ACCIDENT

Aircraft Type and Registration:	Enstrom 280FX, G-OJBB
No & Type of Engines:	1 Lycoming HIO-360-F1AD piston engine
Year of Manufacture:	1999 (Serial no: 2084)
Date & Time (UTC):	25 August 2021 at 1618 hrs
Location:	Rhobell Fawr, Dolgellau, Gwynedd
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Minor) Passengers - N/A
Nature of Damage:	Damaged beyond economic repair
Commander's Licence:	Private Pilot's Licence
Commander's Age:	65 years
Commander's Flying Experience:	419 hours (of which 419 were on type) Last 90 days - 12 hours Last 28 days - 4 hours
Information Source:	AAIB Field Investigation

Synopsis

The helicopter suffered a loss of thrust from the tail rotor while hovering close to the ground near a mountain top, resulting in a loss of control and hard landing. Subsequent examination of the tail rotor gearbox revealed damage to the bevel gears and failure of a bearing, which was consistent with a lack of lubrication. The investigation found inconsistencies in the way maintenance was performed on the tail rotor gearbox, compared to the helicopter manufacturer's maintenance instructions. It is likely that insufficient oil was added to the tail rotor gearbox when it was serviced 25 flying hours prior to the accident.

Three Safety Recommendations are made relating to information in the helicopter Maintenance Manual regarding the required oil quantity and maintenance servicing interval for the tail rotor gearbox.

History of the flight

The pilot, who also owned G-OJBB, was making a local flight from Hawarden Airport. The planned route was to fly to the west of Snowdonia National Park, then south to Barmouth where he would turn to the north-east, towards Bala Lake, before returning to Hawarden. Having completed his pre-flight checks, which included checking the tail rotor gearbox (TRGB) [1] and its oil quantity, the helicopter departed Hawarden at 1509 hrs.

Footnote

[1] In this report the terms tail rotor gearbox (TRGB), gearbox and transmission are used interchangeably.

The weather was dry and sunny, with visibility in excess of 9 km, few clouds at 2,900 ft amsl, a temperature of 21 °C, and QNH of 1027 hPa. The pilot was using a GPS navigation application installed on a tablet computer, which also recorded the helicopter's flight path.

The flight to Barmouth was uneventful and, having turned towards the north-east and Bala Lake, the helicopter approached Rhobell Fawr mountain, whose summit is approximately 2,400 ft amsl. As the helicopter approached Rhobell Fawr (Figure 1), the pilot noticed a stone obelisk[2] near its summit and decided to take a closer look. The pilot made a north-easterly approach towards the obelisk, with a recollection that the wind was from the south at about 10 kt. Having flown past the obelisk by about 20 m, he then brought the helicopter into a hover about two to three feet above an area of gently sloping ground. However, uncommanded by the pilot, the helicopter then rapidly yawed to the right before touching down heavily on its skids. The pilot recalled that the helicopter may have then briefly continued to yaw while on the ground before coming to a stop.

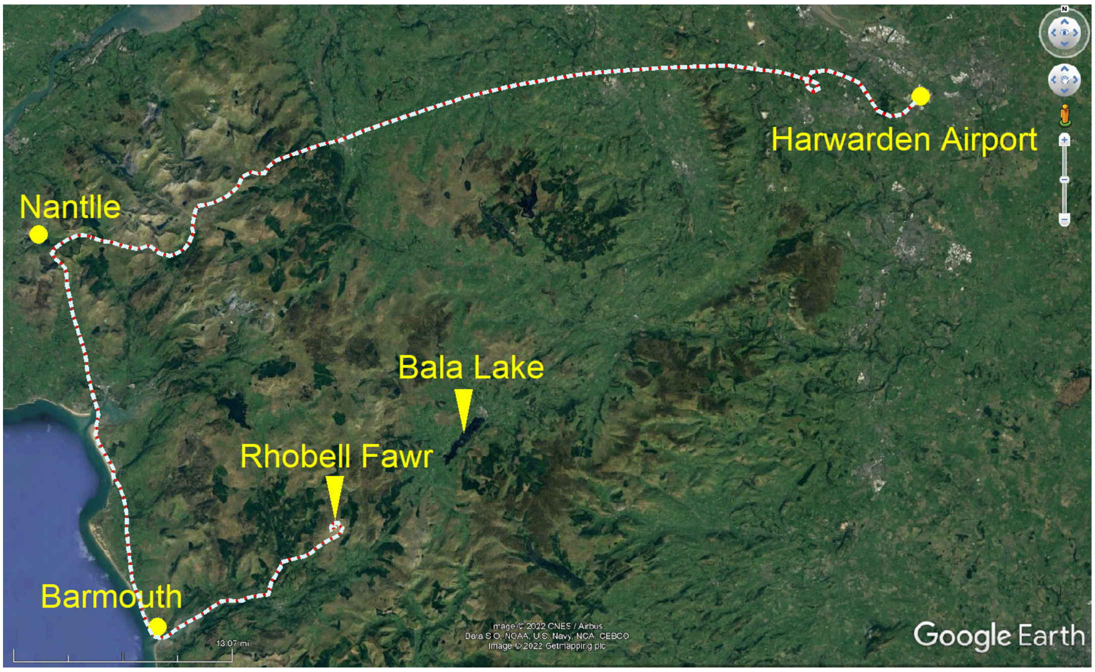

Figure 1

Flight track of G-OJBB (in dotted white/red)

Having selected the fuel and electrical systems off, the pilot vacated the cockpit using the right door. The helicopter's main rotors, tail boom and skids suffered substantial damage (Figures 2 and 3). The pilot sustained minor injuries to his right arm and left leg and was subsequently airlifted from the mountain by a Search and Rescue (SAR) helicopter which flew him to Caernarfon for treatment.

Footnote

[2] Rhobell Fawr triangulation station, also known as a trigonometrical point or informally as a 'trig point', is a fixed surveying point used in geodetic surveying.

The AAIB was notified of the accident and based on the initial information provided, did not deploy to the site, instead giving permission for the wreckage to be recovered by the owner. Two days after the accident, the pilot returned to the helicopter to start preparations for it to be airlifted from the mountain, which included detaching the main rotors and taping up the cockpit doors. During this activity, he did not see any signs of oil leaking, or having leaked, from the helicopter. A few days after this, a video recording of the helicopter while atop the mountain was posted on a social media website by a member of the public. This showed the tail rotor rotating freely in the wind, while the main rotor head remained stationary.

Figure 2

G-OJBB shortly after the accident

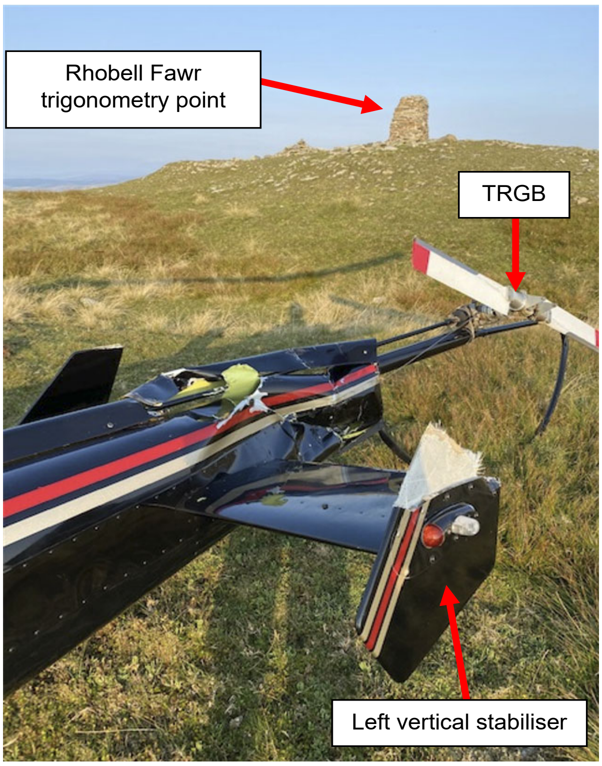

Figure 3

Damage to tail boom and left vertical stabiliser

Aircraft information

General

The Enstrom 280FX is a single engine light helicopter powered by a Lycoming HIO-360-F1AD piston engine. It is fitted with a three-bladed main rotor and a two-bladed teetering tail rotor driven by a TRGB mounted at the aft end of the tail boom (Figure 4). A drive shaft attached to the upper pulley of the main rotor transmission provides input drive to the TRGB. At a nominal engine speed of 3,050 rpm, the main rotor rotates at 351 rpm and the tail rotor at 2,514 rpm.

