Technical report

A-031/2021

Accident on 11 July 2021 involving a Bell412 helicopter operated by Rotorsun, registration EC-MTS, in Ejea los Caballeros (Zaragoza-Spain)

Please note that this report is not presented in its final layout and therefore it could include minor errors or need type corrections, but not related to its content. The final layout with its NIPO included (Identification Number for Official Publications) will substitute the present report when available.

GOBIERNO DE ESPAÑA

MINISTERIO DE TRANSPORTES Y MOVILIDAD SOSTENIBLE

SUBSECRETARÍA

COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

NOTICE

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission regarding the circumstances of the accident that is the object of the investigation, its probable causes, and its consequences.

In accordance with the provisions of Article 5.4.1 of Annex 13 of the International Civil Aviation Convention, Article 5.6 of Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010; Article 15 of Law 21/2003 on Air Safety; and Articles 1 and 21.2 of RD 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent their recurrence. The investigation is not intended to attribute any blame or liability, nor to prejudge any decisions that may be taken by the judicial authorities.

Therefore, and according to the laws specified above, the investigation was carried out using procedures not necessarily subject to the guarantees and rights by which evidence should be governed in a judicial process.

As a result, the use of this report for any purpose other than the prevention of future accidents may lead to erroneous conclusions or interpretations.

This report was originally issued in Spanish. This English translation is provided for information purposes only.

CONTENTS

ABBREVIATIONS

ºC .... Degrees Celsius
%.................................. Per cent
AD .... Airworthiness directive
AEMET.......................... Spain's State Meteorological Agency
AESA .... Spain's National Aviation Safety Agency
AFCU .... Automatic fuel control unit
ATC .... Air traffic control
CMM .... Component maintenance manual
CPL(H) .... Commercial helicopter pilot license
EASA .... European Aviation Safety Agency
ft.................................... Feet
FCU............................... Fuel control unit
h .... Hours
HUET .... Helicopter underwater escape training
GS................................. Ground speed
Inch-lb .... Pounds per inch
kt .... Knots
m .... Metres
MM .... Maintenance Manual
MDCU .... Manual fuel control unit
min .... Minutes
N1 .... Compressor or gas generator turbine speed (N_G)
N2 .... Power turbine speed
NR................................. Rotor speed
Nm .... Newton-metres
p/n................................. Part number
rpm................................ Revolutions per minute
s .... Seconds
s/n .... Serial number
SPM .... Standard practice maintenance manual
TLU .... Torque limitation unit
VFR............................... Visual flight rules
VMC .... Flight visual meteorological conditions

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Owner and operator:	Rotorsun
Aircraft:	Bell Helicopters Textrom Bell412, EC-MTS
Date and time of incident:	Sunday, 11 July 2021; 20:04 local time[1]
Site of accident:	Ejea de los Caballeros (Zaragoza-Spain)
Persons on board:	2 (crew, unharmed)
Type of flight:	General aviation – commercial – firefighting
Phase of flight:	Manoeuvring
Flight rules:	VFR
Date of approval:	25 October 2023

Synopsis

On the afternoon of Sunday, 11 July 2021, the Bell412 helicopter, registration EC-MTS, operated by Rotorsun, was mobilised with 12 people on board to intervene in a fire that had broken out 8 km from its base in Ejea de los Caballeros (Zaragoza). The helicopter took off at 19:54 local time, made an intermediate landing at 19:59 to drop off the fire brigade, and then took off again to head for the Estanca del Charco reservoir, where at 20:03 it began manoeuvres to check the operation of its helibucket while hovering. During these stationary manoeuvres the helicopter appeared to have problems remaining airborne and, at 20:04, the gearbox disconnected from the main driveshaft, causing the helicopter to plummet into the water.

The investigation has ruled out a causal link between the issue with maintaining a hover and the disconnection of the driveshaft, concluding the following:

- With regard to the inability to maintain a hover, the origin of the problem could not be determined, although technical problems have been ruled out.
- With regard to the disconnection of the driveshaft, the cause was found to be at least one of the six threaded joints, which had been operating without a self-locking nut as a result of inadequate maintenance instructions and practices. These maintenance instructions and practices also affected the other threaded joints, degrading the tightening torque and contributing to the complete failure of the transmission.

