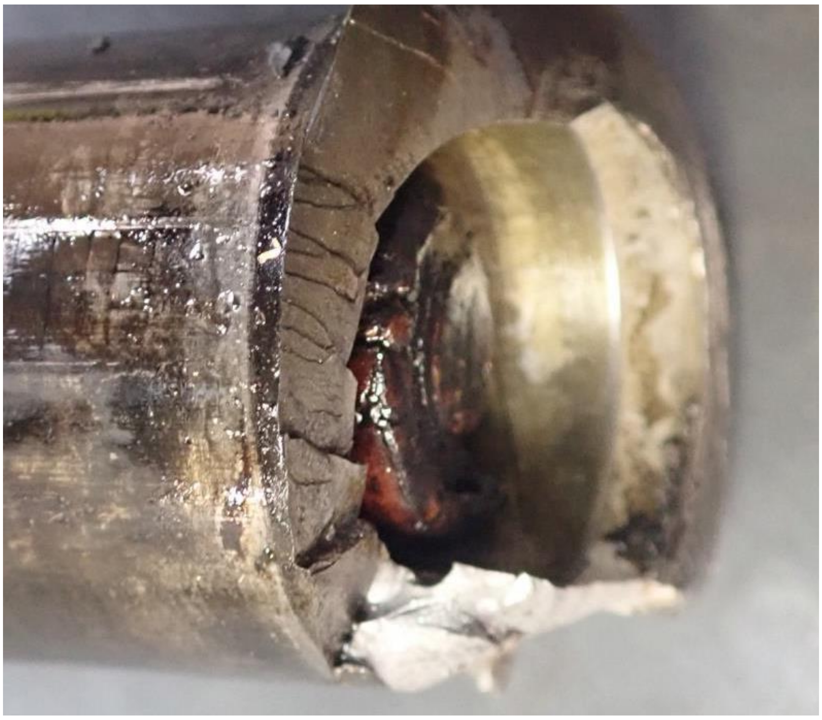

Figure 11: The fracture surface of the pinion showing the visible end of a wine cork. Photo: SEMTEC Laboratories

Figure 12: The input pinion after the end with the fracture surface was cut off. To the left two wine corks. The left cork is partly dissolved and has split in two. Photo: NSIA

1.16.3.2 The fracture surface on the pinion part of the input pinion was largely destroyed by secondary damage (see Figure 13). As the damage on this part was most extensive in the area where the fracture was presumed to have started, a decision was made to examine the opposite fracture surface (see Figure 14). To get the fracture surface into the SEM/EDS[9], the pinion was cut near the fracture surface.

1.16.3.3 It was concluded that the fracture was a fatigue fracture with several initiation points that had merged. The fracture surface in the region where the fracture most likely had started, had been polished and the details had thus been damaged. Nevertheless, it was concluded that the cracks had begun on the outside of the pinion in an area showing traces of a lathe tool used during the manufacturing of the pinion. However, the scratches from the lathe tool were not particularly sharp or deep. There were no signs of wear marks in the area where the cracks had begun.

[9] Scanning Electron Microscope/Energy Dispersive Spectrometer

1.16.3.4 It was confirmed that the steel in the pinion was of type 9310, which was the correct type.

1.16.3.5 In addition to examining the input pinion fracture, SEMTEC Laboratories also examined a total of ten fragments (chips) found on the magnetic chip detectors (see Figure 8).

Figure 13: The fracture surface on the pinion part of the input pinion.
Photo: NSIA/SEMTEC Laboratories

Figure 14: The fracture surface with the least secondary damage in the area where the fracture started (the shaft part). The assumed origin, propagation direction and final overload fracture are indicated. Photo: NSIA/SEMTEC Laboratories

1.16.4 Examination of the fracture surfaces on the input pinion by the Norwegian Defence Laboratories FOLAT at Kjeller

1.16.4.1 After the examination was completed in the USA, the input pinion was further examined by the Norwegian Defence Laboratories. The examination focused on the fracture surfaces on the shaft part. After photo documentation, the part was cut and studied in a Scanning Electron Microscope (SEM). SEMTEC Laboratories' conclusions were confirmed. It was assumed that the steps in Figure 15 originated from several initiation points.

1.16.4.2 The fillet area at the transition between the shaft and the pinion was examined in more detail (see Figure 16). The examination revealed a number of small surface cracks along the entire radius. Moreover, it was pointed out that the surface of the pinion seemed to have been etched or corroded. It also showed traces of machining. Several of the cracks followed these machining marks (Figure 17).