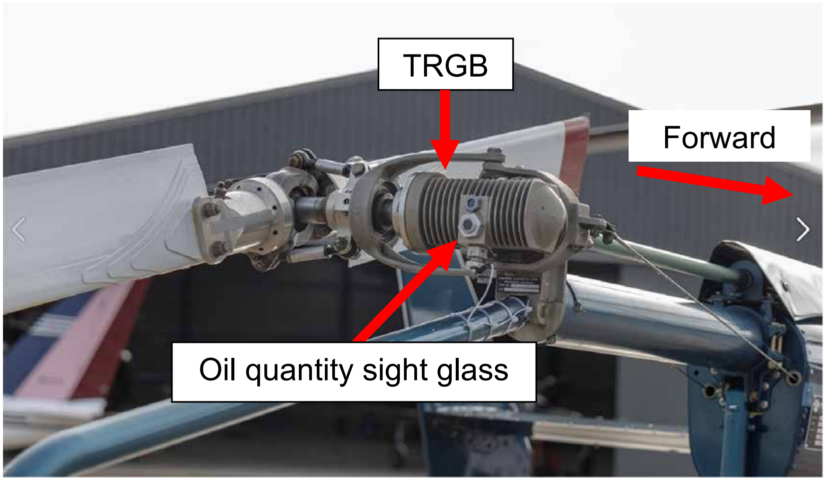

Figure 4

TRGB viewed from rear of 280FX helicopter

TRGB

The TRGB case is manufactured from aluminium and contains an input and output shaft that are each supported by two bearings, with drive between the shafts provided by bevel gears (Figure 5). The same TRGB design is also fitted to Enstrom F-28A, 280, F-28C, 280C and 480 helicopters.

The helicopter manufacturer specified that several alternate bearing part numbers could be used within the TRGB. The two bearings fitted to G-OJBB's input shaft, and the inner bearing on its output shaft, were the same part number[3]. These were fitted with ten balls and a cage manufactured from cotton-fibre reinforced phenolic resin, for which the maximum operating temperature specified by the bearing manufacturer was 107 °C. The outer bearing on the output shaft[4] was fitted with 13 balls and the cage could be manufactured from bronze, nylon or cotton-fibre reinforced phenolic resin. The helicopter manufacturer advised that during normal operation, the TRGB would reach a temperature not exceeding about 30 °C above ambient air temperature[5].

Footnote

[3] Enstrom part number ECD003-13.
[4] Enstrom part number ECD008-11.
[5] This was based on flight test data for its more powerful 480 model of helicopter, that is fitted with a larger rotor that rotated at higher speed than the 280FX.

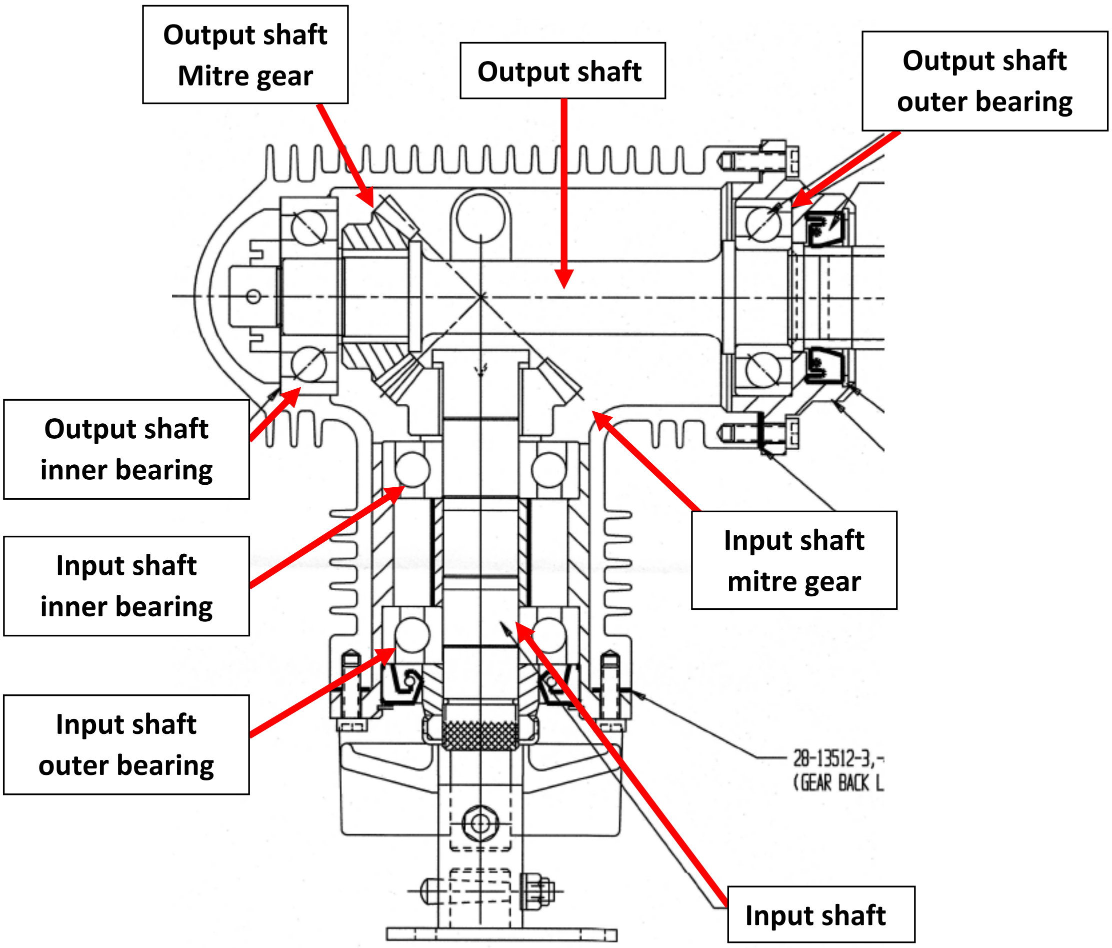

Figure 5

TRGB (reproduced with permission)

The bevel gears and bearings are splash lubricated by oil, with seals fitted to the input and output shafts to prevent oil loss from the unvented TRGB. At the rear of the TRGB case is an oil filler port and below this is an oil quantity sight glass[6] (Figure 6). Early Enstrom helicopters were fitted with a flat sight glass but, in 2008, a dome shaped sight glass was introduced in response to customer feedback, to improve readability. The domed sight glass was fitted to all new TRGB's, and those overhauled by the manufacturer since 2008. G-OJBB was fitted with an original flat sight glass.

On the top of the TRGB case is an inspection plug for the bevel gears, and on the underside, is a quick-disconnect magnetic plug that fits into a self-sealing oil drain plug; this prevents oil loss when the magnetic plug is removed for inspection. The oil circulating within the TRGB enables ferrous metal particles to flow to the magnetic plug. If the particles complete an electrical circuit between the tip of the plug and its outer body, or the case of the gearbox, a TRGB CHIP caution indicator on the cockpit instrument panel will illuminate.

Footnote

6 The helicopter manufacturer's publications use the terms sight glass and sight gauge interchangeably.

The TRGB CHIP indicator bulb can be tested using a switch on the cockpit instrument panel, but this does not provide an end-to-end electrical test of the system.