The investigation has concluded that the accident was caused by an in-flight loss of control of the helicopter following the disconnection of the main driveshaft from the gearbox due to a loss of integrity in the six threaded joints that held them together. This, in turn, occurred because at least one of them had been operating without a self-locking nut, and the remainder were in a deteriorated state due to loss of tightening torque.

[1] All times used in this report are local time, as extracted from the fleet tracking system.

The following main driveshaft maintenance instructions and practices are considered possible contributing factors to the accident:

- The reuse of threaded joint elements.
- The lack of a tare torque check, as a requirement for the reuse of the nuts, in the maintenance procedure.
- The operator's tare torque verification practices.

The report contains five safety recommendations: two addressed to the manufacturer of the helicopter and three to the operator.

1. THE FACTS OF THE INCIDENT

1.1. Overview of the accident

On the afternoon of Sunday, 11 July 2021, the Bell412 helicopter, registration EC-MTS, operated by Rotorsun, which was at its base in Ejea de los Caballeros (Zaragoza), was mobilised for the second time that day to assist in extinguishing a fire that had broken out 8 km away at a 'Clean point' (a waste recycling and disposal site) on the outskirts of the town.

The helicopter, carrying a total of 12 people (9 fire brigade members, 1 nature protection officer and 2 pilots), started its engines at 19:50, took off at 19:54 and flew to the fire zone, where it dropped off the fire brigade without incident at 19:59. The brigade deployed the helibucket, and the helicopter took off again at 20:01 towards the Estanca el Gancho reservoir, to the south of the municipality of Ejea de los Caballeros, to load the water.

The operator's procedures state that at the start of each mission, the operation of the helibucket has to be tested by filling it with water and releasing it, and once this test has been completed satisfactorily, the helicopter is ready to load and proceed to the fire.

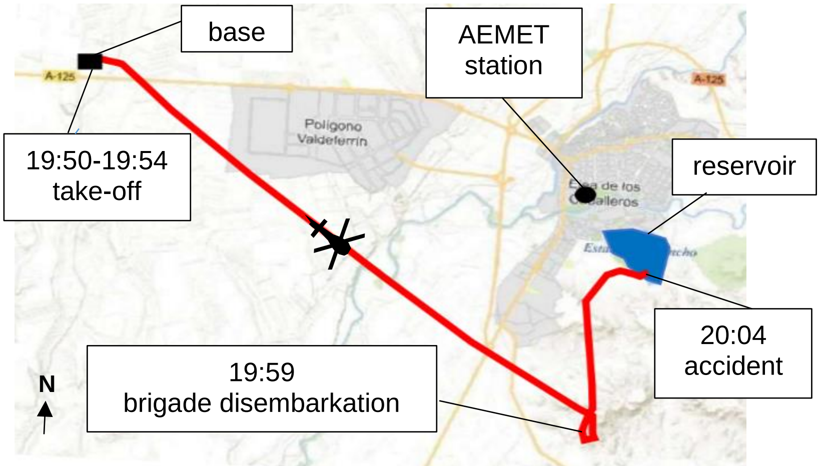

Figure 1. Complete flight path (19:50-20:04)

The accident, which was reported as a loss of power, occurred at 20:03 while the helicopter was hovering over the reservoir to check the helibucket operation. The description given by the crew was as follows:

- Prior to initiating the manoeuvre, everything was normal. The second pilot recalled checking that the NR and N2 values of the two engines were at 100%. The pilot flying was the commander and remained in command during the emergency.
- They lowered the helibucket into the water to load it. They lifted it out of the water and noticed the NR revolutions drop to 94%. Both pilots reported that "all three needles (NR and N2 on both engines) dropped in unison". Immediately the low rotor speed warning[2] and an overtorque warning appeared, which was mentioned by the commander, but not by the co-pilot.
- They released the water from the helibucket and reduced power, descending slightly and getting the warnings to disappear momentarily. The helicopter managed to climb back up a

[2] The LOW RPM warning is triggered when the NR is below 95%. This alert consists of both a visual and an aural warning.

couple of metres, but as the commander described, the NR only reached 97%, so he activated the "increase[3]" switch without getting any improvement.