Figure 15: Photo from a digital microscope showing the fracture surface with the least secondary damage in the area where the fracture started (the shaft part). The red arrows point to a number of initiation points for the fatigue fracture. The blue arrow illustrates the length of the final fracture Photo: NSIA/FOLAT

Figure 16: The arrow points to the radius at the transition between the shaft and the pinion. Photo: NSIA/FOLAT

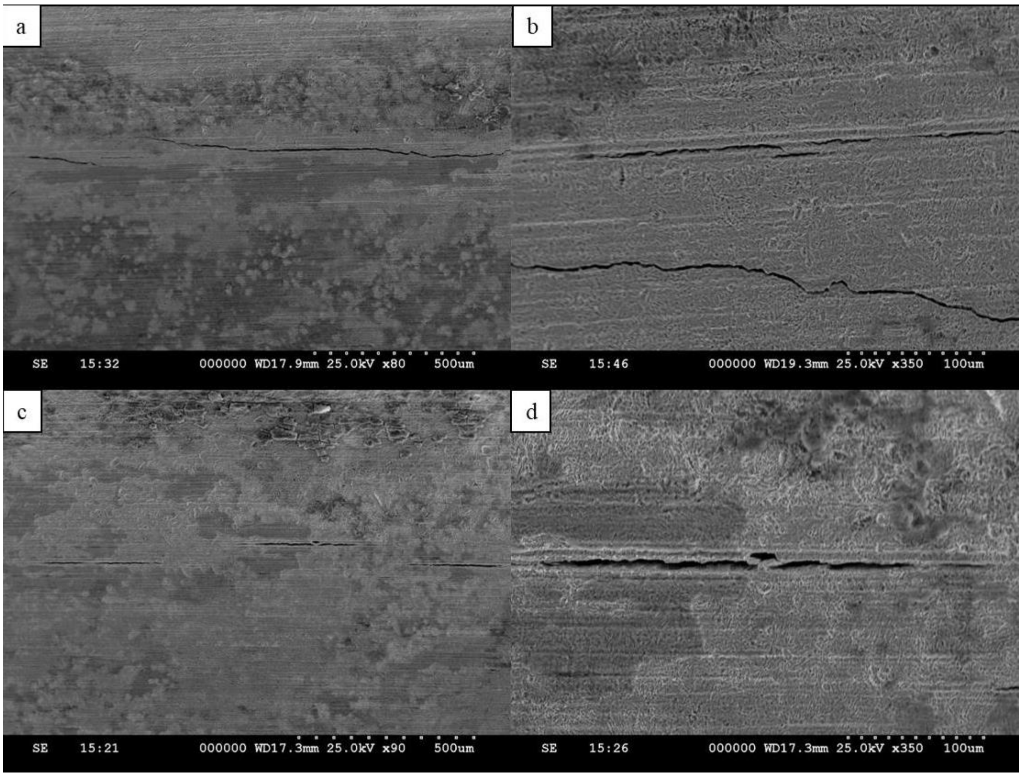

Figure 17: Images from a scanning electron microscope showing radial cracks in the area shown in Figure 16. Photo: NSIA/FOLAT

1.16.4.3 The section was cut in order to be able to examine the alloy, hardness and micro-structure of the steel, Figure 16. The material hardness was measured as 378 ± 11 HV_1[10]. The cuts also made it possible to measure the depth (length) of some of the cracks. One of the cracks is shown in Figure 18. All the cracks that were examined showed both oxidation and mechanical damage, which meant that only a small original fracture surface was available for examination. This prevented attempts to establish a time frame for the crack propagation. However, it has been established that the cracking mechanism was high cycle fatigue.