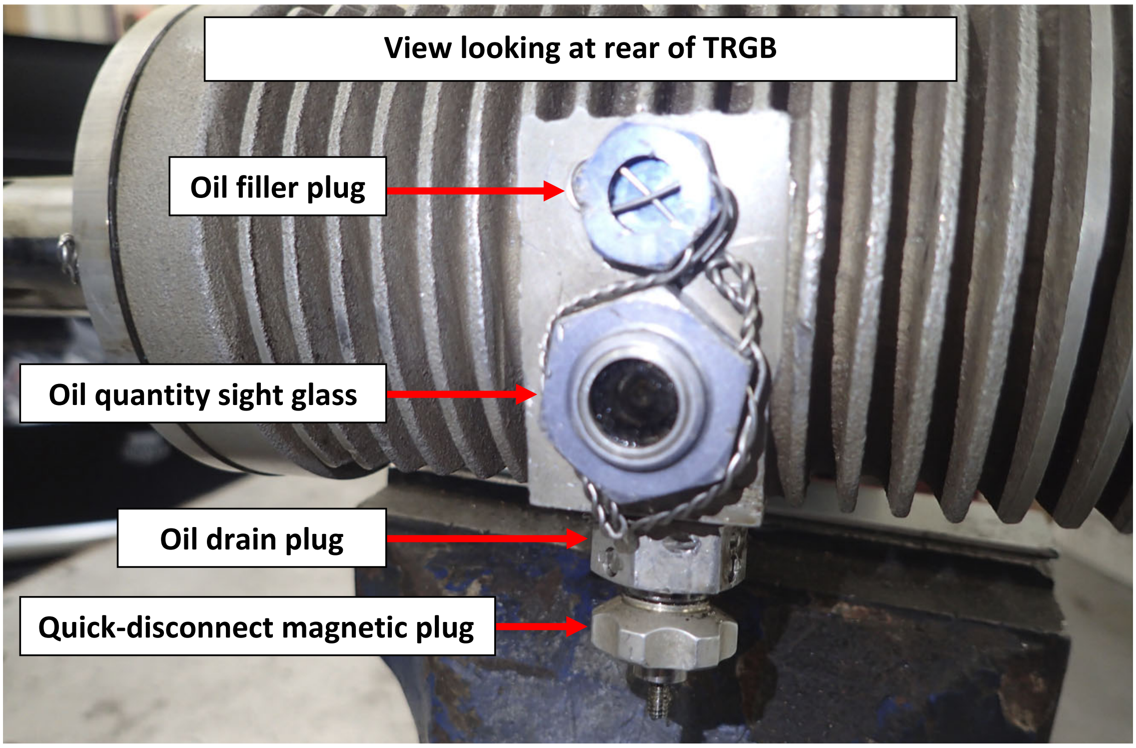

Figure 6
TRGB plugs and sight glass (G-OJBB)

Aircraft examination

Initial examination by pilot and engineer

The helicopter was recovered from the mountain approximately four weeks after the accident, and then transported to its owner's private site. The damage to the helicopter indicated that the main rotors had struck the rear of the tail boom, the tail rotor drive shaft and left rear stabiliser. This had deformed the fuselage, caused the coupling between the main gearbox and tail rotor drive shaft to fail, and severed the upper section of the left vertical stabiliser (Figure 7). The tail rotor blades were intact and their tips undamaged, although one blade had two small indentations adjacent to its leading edge. This was likely to have been caused by the blade striking the severed tip of the left stabiliser.

While the input shaft of the TRGB remained stationary, the output shaft and tail rotor could be turned by hand. The TRGB magnetic plug was subsequently removed and found to be covered in metal particles (Figure 8). The engineer reported that when the plug was initially removed, a few drops of oil dripped from the oil drain plug. The plug was then refitted and the TRGB and tail rotor were sent to the AAIB for detailed examination. Subsequent checks on the helicopter showed that the TRGB CHIP indicator in the cockpit operated correctly when the TRGB magnetic plug connector was electrically shorted to the airframe.

Figure 7
Broken tail rotor driveshaft coupling

Figure 8
TRGB magnetic plug
(Photograph taken shortly after G-OJBB was recovered from Rhobell Fawr)

TRGB examination

The TRGB and tail rotor were free of oil leaks and residue, such as oil staining or splashes on the TRGB case or blades. The TRGB access ports were correctly fitted and appropriately secured with wire locking. The magnetic plug was initially removed to obtain a sample of metallic particles, during which a small amount of oil (about 1 ml) was captured as it dripped from the drain plug. When the magnetic plug was refitted, the oil stopped leaking.

The inside glass of the oil sight glass appeared to be covered in dark brown oil. When the TRGB was tilted forward and backward, it was expected that the appearance of the sight glass would alter, as oil drained away from it, and then covered it over. However, there was no apparent change. The drain plug was then removed, and 16 ml of oil was drained from the TRGB. The oil had a metallic like appearance and when a magnet was passed through it, small metallic particles were evident. Combined with the oil that had dripped when removing the magnetic plug, a total of 17 ml of oil was collected from the TRGB.

Inspection of the bevel gears using a borescope inserted through the inspection port showed that the teeth on both gears exhibited extensive damage, and this allowed the input and output shaft to rotate independently of each other. The TRGB was then disassembled. The shafts, bevel gears, bearings, bearing housings and the internal surface of the TRGB case were coated in an oily sludge which had a metallic appearance.

Following removal of the input and output shaft assemblies, circumferential scoring was evident on the inside of the case, coincident with the position of the heel of the input shaft bevel gear. The scoring on the upper internal surface appeared clean, fresh and free from the oily sludge, while that on the bottom internal surface was coated in the oily sludge.

The teeth on both bevel gears were severely deformed to the extent that they had the appearance of an almost toothless cone (Figure 9).

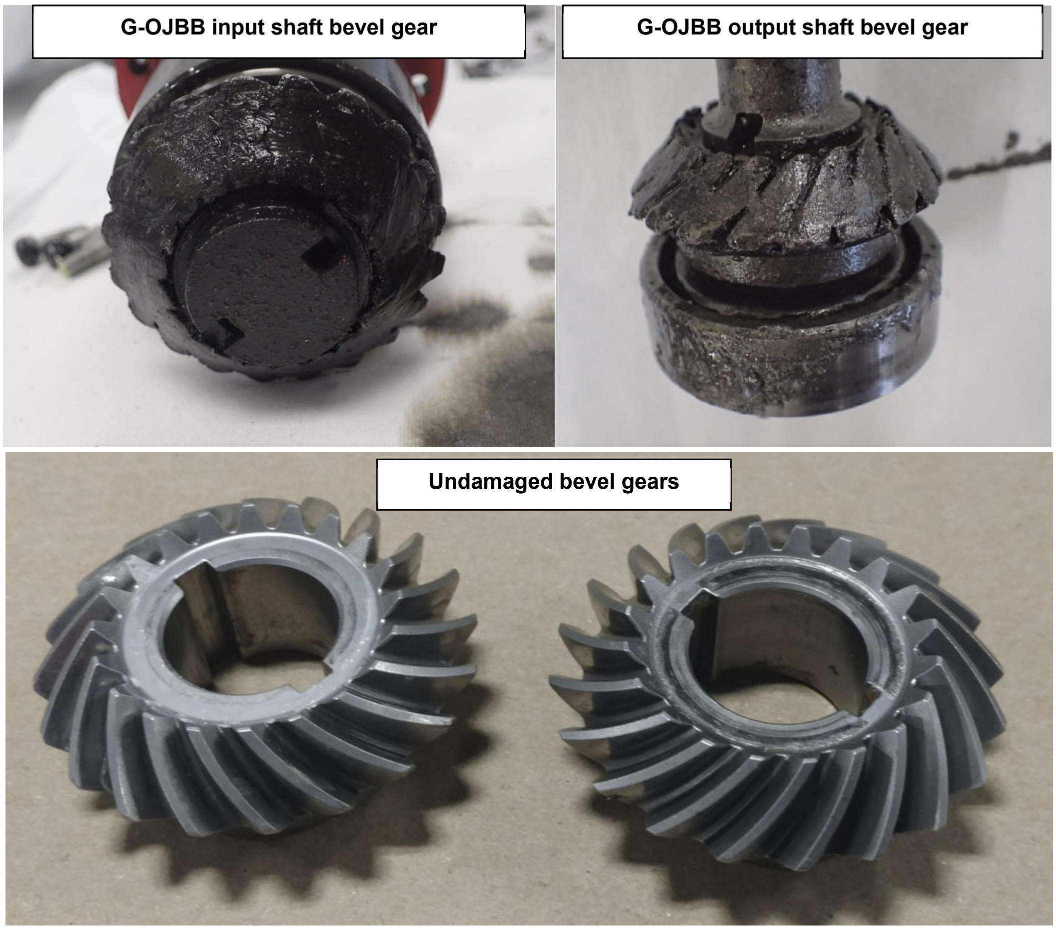

Figure 9

Damage to G-OJBB input and output shaft bevel gears

The two bearings on the output shaft, and the outer bearing on the input shaft, were intact, but felt rough when rotated. The cage of the input shaft, inner bearing had failed such that the 10 balls were no longer symmetrically positioned within the races.