- Faced with this situation, the commander began to look for a landing site but didn't think it was necessary to release the helibucket. He was assessing his options (to the right and ahead was a footpath with lampposts, to the left was the centre of the reservoir and if they turned to the rear they would have to deal with a strong tailwind) when the rotor revolutions began to drop again, and the helicopter descended, impacting the water at 20:04. The readings they recalled were NR 85-90% shortly before contact was made.

The entire manoeuvre was conducted into the wind, which they estimated to be between 15-25 kt and from the north, with downwash effect on the water. Two witnesses recorded the event with their mobile phones. These videos confirmed the two ascent-descent cycles and the loading and release of water described by the crew.

After contact with the water, the helicopter remained upright for a few seconds and then rolled onto its left side. The helicopter was partially submerged in a shallow area (3-4 metres). The two pilots escaped from the aircraft unaided and without sustaining any injuries.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatalities				
Serious				
Minor				
Unharmed	2			
TOTAL	2			

1.3. Damage to the aircraft

Externally, the helicopter sustained minor damages as a result of the initial impact with the water and being submerged in the water four days before it was recovered.

1.4. Other damages

None.

1.5. Information about the personnel

1.5.1 General

The 59-year-old captain had a valid CPL(H) licence and Bell412 rating valid until May 2022. He had a total of 4,290 hours of flight time and had been working in firefighting since 1990 and for Rotorsun since 2020, flying firefighting flights only. The day of the accident was his first day flying at this base, but he had flown the previous season at the Ejea de los Caballeros base, so he was familiar with the area.

[3] The term "increase" refers informally to the INCR/DECR switch located on the collective, which acts on the N2 governor to regulate the N2 speed between 97% and 101.5%. If the N2 is below 97%, the switch will not work. This is achieved through the AFCU as explained later in this document.

The second pilot, aged 36, had a CPL(H) licence and Bell412 rating valid until April 2022. He had 1,550 hours of flight time, of which 1,350 hours were in type. He had worked three firefighting seasons and had been working for Rotorsun since 2020, flying firefighting flights only. He had been at the Ejea de los Caballeros base since March, flying the accident helicopter.

1.5.2 Helicopter underwater escape training (HUET)

Both pilots stated that they had completed the HUET at the SASEMAR training centre in Jovellanos and had received theoretical training at ROTORSUN. They felt they were adequately trained to deal with the emergency and that it was, in fact, less extreme than the scenarios taught in the course.

1.5.3 Previous activity

The commander had been on duty for 11 days (110 hours of service), with a total of 6:25 hours of flight time. The second pilot had also been on duty for 11 days with a total of 9:55 hours of flight time. Both had rested for more than 12 hours prior to the day of the accident.

Because firefighting activity at the Ejea de los Caballeros base requires physical presence, they had been at the base since 10:30 am on Sunday 11 July, along with the fire brigade and the mechanic. The first task they undertook that day was to review the documentation, do the planning, check the operating limitations and the operational status of the helicopter, and brief the brigade. The pre-flight check of the helicopter was also conducted by the pilots, as the assistant mechanic at the base was not qualified to do so. On that day they had been deployed to another fire at 11:37 and worked on it for 1 hour.

They dismissed the possibility that they were distracted or fatigued at the time of the event. They also described the workload as normal.

1.6. Information about the aircraft

1.6.1 General

The Bell412 helicopter, s/n 36050, was built in 1992. Based on its current configuration, it was equivalent to a Bell412 EP. Its empty weight was 3,432 kg, and its maximum weight was 5,398 kg. It was fitted with two Pratt Whitney PT6T-3DF Twin Pac turbine engines, s/n TH0740 (engine 1), s/n TH0741 (engine 2) and a combining gearbox, part of the powerplant, s/n TJ0022. At the time of the event, the airframe had accumulated 12,463 h, the two engines 5,624 h and the gearbox 6,335 h.

The helicopter has been owned by Rotorsun since 2016. At the time of the accident, it was used for firefighting operations, based in Ejea de los Caballeros (Zaragoza), and was fitted with a helibucket with a capacity of approximately 1,000 kg, and the cable of which extends for 6 m when deployed.

In addition to being the owner and operator, Rotorsun manages the airworthiness control (ES.MG.101) and maintenance (ES.145.205) of the aircraft it owns, including the helicopter involved in the accident. The helicopter's maintenance programme was approved by AESA and provided for periodic checks daily, every 25-100-300-600-1000-5000 h and/or every 1-12-60 months.