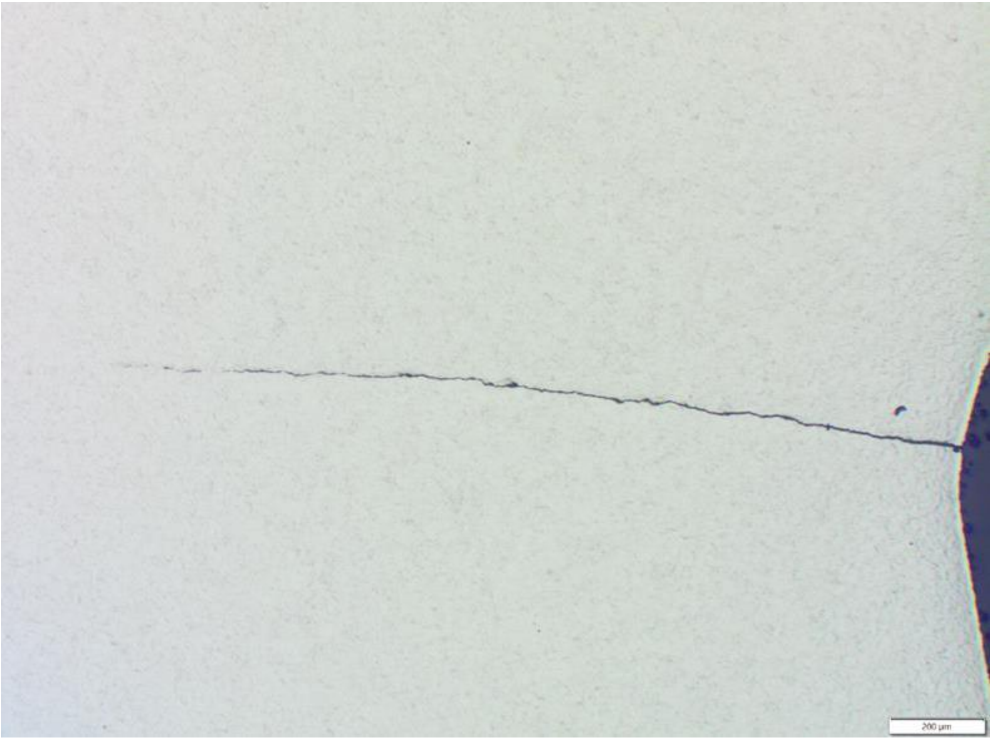

Figure 18: The photo shows the depth of one of the cracks. The fillet is shown on the right. The crack is approximately 1.8 mm long (deep). The scale in the lower right-hand corner is 200 µm long. Photo: FOLAT

1.16.4.4 The Norwegian Defence Laboratories conclude as follows in their report:

> *The present investigation has confirmed that the failure of the pinion assy input drive is a result of fatigue initiated at the radius between the shaft and pinion.*
>
> *The current investigation has also revealed that similar cracking as observed for the main fracture also had initiated at the same region at the opposite side of the component.*
>
> *The crack initiations seem to be associated with surface irregularities originating from machining and surface oxidation.*
>
> *Due to the fact that the fatigue initiations seem to have mainly been initiated on two opposite sides, bending loadings may have contributed to the initiations and subsequent fatigue crack growth.*

[10] Hardness Vickers with 1 kg force.

The base material alloy composition for the component determined by EDS in SEM, complies with the 9310 steel per AMS 6265 material specified in DWG.NO. 369D25121.

1.16.4.5 Based on the fact that the cracks seem to have started in connection with machining marks, it was decided to measure the surface roughness in the crack initiation area. To do this, the Norwegian Defence Laboratories used a Mitatoyo SJ-210 Surface Roughness Tester. This is not designed to measure the roughness of concave surfaces. For that reason the less curved surfaces were chosen for the test. The result showed that the surface roughness was Ra 0.45 – 0.85, corresponding to RMS 16 – 32. This is in accordance with the manufacturer's requirements (see 1.6.3.2).

1.17 Organizational and management information

1.17.1 The Polish helicopter operator First European Aviation Company Sp. z.o.o. (FEAC) operated SE-JVJ on behalf of the Swedish company Visimind AB. The helicopter was leased from the Swedish company GCC Capital AB and was based in Eskilstuna, Sweden. FEAC has an authorized maintenance organization according to Part-145 and had performed maintenance on SE-JVJ since 2017.

1.17.2 The inspection equipment that was used for the power line inspection, DMA-H, was owned by the Polish company Visimind Ltd. Sp. z.o.o, a subsidiary of Visimind AB in Sweden.

1.18 Additional information

1.18.1 Maintenance documentation

The owner or operator of the aircraft is responsible for ensuring that the helicopter maintenance documentation is kept in accordance with the regulations (i.e. protected against fire, water damage and theft) for a period of 36 months, or until the documentation has been superseded by new information equivalent in scope and detail.[11]

1.19 Useful or effective investigation techniques

No methods qualifying for special mention have been used in this investigation.

[11] Ref. EF EASA 1321/2014, Part-M Annex 1 M.A.305(h)

2. ANALYSIS

2.1 Introduction

2.1.1 The NSIA has managed to establish a clear picture of the course of events and the immediate reason for the sudden loss of rotor speed. The commander gave a detailed statement to the NSIA, which corresponds with findings at the crash site and the helicopter wreckage. The lack of flight data recorders was partially made up for by the fact that the commander used an iPad which registered and stored the flight route. The conclusion is that the commander handled the situation that occurred well.