Detailed metallurgical examination

The input shaft bevel gear and the four TRGB bearings were subject to detailed metallurgical examination.

On the input shaft bevel gear, the apexes of the teeth had folded over into the roots and the surface of the gear showed evidence of high temperature oxidation (blueing) in places (Figure 10). The damage to the output shaft bevel gear appeared similar.

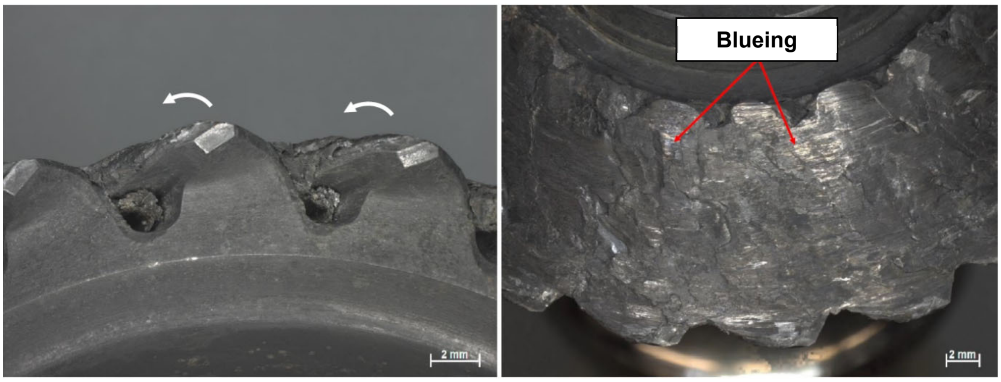

Figure 10
G-OJBB input shaft bevel gear

Input shaft, inner bearing

The bearing was an angular contact bearing having one heavy shoulder (thrust shoulder) and one lighter shoulder (non-thrust shoulder) on the outer race. In the installed position, the thrust shoulder would be on the forward face of the bearing.

Damage was present on the raceway over approximately one quarter of its circumference. The entire circumference of the non-thrust shoulder also exhibited damage (Figure 11).

Figure 11
Outer race of input shaft, inner bearing

Examination of the outer race in the scanning electron microscope (SEM) revealed that the damage in the raceway consisted of tongues of material pushed from the surface and smeared along it. Fragments of a foreign material had also been pressed into the raceway in some areas and Energy Dispersive X-Ray (EDX) analysis showed that it was aluminium. The damage on the non-thrust shoulder was similar but also included fractures, which appeared to have resulted from adhesive wear, with material torn from the surface and then rolled into adjacent areas.

The inner race was damaged around its full circumference, across the rear half of its raceway and rear shoulder. In contrast to the damage observed on the outer race, the inner race damage was heavily oxidised and showed evidence of blueing in places, as well as material tongues rolled into the surface (Figure 12). Material removal in the form of pits was evident in the raceway. The damage on the shoulder was consistent with balls having run along it.

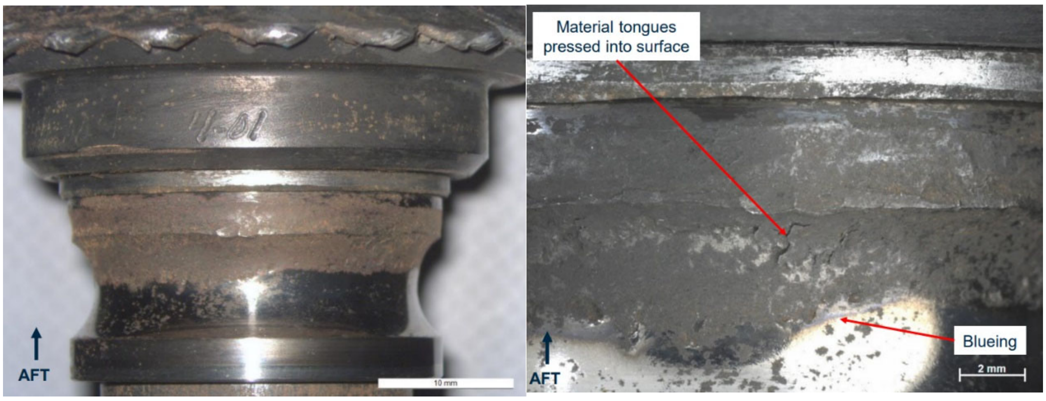

Figure 12

Inner race of input shaft, inner bearing

The surfaces of the 10 balls were deformed, with material removal, surface dents and tongues of smeared material present (Figure 13).

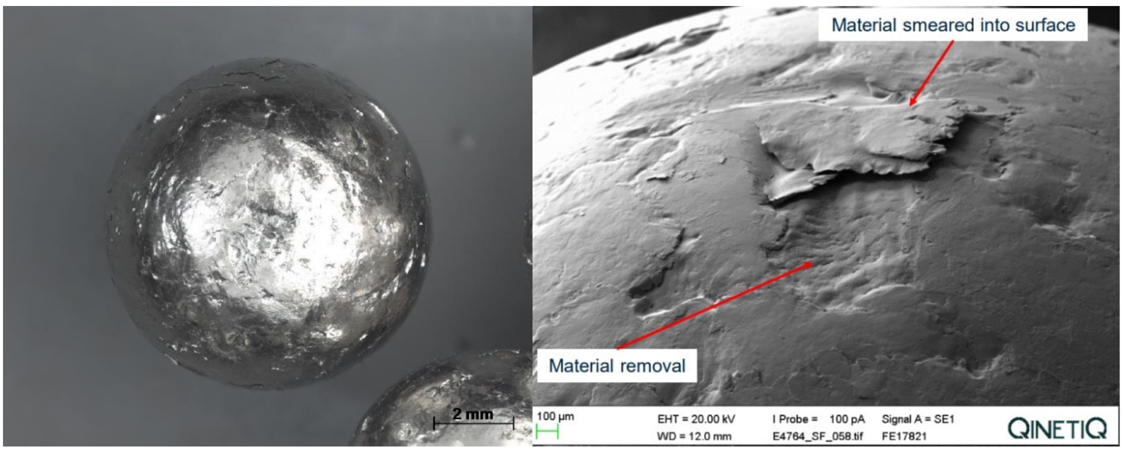

Figure 13

Example of damage to ball from input shaft,
inner bearing (left) and detailed SEM view (right)

The bearing cage is a single-piece cotton-fibre reinforced phenolic resin cage, formed from two faces joined by axial posts. The cage had broken into eight pieces; one piece made up the whole of one face and the remaining seven pieces made up the other face (Figure 14). Material loss was evident on the inner circumference of the face that had broken into seven pieces, but not on the inner circumference of the intact face. SEM examination of one of the fractured axial posts showed cotton fibres present with very little phenolic resin visible. Resin was also missing from the sidewall adjacent to the fracture.

Figure 14
Cage from input shaft, inner bearing

Input shaft, outer bearing

The outer race contained a continual track of damage around the circumference of the bearing raceway, at the edge of the non-thrust shoulder. It consisted of tongues of material pushed into the surface and smeared along it. In some areas, it appeared that the material had spalled from the surface.

The inner race did not exhibit any material loss, although metallic debris had been rolled into the surface and indentations (brinelling) were present.

The cage appeared to be undamaged.

Output shaft, inner bearing

The inner race contained two areas of spalling damage and metallic debris had been rolled into the surface and indentations were present. The outer race had similar indentations and metallic debris as the inner race, but no material loss was evident. The cage had one area of mechanical damage.

Output shaft, outer bearing

Both the inner and outer race were in a similar condition, exhibiting surface indentations and metallic debris rolled into the surface. There was no evidence of spalling or smearing present on either raceway. The cage was undamaged.