1.6.2 Power transmission

The Bell412 EC-MTS helicopter is powered by two Pratt and Whitney engines mounted in parallel and connected to a gear reduction box, called a gearbox, which is part of the powerplant. This whole engine and gearbox assembly is called a Twin Pac. The gearbox, which has its own lubrication system, has the task of reducing the N2 rotational speeds of the turbines from 33,000 rpm to the 6,600 rpm it delivers to the main driveshaft.

The main driveshaft, driven by the gearbox at 6,600 rpm, is, in turn, connected to the transmission. From the transmission the power is transmitted to the main and tail rotors. The shaft is housed in a fire bulkhead, as shown in figure 2.

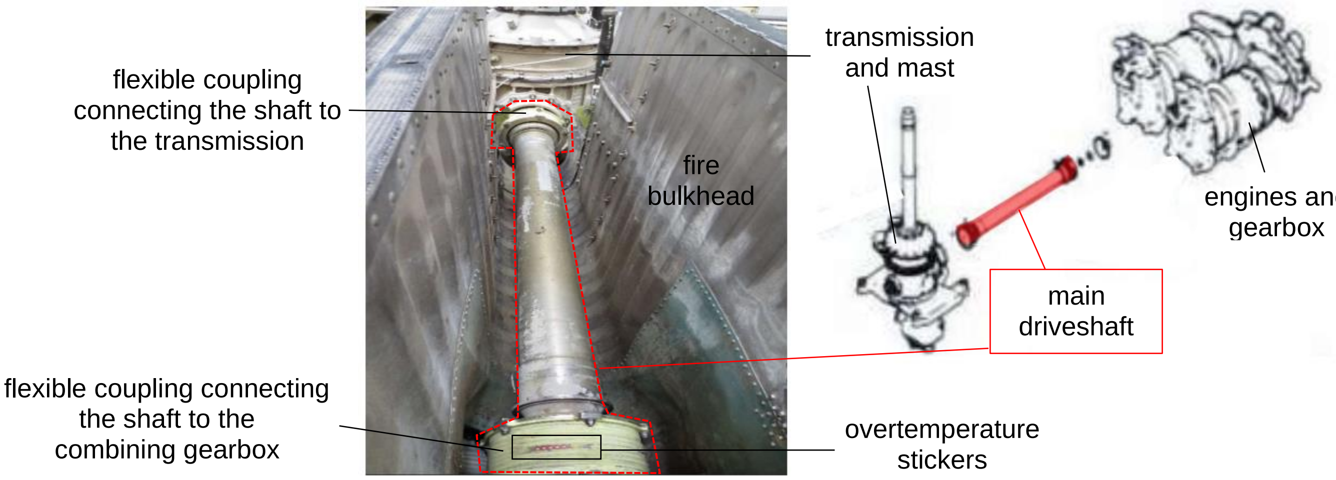

Figure 2. Main driveshaft

The main driveshaft is, therefore, connected at one end to the gearbox (via an adapter) and at the other end to the transmission. To absorb vibrations and allow a certain amount of play between these elements (gearbox-shaft-transmission), the ends of the driveshaft have greenish flexible couplings (figures 2 and 3), which are connected with 6 threaded joints consisting of a bolt-washer-self-locking nut system on each flange. In total, each coupling requires 12 joints, and the complete shaft requires 24. In these threaded joints, between the washer and the part, the counterweights that might be needed to balance the shaft are installed. In this case, the assembly would then look like this: bolt-washer-counterweight-part-nut. This balancing must be carried out each time the shaft is uninstalled (according to Maintenance Manual BHT-412-MM). There are also stickers that detect overtemperature in the coupling by changing the colour of their circles (from white to black).

In the EC-MTS helicopter accident, the flexible coupling connecting the main driveshaft to the gearbox was found to be disconnected, and the 6 threaded joints on that flange had separated.