2.1.2 The accident involving SE-JVJ mainly comprises technical aspects. The NSIA analysis will therefore not discuss the operative aspects of the accident in any detail. The NSIA has not been able to gain sufficient overview of the main gearbox's maintenance history. Thus, it has not been possible to conclude why the main gearbox input pinion developed a fatigue fracture, nor establish a time frame for the crack propagation.

2.2 Analysis of the course of events

2.2.1 The fracture in the main gearbox input pinion was not visible until the main gearbox had been disassembled. Thus, it would not have been possible for the commander to discover the fracture, neither during the daily inspections, nor during pre-flight inspections. Moreover, the fracture would not have been noticeable during flight before the deformation of the pinion caused imbalance and vibrations.

2.2.2 When the commander noticed the vibrations, the crack had most likely progressed close to causing the pinion final fracture. The vibrations came from the main gearbox input pinion which rotated at approximately 6,000 rpm, giving a vibration frequency of 100 Hz. This is significantly higher than the vibration frequency from the main rotor and the tail rotor. Consequently, there was no reason to suspect that the vibration came from the rotors. The NSIA would like to commend the commander for taking the vibrations sufficiently seriously to abort the flight although they were hardly noticeable. The accident illustrates the importance of taking all changes in the vibration pattern or the sound picture in a helicopter very seriously.

2.2.3 It is difficult to assess how quickly a fault can develop. In this accident, only a minute or so passed from when the vibrations were noticeable and until the shaft failed. When this happened, the helicopter was 2 – 3 meters above the ground. The fracture meant that the rotor system lost all its power. From 2 – 3 meters above the ground, and almost in hover, it was impossible to establish autorotation. The kinetic energy in the rotor system was insufficient to dampen the fall and the helicopter hit the fairly steep field with relatively great force. Due to the slanting terrain, the right skid hit the ground first and bore the brunt of the impact. This may be the reason that the right undercarriage broke and the main rotor and the tail fin hit the ground on the right-hand side. When the undercarriage on the right-hand side broke, the mapping equipment was pushed into the belly of the helicopter and was damaged. The damage to the helicopter belly punctured the fuel tank.

2.2.4 The crash was not hard enough to activate the emergency locator transmitter.

2.2.5 The fact that the pinion broke at a low altitude, was decisive for the crew escaping the accident without injuries. If it had broken at a higher altitude, for instance while the crew were conducting the power line inspection, the outcome could have been much more severe.

2.2.6 When the pinion broke, the fracture surfaces started to rotate against each other. As the fracture surfaces were uneven, an axial force was generated which pushed the surfaces away from each other. This made parts of the main gearbox fracture, the belt that drives the oil cooler fan snapped, and the ceiling panel in the cabin was pushed down (see Figure 7). The main gearbox fracture caused some oil spillage from the gearbox.

2.2.7 The fatigue fracture was of such a nature that it most likely generated very few metal chips before the pinion split. This could be a contributing factor why the magnetic chip detectors did not activate a warning before the accident occurred (see section 1.16.1.1). The metal chips that were discovered on the magnetic chip detectors were most likely produced when the two fracture surfaces rubbed against each other with great force. Some metal chips may also originate from damage caused to the pinions after the input pinion split. The metal chips that attached to the magnetic chip detectors should, however, have caused the electrical resistance to approach 0 Ohm, thus activating a warning. The fact that this did not happen may raise the question whether the magnetic chip detectors in the main gearbox worked as intended. Another possibility is that the faulty installation of bushing surrounding the bearing (see section 1.16.2.3) reduced the oil flow past the magnetic chip detectors so that fewer metal chips were collected.

2.3 The fracture and crack initiations

2.3.1 It has not been possible to establish unambiguously why the fracture occurred. However, the FOLAT report indicates that the pinion may have been subject to a bending moment. This is supported by the fact that crack initiations were discovered on two opposite sides of the pinion. The cause of this possible bending moment has not been established.

2.3.2 Most likely, the fatigue fracture has existed for some considerable time. This is supported by the merger of several initiation points. The small final fracture indicates that the load on the part was low in relation to the design, indicating a slow progressing high cycle fatigue. Another factor that supports a slow progress is that only a small original fracture surface remained due to oxidation and machining. Nor is there any recent maintenance documentation showing an oil leakage from the main gearbox input pinion. See also section 2.4.3.4.