Testing of G-OJBB's oil sight glass

Examination of the oil sight glass showed that it had dark coloured deposits of oil present on the inside of the glass (Figure 15). The sight glass was fitted to a test container and oil was then gradually added so that when viewed from the inside of the container, the oil level could be set at just below the sight, at its centre and above it. However, when viewing the oil level from the outside of the sight glass, its appearance did not significantly alter such that it was unclear as what level the oil was inside the container.

Figure 15

Oil quantity sight glass removed from G-OJBB's TRGB

The inside of the sight glass was then cleaned, before re-fitting it to the TRGB case, which had also been cleaned. The case was then sealed, and oil gradually added. As the oil quantity increased, it could be observed through the sight glass. Upon reaching the top of the glass, a bubble was present, but this disappeared on tilting the TRGB back and forth.

Testing of the magnetic plug

When the magnetic plug was circulated in the drained oil from the TRGB, metallic particles would collect on its tip, but did not provide an electrical short circuit path. However, upon agitating the metallic particles on the tip of the plug using air flow, it was possible to establish a short circuit.

Manufacturer's oil quantity measurement trial

Using a representative helicopter, the manufacturer performed a series of tests to ascertain the relationship between actual oil quantity and observed quantity using the TRGB sight glass. The helicopter was level on its skids and a flat sight glass was used during the testing, with the results provided in Table 1.

At an oil quantity of 15 ml and 18 ml, the manufacturer indicated that the oil level would drop somewhat during operation of the TRGB as the oil is splashed and lubricated.

Total oil quantity	Findings
15 ml	The oil level was below the level of the sight glass, and just above the bottom of the window in the adjacent magnetic plug housing. The heels of the bevel gear teeth were in the oil, but the oil level appeared to be below the outer race of the bearings closest to the filler port.
18 ml	The oil level was below the level of the sight glass. The magnetic plug was submerged in oil, but the top of the magnetic plug housing was not.
~ 45 ml	The oil level was just visible in the bottom of the sight glass. The magnetic plug was "thoroughly" submerged in oil.
~ 55 ml	The oil level was at approximately the centre of the sight glass.
~ 65 ml	There was a small bubble in the top of the sight glass.
~ 70 ml	The sight glass was full of oil, and no bubble was present.
~ 160 ml	Oil was seeping out of the filler port.

Table 1

Oil quantity test results

The manufacturer subsequently assessed the effect of the helicopter's attitude on the sight glass oil level, with 18 ml of oil in the TRGB. This was done on an F-28F helicopter, which has the same geometry as the 280FX. The TRGB was fitted with a domed sight glass. With the ground handling wheels extended, the helicopter's tail was 1.3° down from level and the oil was not visible in the sight glass (Figure 16). When the tail was lowered until it was approximately 5.5° below level, the oil level was at approximately the centre of the sight glass (Figure 17). Lowering the tail further to 8° below level resulted in only a slight change in the oil level (Figure 18).

Information from helicopter manufacturer's manuals

Pre-flight checks – TRGB

The manufacturer's Rotorcraft Flight Manual (RFM)[7], Section 4-5 *'Pre-flight inspection-Exterior'*, stated that the TRGB should be checked for oil leaks and oil quantity, with Section 8 *'Handling, Servicing and Maintenance'*, providing guidance on the appropriate oil quantity. This stated: '*The gauge should indicate filled at or near the top of the sight gauge with the aircraft in a relatively level position.*'

The helicopter manufacturer advised that its principal flight instructor also taught that the oil quantity "should definitely be more than three quarters full" on the sight glass.

Footnote

[7] Revision 13, which was extant at the time of the accident.

Figure 16
Helicopter at 1.3° tail-down from level

Figure 17
Helicopter at 5.5° tail-down from level

Figure 18

Helicopter at 8° tail-down from level

The RFM also required that the annunciator panel indicators should be checked on the instrument panel prior to flight, which included the TRGB CHIP indicator as fitted to G-OJBB.

Maintenance requirements – TRGB

The helicopter manufacturer's Maintenance Manual (MM)[8] and MM Supplement (MMS), contained multiple references relating to the servicing requirements and required oil quantity for the TRGB. These included the following:

- MM Section 4-2, *'Description-Servicing'* stated: '*Servicing of F-28/280F series helicopter is normally accomplished at specified hourly intervals.'* For the tail rotor transmission, it stated (in Table 4-1) that the oil quantity was '*5 US Ounces/.15 Litres*' and specified (in Table 4-2) the service interval as '*100 hours/As Required*.'

- MM Section 4-15, *'Servicing Tail Rotor Transmission'* included the following note: '*When the tail rotor transmission is properly serviced (5 oz/.147 l), the sight glass will be completely full. The transmission oil level is serviceable until the oil level is at the center* [sic] *of the sight glass.*' The procedure

Footnote

8 Enstrom F-28 and 280F series maintenance manual, Revision 12, which was extant at the time of the accident.

included advice to raise and lower the tail to '*change the attitude*' of the helicopter, in order to verify the oil level if a bubble was present in the sight glass. It contained the procedural *step: 'Add 5oz./.147l of oil if servicing the transmission after draining or slowly add oil until oil flows from the filler port'.*

- MM Section 4-45, *'Recommended overhaul cycles'* stated that the overhaul period for the TRGB was every '*1200 Hrs*'.

- MMS 25-3, *'Tail Rotor Gearbox Chip Detector'* stated: *'The tail rotor gearbox lubricant should be changed every 100 hours…'.*

Section 4.49 to 4.53 of the MM included periodic inspection checklists to be followed for 50 hr, 100 hr, annual, 200 hr and 400 hr checks.

- MM Section 4-49, *'Periodic Inspection Checklists'* stated: *'Perform a 100 hour inspection as a minimum, to meet the requirements for an Annual inspection'.*

- MM Section 4-51, *'100 Hour/Annual Inspection Guide, Periodic Inspection'* included the following three separate steps for the tail rotor transmission: '*1) Inspect the transmission for leaks… 2) Drain the transmission and inspect the magnetic plug/chip detector for the presence of particles* and *3) Service the transmission*.'

Discussions with the helicopter manufacturer indicated that its intent was for the oil in the gearbox to be replaced every 100 hours or annually, whichever comes first but wording to reflect this did not appear in the MM.

Maintenance requirements – main rotor gearbox

The main rotor gearbox oil quantity is also checked using an oil sight glass. MM Section 4-12, 'Servicing Main Rotor Transmission' stated: *'With the helicopter in a relatively level position, the oil level should be at or near the halfway level of the sight gauge. If oil is visible, no additional oil is required. If oil is not visible, add oil until the oil level is half way up the sight gauge.'*

Metallic chips/particles – MM instructions and guidance

Information regarding metallic particles was provided in MM Section 4-62, *'Main Rotor or Tail Rotor Transmission Chip Indication – Special Instructions'*. This advised that a new or recently overhauled main gearbox or TRGB will often make a magnetic *'fuzz'* which will collect on the magnetic plug as a grey sludge. It described the sludge as *'a mixture of oil and fine metal particles resulting from normal gear operation'* and that this was normal, and the sludge may be cleaned off the plug before refitting it.

If any magnetic particles with a cross section of larger than *'.065 inch/1.65mm'* were found in the main gearbox, or *'.035 inch/.9 mm"* in the TRGB, the aircraft was to be removed from service until further instructions were received from the helicopter manufacturer.

Section 4-62 also stated: *'Sludge normally will not cause a chip indication by itself. There is normally a small particle, flake or sliver on the detector also.'*

MM Section 10-5 *'Tail rotor gearbox'* also provided a troubleshooting guide, that included the following information:

Cause	***Problem***	***Required Action***
Large pieces or slivers of metal flaking from gears or bearings.	*Excessive metal particles on mag plug.*	*Return to factory or overhaul facility for overhaul.*
Fine powdery-type metal can result from normal gear break-in.		*Drain oil from gearbox. Flush with kerosene or equivalent cleaner. Clean map[sic] plug and reinstall. Fill gearbox with oil and recheck mag plug after 10 hours. NOTE: If excessive metal appears at this point, return gearbox for overhaul inspection.*

The MM did not provide photographs that depicted *'excessive metal particles'*, *'fuzz'* or *'sludge'*.