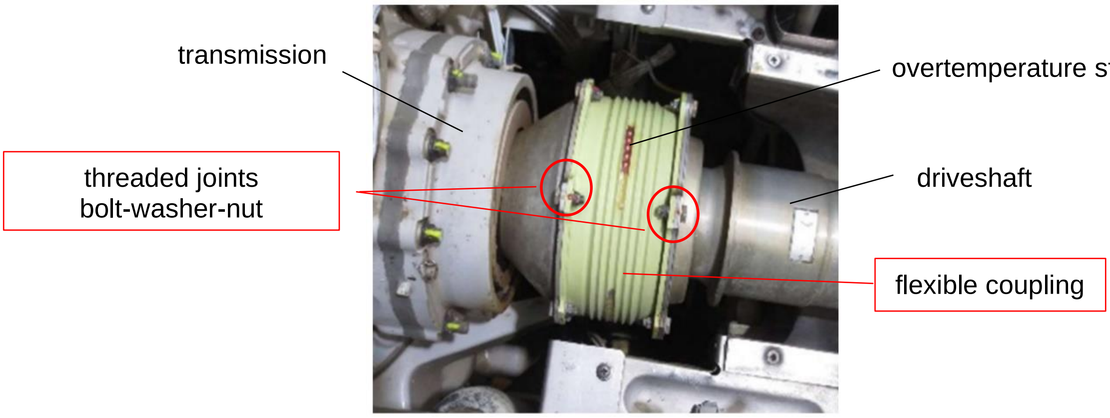

Figure 3. Flexible coupling of the main driveshaft

1.6.3 Maintenance of the main driveshaft

The manufacturer, Bell, requires maintenance of the power driveshaft every 600 h or 12 months, and this was included in the maintenance programme approved by AESA. To carry out this maintenance, the Maintenance Manual (BHT-412-MM) requires the disassembly of the shaft, for which the 24 bolt-washer-nut threaded joints mentioned in section 1.6.2 must be removed (figure 3).

The maintenance instructions included in the Maintenance Manual (BHT-412-MM) specify a torque value of 70-90 in-lbs (7.91-10.16 Nm) for this joint but do not contain any warning as to what checks need to be performed in order to reuse the disassembled threaded joint elements. In other words, according to the Maintenance Manual, the bolts, nuts and washers can be reused indefinitely if no defect is detected, with no mention of checking the tare torque.

However, in addition to the Maintenance Manual, there is another document, the Bell Standard Practices Manual (BHT-ALL-SPM), which specifies the following[4]:

- Self-locking nuts may only be reused if the tare torque is checked using the following procedure:
  a) the tare torque must be measured on the same combination of elements,
  b) a dial indicator must be used,
  c) it should be measured when the nut has run through all threads, and
  d) if the measured torque is less than the tare torque, the element must be rejected.
- The tare torque depends on the characteristics of the bolt thread, and in the case of the EC-MTS bolts (1/4-28), the tare torque was 3.5 in-lbs (0.40 Nm).

In other words, in order to be able to reuse the self-locking nuts installed on the driveshaft, a tare torque of 3.5 in-lbs (0.40 Nm) must be measured beforehand to ensure that the nut still has its locking or friction capacity. Once checked, the assembly torque should be applied.

[4] A third installation criterion is also included, which is that the total assembly torque for the self-locking elements is the sum of the specific torque (70-90 in-lbs) and the tare torque (3.5 in-lbs). In this case, the assembly range of the specific torque would encompass the tare torque, and therefore this aspect is not considered to be of influence in this accident.

In meetings with the operator, it was confirmed that this tare torque check was carried out qualitatively, based on the friction provided by the nut when it was screwed on, and that the standard practice manual (SPM) was not consulted.

1.6.4 History of directives concerning the self-locking nuts

The nuts fitted to the main driveshaft of the Bell412 had a history of changes that began after the discovery of fractures in some nuts due to the brittleness of the material they were made from. This problem gave rise to an EASA airworthiness directive (EASA AD2014-0118) and a series of Bell service bulletins (ASB412-14-160) mandating that the nuts be replaced.

Consultation with the manufacturer and the national and European incident reporting repositories yielded no information on cases similar to the EC-MTS event. The fractured nuts were discovered during maintenance checks but had not caused any power transmission problems in operation.

1.6.5 Engine control

Under normal conditions, the total power required for flight is delivered by both engines equally. The system is designed to maintain the NR at a constant value using the two power turbines (N2). Gears connect the N2 and NR. N2 is maintained by the two fuel control units (FCU), one per engine, which control the fuel injected into the combustion chambers. These units can operate in automatic or manual mode, the standard mode of operation being automatic (AFCU), which was the mode that was activated during the accident.