2.4 Maintenance of the helicopter

2.4.1 <u>Introduction</u>

2.4.1.1 In connection with the accident investigation, the NSIA expresses concern with several aspects of the maintenance that had been conducted on the main gearbox:

- The main gearbox had been disassembled at least once after it was manufactured. MD Helicopters has confirmed that the gear box was modified in accordance with AD 87-18-12. However, it has not been possible to obtain maintenance documentation confirming disassembly or modification of the gearbox.

- Several of the observations that were made during the disassembly (see section 1.16.2.3) indicate that the maintenance was not performed according to expected standards.

- Two wine corks were discovered inside the main gearbox input pinion.

- At the time of the accident, the main gearbox had a total operating time of 3,749.5 hours. This is 749.5 hours more than the permitted overhaul interval of 3,000 hours. The main gearbox did not meet the requirements for extension of the maintenance interval to 4,000 hours (see section 1.6.5.2).

2.4.1.2 The scratches observed on several of the shafts, the incorrect use of shim and the incorrect assembly of the bushing on the input pinion bearings are unlikely to have affected the course of events, but indicate that the maintenance was not conducted in accordance with expected standards.

2.4.1.3 However, the two wine corks and the extensive operating time are likely to have been contributing factors (see chapter 2.4.2 and 2.4.3).

2.4.1.4 The NSIA has no reason to believe that FEAC har performed the above mentioned maintenance on the main gearbox.

2.4.1.5 The NSIA has decided not to issue any safety recommendations in connection with this investigation. Based on information from MD Helicopters, the input pinion does not have a history of failing. It is unlikely that the pinion would have failed had the maintenance been carried out according to regulations, and the fracture is therefore considered an isolated case. Consequently, the issue of an order to disassemble all main gear boxes to check the input pinions for cracks, is not justified in this case.

2.4.2 <u>The wine corks</u>

2.4.2.1 It is obvious that the two wine corks discovered inside the input pinion were unapproved and not according to regulations. The wine corks were not authorized parts of the gearbox, and, as far as the NSIA is aware, they were not installed as part of any approved maintenance procedure. A possible explanation of why the wine corks had been installed may be that an oil leak through the pinion had occurred at some point. The pinion is hollow and goes into the main gearbox. To prevent oil leaks from the gearbox into the hollow input pinion, the bore was originally plugged by a cork (see Figure 5). It is possible that someone erroneously assumed that the leak came from a leak in this plug.

2.4.2.2 If so, the wine corks are likely to have stopped the oil leak. The wine corks is a very creative, but highly irregular way of stopping a leak. However, if the oil leak came from an incipient fatigue fracture, and not from a leak in the original seal plug, the two wine corks will have hidden the real cause of the oil leak and thus prevented further troubleshooting.

2.4.2.3 One factor which indicates that the fracture has existed for a long time is that one of the wine corks seemed old and was partially dissolved. It is not possible to determine whether both wine corks were inserted at the same time, or if the lower wine cork was inserted after the upper (first) one had started to dissolve.

2.4.2.4 The NSIA can conclude that the fracture is likely to have developed over several years, and that the non-regulatory use of the two wine corks prevented it from being discovered in time. If the cause of the oil leak had been further examined, the accident could have been prevented.

2.4.3 Continuing Airworthiness

2.4.3.1 The NSIA finds that the First European Aviation Company (FEAC) did not follow the helicopter manufacturer's recommendations concerning main gearbox maintenance intervals (see section 1.6.5.2). In this case, the NSIA is of the opinion that these recommendations should not be disregarded. The operator's maintenance program contained errors and deficiencies that entailed that the main gearbox had not been overhauled at the correct time.

2.4.3.2 The operator's continuing airworthiness management system contained erroneous information relating to the main gearbox operating time. According to the information, the main gearbox had an operating time of 2,749 hours, with a remaining flight time of 261 hours at the time of the accident. The gearbox had in fact been in service for 3,749 hours and the recommended overhaul interval had been exceeded by 749 hours. The condition is that the main gearbox should have been overhauled after 3,000 hours as Mobil 254 oil had been used in the overhaul period.