Metallic chips/particles – helicopter manufacturer experience

The helicopter manufacturer's experience of TRGBs returned for overhaul because metallic particles had been found, was that the metallic particles were predominantly from the bearings. It advised that no specific bearing position was more prone to releasing metallic particles than others and, in general, pre-existing maintenance requirements had resulted in the removal of gearboxes from service before a failure could occur.

G-OJBB background and operational experience

G-OJBB was manufactured in 1999. In September 2002, at 371 flying hours, the TRGB was replaced with an overhauled unit provided by the helicopter manufacturer.

The pilot purchased G-OJBB in 2014, when it had about 800 hours flight time, and the TRGB about 430 hours since overhaul. It was thereafter operated from Hawarden Airport, where it was also hangered. At the time of the accident, the helicopter had accrued 1,085 flying hours, and the TRGB 723 hours since overhaul.

Since purchasing G-OJBB, the pilot was the only person to have routinely flown it. During his ownership, he reported that the TRGB had been free from oil leaks, with no maintenance required to top up the oil level between annual services. The pilot also reported that he had not observed the TRGB CHIP indicator illuminate, other than when checking its operation prior to flight.

The pilot reported that his initial walk around checks included checking the TRGB oil quantity in the sight glass. He stated that with the helicopter in a level attitude the oil quantity in the TRGB should "be at the centre of the sight glass", which was what he had been taught since learning to fly in an Enstrom 280C in 1996.

G-OJBB maintenance – TRGB

Recent maintenance

G-OJBB's most recent maintenance inspection was carried out on 7 March 2021, at 1,069 flying hours and 697 hours since overhaul of the TRGB. This was an annual inspection and was performed by the same engineer who had maintained G-OJBB since 2015. The engineer stated that during the inspection, he had completed a "full service" on the TRGB, which he explained included draining and replenishing its oil. This was reflected in the maintenance worksheets for the annual inspection which included copies of the 100 hour / annual checklist from the manufacturer's MM and each of the items relating to the servicing of the tail rotor transmission was signed off. The logbook certificate for the annual inspection included the statement *'100 Hr/Annual inspection carried out in accordance with the Enstrom Maintenance Manual.'*

G-OJBB's Airworthiness Review Certificate was valid until 22 March 2022.

Previous maintenance

The engineer stated that he had also changed the oil in G-OJBB's TRGB during the annual maintenance inspections in August 2015 at 889 flying hours, and October 2017 at 988 flying hours. However, he had not changed the TRGB oil during the annual inspections in August 2016, January 2019, and February 2020 due the low utilisation of the helicopter. He considered that changing the oil was only required every 100 hours of operation and G-OJBB never achieved this in the intervals between annual inspections[9].

The engineer was unable to produce the corresponding worksheets for the annual inspections carried out between 2015 and 2020, advising that they had been lost during a flood of his premises. However, he indicated that he would have recorded the work in the same manner as the 2021 annual inspection, by signing the three checklist items for the tail rotor transmission, on those occasions when the TRGB oil had been drained and replaced, and on those when it had only been checked or topped up.

G-OJBB's signed logbook certificates for each of the annual inspections carried out between 2015 and 2020, contained the statements *'12 monthly inspection carried out in accordance with CAA LAMP(H)2007 Iss1[10]'* and *'100Hr inspection carried out in accordance with Enstrom Maintenance Manual.'*

Footnote

9 Since 2015, G-OJBB's annual utilisation varied between 21 and 52 hours.

10 This refers to the CAA Light Aircraft Maintenance Programme (Helicopters), known as LAMP (H), which has since been discontinued, having been supersede by Part-ML.

Engineer's understanding of and approach to TRGB servicing requirements

When questioned about the servicing requirements for the TRGB, the engineer advised that his understanding was that the TRGB fitted to F-28A, 280, F-28C and 280C models of Enstrom helicopters was to be "fully serviced every 100 hours". He explained that due to the relatively low annual flying hours of private owners, it could be several years before he renewed the oil in the TRGB of those helicopters he maintained. He stated that this was based on his interpretation of the MM and pointed out the MM included instructions to change the TRGB oil every 100 hours. He confirmed that this had been his understanding for many years.

When fully servicing the gearbox, the engineer stated that he would drain and renew the oil, clean the sight glass if required, and check for oil leaks after a ground run. He would also check the magnetic plug and the drained oil for magnetic particles. He described that the drained oil was normally dark brown in colour, and he would filter it through fine filter paper to collect any particles, having thinned the oil using AVGAS. Having refitted the drain plug and sight glass, the engineer would check that the helicopter was level and then, having measured 5 fluid ounces of oil into a measuring jug[11], slowly fill the gearbox via its filler port using a syringe. He would then turn the tail rotor several times, to assist in distributing the oil within the gearbox, before checking the sight glass. He stated that he expected the oil quantity "to be in the centre of the sight glass". He stated that sometimes he would get the entire 5 fluid ounces in the TRGB and sometimes he would not; it depended on the exact orientation of the TRGB.

At an annual inspection, when the helicopter had not flown 100 hours since the last TRGB oil change, the engineer stated that he would check the TRGB for oil leaks, check the magnetic plug for metal particles and check that the oil quantity was "at the centre of the sight glass". He advised that occasionally, a few drips of oil could be lost when the magnetic plug was removed, in which case he would top up the oil quantity. However, he stated that this could result in the oil level then increasing above the centre of the sight glass, and if that happened, he would then drain some oil until it was back at the centre.

When checking the magnetic plug, the engineer advised that he would normally expect to see some "fuzz" on it, which he described as "looking like carbon and had hairlines that are black, not shiny". He stated that he would consider this as normal and clean it from the plug before re-fitting it. Some years previously, the engineer had observed large "metallic flakes" during maintenance of two other Enstrom helicopters. Both those gearboxes were removed from service and sent for overhaul. He stated that he had never seen anything similar when inspecting the magnetic plug from G-OJBB.

The engineer further commented that he found the new style dome shaped oil sight glass easier to read than the flat type fitted to G-OJBB. He also said that during each annual inspection of G-OJBB, he would test the electrical chip detector system by touching the tip

Footnote

[11] The jug used by the engineer was scaled with metric and imperial measurements. The engineer advised that he would normally measure quantities using imperial units.

of the magnetic plug against the gearbox case and checking that the TRGB CHIP indicator illuminated in the cockpit.

Maintenance personnel

The engineer was experienced having started working on helicopters in the 1960's and had attended Enstrom training courses in the late 1980's and 1990's, which included maintenance of 280F series helicopters. He also worked on other helicopter types, which included those manufactured by Robinson and Bell. He held a valid EASA Part 66 category B1 aircraft maintenance licence issued by the CAA which entitled him to work on piston and turbine helicopters. He also held a type rating on the Enstrom 480.

The engineer advised that he had previously owned a maintenance organisation which held Part 145 and Part M approvals, and he had maintained helicopters for flying schools and private owners under these approvals. However, he relinquished the approvals around 2015. Thereafter, using the privileges of his licence, he continued to maintain only those helicopters operated privately.

G-OJBB's owner engaged a separate organisation which held a Part M approval to conduct the annual Airworthiness Review on G-OJBB.

Light helicopter maintenance intervals

CAA position

The CAA General Aviation Unit advised that the accepted philosophy in the industry was 100 hour check items should be accomplished at 100 hours or the annual inspection, whichever comes first. It expected this concept to be commonly understood among licensed engineers.

Regulatory requirements

G-OJBB was historically maintained under the UK CAA's generic Light Aircraft Maintenance Programme (Helicopters), known as (LAMP(H)), as well as the aircraft and engine manufacturers' maintenance inspection schedule. On 24 March 2020 Part M Light (Part-ML) under Regulation (EU) 2019/1383[12,13] came into force as the continuing airworthiness standard for all EASA-regulated general aviation light aircraft (including light rotorcraft) and LAMP(H) became obsolete.

Footnote

12 Regulation (EU)2019/1383 came in as an amendment to Regulation (EU) 1321/2014, known as Part M.
13 This is a retained regulation in the UK following the UK's exit from the European Union and is therefore still applicable at the time of publication of this report.