When operating in automatic mode (AFCU), the fuel control is dependent on the following input information (the first three come from the pilot's controls):

- The throttle position, which affects the N1 governor.
- The rpm INCR/DECRE control, which adjusts the N2 governor.
- The collective position, which adjusts the N2 governor.
- The N2 governor, which controls P_G.
- The TLU, which modifies P_G.
- The NR changes, which affect the N2 governor.
- The N1 governor, which modifies P_Y[5].

With all these elements, in the event of a drop in NR, the system would react as follows: the drop in NR would be transferred to the shafts of the N2 power turbines; this drop in N2 would be detected by the N2 governor in each engine, which would generate an increase in the P_G pneumatic signal; this signal would be sent to the AFCUs in order to increase the fuel and consequently produce an increase in N1 and N2, which, in turn, would increase NR.

In addition, the torque provided by the two engines is monitored by the torque limiting unit (TLU) to protect the integrity of the main transmission. This unit kicks in when the torque at the mast reaches 108-109%. In other engines, the TLU is also responsible for the balancing and torque control of both engines, but the EC-MTS helicopter doesn’t have this function.

[5] The pressures P_X, P_Y P_G y P_R are pressures derived from P_3. The FCU uses these pressures to control the fuel.

1.6.6 Activity on the day of the accident

The accident flight was the second flight of the day. That morning, at 11:37 am, the helicopter was mobilised to another fire, carrying out 3 water drops. According to the crew, the NR revolutions also dropped on that first flight, but the LOW RPM warning wasn't activated and pressing the "increase" switch managed to get them back to 100%.

After the first flight of the day, the aircraft was refuelled with approximately 1,630-1,650 lb of fuel, the post-flight check was conducted, and the aircraft was left ready for future mobilisations.

1.6.7 Information about the aircraft from the interviews

The co-pilot, who had been flying the EC-MTS helicopter at the base since March, indicated that there had been no operational problems.

The commander, interviewed twice, described the need to use the "increase" on that morning's flight but noted that they didn't detect any other issues. It was his first day at the base, so it was also his first day flying this particular aircraft.

Another commander who had flown the EC-MTS helicopter the previous day and had been at the base for 10 days was interviewed. He also reported having no operational problems. The only thing he mentioned was having a torque needle separation of more than 4% (this was identified in the April 2021 flight report).

The assistant mechanic, who was permanently present at the base, also reported no previous problems with the helicopter. However, his role at the base was to check levels, assist with start-ups, refuelling and daily checks of the fuel tank. He didn't perform maintenance activities per se, but if any problems occurred, he contacted the certifying mechanic.

The certifying mechanic, who was also interviewed, attended the inspections that are carried out every 25 hours. The last time he had been at the base was on 2 July, 9 days before the accident. He described the maintenance and operational status of this helicopter as good.

1.6.8 Notes in the flight logs

A year of flight logs were reviewed to check the notes made by the crews. Only three notes were found:

- May 2021: Increased oil temperature of engine 1 of the combining gearbox.
- April 2021: Decrease of TQ, N1 and ITT values of engine 1 and decrease of NR. This fault was identified as a “Low Side[6]”.
- January 2021: AFCS light flashing.

[6] The term “Low Side” refers informally to a Low-Side FCU fault. It's a malfunction of the FCU fuel control unit, whose primary mission is to maintain NR by keeping the engine's N2 between 97-100%. A Low-Side fault is usually caused by a leak in the pneumatic P_G line. The effects on the helicopter are a loss of power and a drop in NR.

1.6.9 Maintenance actions

The maintenance checks and actions carried out in 2021 were as follows:

- 11/07/2021: Accident (12,463 h).
- 02/07/2021: 25 h inspection (12,455 h).
- 13/06/2021: 25 h inspection (12446 h).
- 02/06/2021: Inspection due to lightning strike (12,446 h).
- 26/05/2021: 150 h/6m inspection of engines and change of oil cooler blower on engine 1 (12,443 h).
  Action as a consequence of the note made in May 2021.
- 04/05/2021: 25 h inspection (12436 h).
- 24/04/2021: Replacement of fire extinguisher (12,433 h).
- 11/04/2021: Replaced P_Y accumulator due to air leak (12,431 h) after troubleshooting the FCU of engine 1.
  Action as a consequence of the note made in April 2021.
- 05/04/2021: 25 h and 50 h inspection (12,430 h).
- 10/03/2021: 25 h inspection (12410 h).
- 08/02/2021: 25 h inspection (12,392 h)
- 18/01/2021: Replacement actuator (12,397 h).
  Action as a consequence of the note made in January 2021.