2.4.3.3 The NSIA is of the opinion that the errors in the maintenance program and the erroneous registration of the main gearbox's operating time are serious, as this is one of the most safety-critical components in a helicopter. The errors most likely occurred when FEAC assumed responsibility for the maintenance, or when the maintenance program was established. During the period leading up to the accident, the maintenance program was initially approved by the Swedish Transport Agency. It was subsequently revised several times and subject to an airworthiness review, but the errors were not discovered. The NSIA believes that the reason why the errors remained undiscovered may have been that the aviation authorities do not usually check the aircraft's maintenance status when the country of registration is changed within the EU[12].

2.4.3.4 The NSIA finds it likely that the fracture existed for more than 749 flight hours. If the fracture existed for more than 749 flight hours, it could have been discovered during a 3,000-hour overhaul. This means that it is likely that the fracture would have been discovered before the accident occurred, had the overhaul interval been complied with.

2.4.4 Maintenance documentation

2.4.4.1 According to current European requirements, maintenance documentation must be retained for 36 months. However, the helicopter was manufactured in 1982 and was registered on the Italian register until 27 February 2017. During this period, the requirement for documentation has varied and been subject to both national and European requirements. Consequently, it would require substantial resources to clarify what documentation should have been retained at any one time. However, there is no doubt that it must be possible to trace or hand over important maintenance documentation in order to document that an aircraft is airworthy.

2.4.4.2 A main gearbox is a highly safety-critical component. FEAC in Poland has not been able to provide satisfactory documentation of vital maintenance performed on the helicopter's main gearbox. In particular, this applies to when the main gearbox was last opened, and what maintenance was performed in that connection.

[12]This applies to aircraft weighing less than 2,730 kg.

2.4.4.3 Generally, the NSIA would like to emphasize the importance of clarifying the essential maintenance history of components with time limitations in an aircraft before it is given a new registration.

3. CONCLUSIONS

3.1 Main findings

The helicopter lost all its power to the rotor system due to failure of the input pinion in the main gearbox. The crew noticed vibrations in the helicopter shortly before the failure but did not receive any other warnings. The fact that the input pinion failed at low altitude, was crucial for the crew escaping without injuries.

The input pinion failure was caused by fatigue. However, it has not been possible to determine what caused the fatigue. Regardless of the cause, however, the NSIA is of the opinion that some of the main gearbox maintenance was not performed in accordance with expected standards. Moreover, the NSIA finds that the continuing airworthiness management and the submitted maintenance documentation were inadequate.

3.2 Investigation results

a) The weather was ideal for a line inspection and was not a contributing factor in the accident.

b) At the time of the accident, the helicopter was operating within its mass and balance limitations.

c) The commander aborted the power line inspection because he noticed vibrations in the helicopter.

d) When the vibrations increased in intensity and when also noise was heard, the commander decided to land to examine this further.

e) On impact with the steep field, the helicopter sustained major damage.

f) The crash was not hard enough to activate the emergency locator transmitter.

g) The failure of the main gearbox input pinion occurred at a speed and altitude where it was impossible to establish autorotation.

h) Metallurgical examinations revealed that the input pinion failed due to fatigue.

i) Metallurgical examinations have revealed numerous crack initiations, and several of these had merged and formed one large fracture.

j) This fracture had most likely existed for several years before the input pinion finally failed.

k) It is likely that an oil leak that seeped through the fracture had, contrary to regulations, been plugged with two wine corks.

l) Most likely, the use of the two wine corks concealed the real reason for the oil leak and thus prevented further troubleshooting.

m) At the time of the accident, the main gearbox had operated 749.5 hours beyond the permitted overhaul interval.

n) In all likelihood, the accident could have been prevented had the overhaul of the main gearbox taken place within the specified overhaul interval.

4. SAFETY RECOMMENDATIONS

The NSIA has not issued any safety recommendations in connection with this investigation.

The Norwegian Safety Investigation Authority (NSIA)

Lillestrøm, 22 June 2021

APPENDICES

Appendix A: Abbreviations

ABBREVIATIONS

AD	Airworthiness Directive
CAMO	Continuing Airworthiness Management Organization
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FEAC	First European Aviation Company Sp. z.o.o, Poland
ft	Feet (0.305 m)
hPa	hektoPascal
Hz	Hertz (cycle per second)
ICAO	International Civil Aviation Organization
kt	knot(s) – Nautical Mile(s) (1,852 m) per hour
lb	pound(s) (0.454 kg)
NM	nautical mile(s) (1,852 m)
NSIA	Norwegian Safety Investigation Authority
NTSB	National Transportation Safety Board
QNH	Altimeter pressure setting to indicate elevation amsl
SEM	Scanning Electron Microscope
UK	United Kingdom
UTC	Coordinated Universal Time