Prior to its withdrawal, LAMP(H) included the following information on maintenance intervals:

The Maintenance Check Cycle

Check title	Content	Period
Pilot pre-flight	Refer to helicopter flight manual	Prior to every flight
Check A	Check A	Prior to first flight of the day
50 hour check	50 hour check items	Not exceeding 50 flying hours or 6 months, whichever is the sooner
100 hour check	50 and 100 hour check items	Not exceeding 100 flying hours
Annual check	50, 100 hour and annual check items	Not exceeding 12 months

The LAMP(H) generic maintenance schedule contained the following single item for transmission servicing in the *'Annual check/Non-Aligned tasks'* section, which applied equally to the main and tail rotor transmissions.

Transmission Lubrication:

84	Transmission oil change. Oil filter and screens. **Note:** In accordance with type design organisation recommendations. Next due:	SERVICE	100 FH or see Note		

The introduction of Part-ML formally transferred responsibility for all aspects of owning and maintaining an aircraft to the aircraft owner, including development of an Aircraft Maintenance Programme (AMP) that does not require an approval from the CAA. This is known as a Self-Declared Maintenance Programme (SDMP). For many aircraft categories, the owner can decide to base the SDMP either on the manufacturer's recommendations or on the EASA published Minimum Inspection Programme (MIP), as long as the SDMP is not less restrictive than the MIP. All applicable aircraft were required to transition to a Part-ML compliant AMP not later than 24 March 2021.

Part-ML does not contain a MIP for rotorcraft and therefore the SDMP must be based on the continuing airworthiness instructions issued by the Design Approval Holder (DAH). Any deviations from the DAH's maintenance recommendations must be documented in the SDMP. G-OJBB transitioned to an SDMP in August 2020, and it was based on the helicopter and engine manufacturer's recommended maintenance schedule. No deviations were documented.

When creating G-OJBB's SDMP the engineer stated that he did not include a documented deviation from the manufacturer's recommended 100 hour/annual inspection checklist, because in practical terms there was no change to the work he had been doing for many years and he believed his interpretation of the maintenance interval was correct. He considered there would be no change to this under the SDMP.

For other aircraft categories which do have a MIP included in Part-ML, the MIP contains the following information with regards to maintenance intervals: *'To be performed at every annual/100 h interval, whichever comes first.'* In the absence of a MIP, no equivalent wording appears in Part-ML relating to light rotorcraft.

Manufacturer position

The helicopter manufacturer indicated that as the checklist for the 100 hour/annual inspection contained an item requiring the TRGB to be drained and refilled, in order to complete an annual inspection in accordance with its instructions, the oil must be changed. It considered this checklist item could not be signed off without completing the step. As many privately owned aircraft never achieve 100 flying hours within a calendar year, the manufacturer stated its intent was that this task would be completed at whichever maintenance interval comes first. The helicopter manufacturer was not aware of this issue having arisen before.

The helicopter manufacturer also indicated that under the FAA airworthiness regime, every aircraft is required to have an annual inspection for renewal of its certificate of airworthiness. The MM Section 4-49 indicated a 100 hour inspection should be completed as a minimum to meet the requirements for an annual inspection.

With specific regards to the implications of the TRGB oil not being replaced for several years, even if the aircraft was below the 100 hour threshold, the helicopter manufacturer advised that more frequent servicing provides more opportunities to identify any problems, defects or degradation within the TRGB. Furthermore, if the extended interval between servicing was due to a prolonged period of disuse, oil would run off the top half of the TRGB bearings and they may become susceptible to corrosion. No other specific issues were identified.

When queried about the engineer's practice of filling the TRGB until oil was halfway up the sight glass, the helicopter manufacturer advised that in its experience, as long as you see oil in the sight glass, it should be enough to provide lubrication. At half sight glass, the TRGB is airworthy, but it is at the bottom limit of what is acceptable and provides no contingency, such as in the case of minor leakage from the internal seals.

Previous event

On 7 July 1994, an Aerospatiale AS355F1 helicopter, registration G-SASU, was performing an air test following maintenance, when the TRGB chip detector warning light illuminated. The aircraft yawed left while also rolling violently to the right, but the pilot was able to regain sufficient control to land the helicopter safely. The AAIB investigation[14] of this incident identified that oil had leaked out the TRGB during maintenance, but this had gone undetected as the oil sight glass was darkly stained, providing an illusion that the oil level was satisfactory. The TRGB had subsequently overheated and damage within the TRGB led to a loss of tail rotor thrust.

Footnote

14 https://www.gov.uk/aaib-reports/aerospatiale-as355f1-ecureuil-ii-g-sasu-7-july-1994 [accessed 30 August 2022].

Analysis

Introduction

When G-OJBB's TRGB was drained at the AAIB facilities, approximately 17 ml of oil was recovered. This was substantially less than the required amount specified by the helicopter manufacturer and would have been insufficient to lubricate and cool the TRGB bearings and bevel gears. Physical evidence from the examination of the TRGB examination was consistent with failure of the input shaft inner bearing due to overheating, resulting from a lack of lubrication.

TRGB failure

Reduced lubrication would have caused increased friction in the rolling elements of the bearings, resulting in excessive temperatures. Evidence of overheating (blueing) and oxidation on the inner race of the input shaft inner bearing indicated that the bearing had been running hot. An absence of similar indications on the outer race suggested that the inner race was running hotter than the outer race; possibly because the outer race was in contact with the TRGB casing that is air cooled. The bearing cage showed evidence of resin loss, indicating that it had likely exceeded its maximum operating temperature of 107 ºC. This would have made the cage brittle. Increased drag on the cage by the balls due to a lack of lubrication is likely to have caused the cage to fail, especially in its embrittled condition. The final failure may have been precipitated by the higher loads that would have been placed on the transmission as the pilot brought the helicopter into the hover.

Once the bearing cage had failed, the balls within the bearing would no longer be separated or equally spaced. This would allow contact between adjacent balls (with an associated increase in friction and temperature), unequal loading, and damage to both the raceways and balls. Damage observed on the shoulders of both raceways provided evidence that the balls had moved out of the raceway. Either this, or grouping together of all the balls, is likely to have caused the input shaft to move out of axial alignment. Loss of alignment would alter the normal engagement of the input and output bevel gears so that they could move apart. This in turn would result in increased contact between the tips of the teeth, leading to skipping and deformation. When the deformation progressed to the extent that the gears were effectively 'toothless' (Figure 7), there would have been no effective connection between the TRGB input and output shafts. At this point, the anti-torque thrust from the tail rotor would have been lost, resulting in the rapid rotation of the helicopter and subsequent loss of control.

Examination of the remaining TRGB bearings showed that two of the three exhibited a similar pattern of spalling and smearing damage as the input shaft inner bearing but were at a less advanced stage of degradation.

Magnetic plug chip detector operation

The metallic fragments in the TRGB oil would have been created when ferrous bearing material was liberated as a result of spalling during the bearing failure sequence. From the photograph of the magnetic plug taken shortly after the helicopter was recovered (Figure 6) and from the extent of damage subsequently found within the TRGB, it was considered that the TRGB CHIP indicator light in the cockpit should have illuminated. However, the pilot reported that he had not seen it illuminate during either the accident flight, or any preceding, flight.

Testing of the indicator light and associated wiring to the plug by the engineer did not identify a fault in the system. The AAIB found during testing that when the magnetic plug was drawn through the TRGB oil to collect metallic particles on its tip, a short circuit path was not established. However, following agitation of the particles, a short circuit was then created. Therefore, it is possible that the TRGB CHIP indicator light did not illuminate because the low quantity of oil found in the TRGB, which may not have been sufficient to submerge the plug when the TRGB was operating, either did not provide sufficient agitation of the particles or did not enable larger debris to reach the plug.

TRGB servicing information in the maintenance manual

The engineer's target fill level when replenishing the TRGB oil was the centre of the sight glass. This differed from the MM Section 4-15 servicing requirement which stated: *Add 5oz./.147 l of oil if servicing the transmission after draining or slowly add oil until oil flows from the filler port'.*

It was not clear how the engineer had come to this understanding, but the investigation considered factors which may have contributed. Of note is that the target oil level for the main rotor gearbox is at the centre of the sight glass, and this may have been a source of confusion. Additionally, MM Section 4-15 included a note which stated that: *'When the tail rotor transmission is properly serviced (5 oz/.147 l), the sight glass will be completely full. The* [tail rotor] *transmission oil level is serviceable until the oil level is at the center* [sic] *of the sight glass.*' The language employed in the second sentence of this note focuses solely on the serviceable condition. It does not draw attention to the point at which the TRGB oil level would become unserviceable, nor contain any cautions or warnings regarding the TRGB oil level. Nor did this section highlight the different target fill levels for the main and tail rotor gearboxes. Therefore, the following Safety Recommendation is made:

Safety Recommendation: 2023-001

It is recommended that Enstrom Helicopter Corporation amends the wording in Section 4-15 of the Enstrom F28F and 280F series Maintenance Manual, to clearly identify the minimum and maximum oil levels required for tail rotor gearbox operation.

The MM was not consistent in the quantity of oil specified for the TRGB, with three differing values quoted: '*5 ounces/.15 litres*', '*5 US Ounces/.15 Litres*' and '*5 oz /.147* l'. Although the difference between 5 US ounces and 5 imperial ounces is less than 6 ml, and which alone would not result in significant underfilling of the TRGB oil level such that it was unserviceable, it could result in less than the optimum amount of oil being added during maintenance. Additionally, inconsistency in the specified quantity could create confusion.

Therefore, the following Safety Recommendation is made:

Safety Recommendation: 2023-002

It is recommended that Enstrom Helicopter Corporation amends the Enstrom F28F and 280F series Maintenance Manual to achieve a consistent reference to the required quantity of oil for the tail rotor gearbox.

100 hour and annual maintenance requirements

The engineer stated that he changed G-OJBB's TRGB oil every 100 hours, indicating that this was his interpretation of the information in the MM. The helicopter manufacturer indicated that the intent of the MM instructions was for the TRGB oil to be replaced every 100 hours or annually, which ever came sooner. However, the MM and MMS did not include specific wording to this effect.

Servicing intervals for the TRGB were specified in the MM and MMS as '*100 hours/As Required*' and '*… every 100 hours*'. While MM Section 4-49, indicated that a 100 hour inspection should be completed as a minimum to meet the requirements for an annual inspection, no equivalent statement appeared in the 100 hour/annual checklist itself.

Up to August 2020 G-OJBB was maintained under the CAA's LAMP(H), which stated that 50 hour, 100 hour and annual check items should be accomplished at an annual inspection. For the task specifically relating to transmission oil change it stipulated a maintenance interval of 100 hours or *'in accordance with the type design organisation recommendations.'* G-OJBB's maintenance programme (SDMP) at the time of the accident was based entirely on the helicopter and engine manufacturer's recommended maintenance schedule.

Part-ML does not define a MIP for light rotorcraft and therefore contains no additional requirements for the periodicity of specific maintenance inspections. The absence of such information in regulation places emphasis on the need for clarity in the manufacturer's maintenance instructions, therefore, the following Safety Recommendation is made:

Safety Recommendation: 2023-003

It is recommended that Enstrom Helicopter Corporation amends the 100 hr/Annual checklist and other related sections of the Enstrom F28F and 280F series Maintenance Manual to clearly reflect the intended periodicity for changing the tail rotor transmission oil.

Based on the engineer's stated approach, G-OJBB's TRGB oil is likely to have been replaced a maximum of three times between 2015 and March 2021, with 41 months between the previous change in 2017 and that in 2021. The manufacturer advised that routine changing of the oil every 100 hours, or every calendar year for low utilisation helicopters, provides more opportunities to identify any problems, defects or degradation within the TRGB. If the helicopter was not flying routinely between oil changes, the TRGB bearings may become susceptible to corrosion. But aside from those issues, it did not identify specific concerns with the cooling or lubricating performance of the oil if maintained at a serviceable level.

Maintenance documents

There were three tasks in the 100 hour/annual checklist relating to the TRGB. The worksheets for the annual inspections between 2015 and 2020 were not available to the investigation, but the engineer advised that he would sign off all three tasks, even on those occasions where he did not drain and replenish the TRGB oil. The signed logbook certificates for the annual inspections between 2015 and 2021 contained a statement that the work had been carried out in accordance with the MM, and no deviation was documented in the SDMP relating to changing the TRGB oil. Therefore, even if the previous worksheets had been available, these would not have provided clarification of when the TRGB oil had or had not been replaced. This information was only available due to the engineer's recollection of having changed the oil and his stated approach to servicing intervals.

March 2021 annual inspection

G-OJBB's most recent annual inspection in March 2021 was carried out four months and 25 flying hours before the accident, during which the engineer stated he drained and replaced the TRGB oil.

The engineer reported that he had not been alerted to anything unusual when he examined the magnetic plug and the drained oil. He stated that he normally expected to see some "fuzz" on the magnetic plug, which he described as "looking like carbon and had hairlines that are black, not shiny". The MM described that TRGBs in normal service may generate fuzz or grey sludge which was a mixture of oil and fine metal particles. The findings of the engineer appear consistent with the MM information, but the MM did not contain any images which may help identify the different types of metallic particles or debris.

Based on the available information, since 2015 when the engineer had started servicing G-OJBB, the TRGB had been operated with an oil level which was at, or close to the centre of the sight glass. This was at, or close to, the level below which the helicopter manufacturer considered the TRGB oil level to be unserviceable. Despite this, and the infrequent changing of the oil, there was no reported evidence that it had resulted in anything other than normal wear products being apparent on the magnetic plug, up to and including the annual inspection in March 2021.

The engineer described his approach to refilling the TRGB as measuring 5 imperial fluid ounces (142 ml) into a measuring jug and then using a syringe to add oil through the filler port. In aiming to achieve an oil level at the centre of the sight glass (which the helicopter manufacturer indicated to be about 55 ml), this would result in a substantial amount of oil being left in the jug.

Following the accident approximately 17 ml of oil was recovered from the TRGB. This was 130 ml (88%) less than the amount specified in the MM and 38 ml (~70%) less than the 55 ml required to fill the oil level to the centre of the sight glass. There was no evidence of oil having leaked from the TRGB at any point prior to or after the accident, other than a few drops when the magnetic plug had been initially checked, which raised the possibility that on this occasion, the engineer added even less oil than he was normally accustomed to doing.

The sight glass was found to be covered in dark deposits. Testing showed that in this condition, it did not provide a clear indication of the actual oil level. The engineer could not recall if he had cleaned the sight glass during the annual inspection. If not, it is possible that the deposits on the glass affected the engineer's ability to read the oil level. Several similarities were noted with a previous serious incident investigated by the AAIB on another helicopter type, which resulted in an insufficient quantity of oil in the TRGB. In that case the sight glass was darkly stained and gave the illusion of a satisfactory oil level.

The flat sight glass fitted to G-OJBB was acknowledged by the engineer and the helicopter manufacturer to be more difficult to read than the domed style sight glass fitted to some Enstrom helicopters. However, when the sight glass from G-OJBB was cleaned and tested, the oil level was apparent.

Pilot's understanding of oil level and measurement

The pilot stated that since learning to fly an Enstrom 280C helicopter in 1996, he had been taught that the TRGB oil level was to be at the centre of the sight glass. It was not established why this misunderstanding came about, although one possibility is that the check had inadvertently been aligned with the main rotor transmission oil level, which is to be at the centre of the sight glass.

With 18 ml of oil in the TRGB, an amount close to that recovered from the TRGB after the accident, the manufacturer demonstrated that the helicopter's tail would have to be about 5.5° below level, in order for the oil level to be at the centre of the sight glass. At this attitude, the helicopter is noticeably nose-high/ tail-low (Figure 17) and the skids no longer parallel to the ground. The pilot did not report having to lower the helicopter's tail more than normal when checking the TRGB oil level following its return from the annual inspection in March 2021. However, if deposits had been present on the sight glass, this may have affected the pilot's ability to correctly read the oil level and may explain why he did not identify the low oil level during pre-flight checks.

Conclusion

The helicopter suffered a loss of tail rotor drive close to the ground, following a failure of the TRGB. The quantity of oil found in the TRGB was insufficient to have provided adequate cooling and lubrication of its bearings and gears. This led to the break-up of one of the internal bearings and ultimately to a loss of output from the TRGB. There were several inconsistencies between the way maintenance was performed on the TRGB and the prescribed procedures in the maintenance manual.

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