1.6.10 Maintenance on the main driveshaft

The 600-h/12-month inspections of the main driveshaft, which was found separated from the combining gearbox, are listed in chronological order. For each inspection, it has indicated whether the components of the threaded joints were replaced:

- January 2014: Installation of 12 screws by the previous operator (Global Helicopter Service GMbH). The installation position of these screws is unknown.
- February 2016: Commencement of operation of the helicopter by ROTORSUN.
  Installation of 24 MS21043-4 nuts according to ASB412-14-160 rev A.
- May 2017: Installation of 6 NAS6604-4 bolts manufactured by LFC Industries from a batch of 20 bolts purchased in 2014 from AEROGLEN International. The work order does not specify which bolts were replaced or in which area.
- May 2018: 600 h /12 m inspection without component replacements.
- May 2019: 600 h /12 m inspection without component replacements.
- May 2020: Installation of 24 90-132L4 nuts according to ASB412-14-160 rev B (EASA AD 2014-0118), from a batch of 45 nuts purchased from Bell.
- Nov 2020: 600 h/12 m inspection. This inspection would have been done in May 2021, but it was brought forward by 6 months due to workshop scheduling. No component replacements. Counterweights did not need to be installed for balance in this overhaul.
- 11/07/2021: Accident.

1.7. Meteorological information

Three data sources were used to assess the weather conditions. All provided consistent information:

- AEMET data: The AEMET weather station at Ejea de los Caballeros is located to the south of the town, at an elevation of 321m. At 20:00 (18:00 UTC), it recorded the following data: overcast sky, 30.7ºC temperature, 41% humidity, average wind of 4.5 kt (2.3 m/s) from the northeast (046º) and gusts of 13 kt (6.7 m/s) from the north (012º). Figure 1 shows the location of the weather station.
- Crew: Refered to a northerly wind of between 15-25 kt.
- Video: In the two videos recorded, the presence of a moderately strong wind from the north-northeast and overcast skies can be clearly seen. Figures 6 and 7 show these conditions.

With regard to the previous flight on the same day, the temperature was 32ºC.

1.8. Aids to navigation

The flight was conducted with visual reference to the ground. No navigation aids were used and the flight was not recorded by the ATC surveillance systems.

1.9. Communications

The flight did not communicate with any ATC unit. With regard to communications with the firefighting services, at the time of the accident the crew was not engaged in any external communications.

1.10. Information about the aerodrome

Relevant information on the areas used for the operation on the day of the accident is as follows:

- Ejea de los Caballeros base: elevation 341 m. It houses a rest area for the crew and firefighters, a helipad with two parking areas and a fuel storage tank.
- Clean point fire: the height of the area where the helicopter dropped off the fire brigade was 322 m.
- Estanca del Gancho reservoir: elevation 326 m, surface area of approximately 27 hectares, surrounded by a circular walkway. The crew chose this reservoir because of its proximity to the fire and its size.
- Previous fire: the firefighters disembarked at an elevation of 365 m, and the 3 water loads were conducted at 390 m.

1.11. Flight recorders

1.11.1 Sources of information

The helicopter was not equipped with flight recorders because they are not a requirement for its operations. However, it was possible to reconstruct the flight from:

- the fleet tracking system, which recorded the entire flight, and
- two eyewitness videos recorded on the south and northwest banks of the reservoir, which captured the last 65 seconds of the flight, and thus the crash.
  a) The video from the northwest bank did not record the sound of the helicopter, but it did record virtually the entire manoeuvre to check the operation of the helibucket and the eventual accident.
  b) The second video, recorded from the south, was closer than the previous one, covered the last 20 seconds of the flight before the accident and captured the sound of the helicopter (see section 1.16.2).

The information in this section focuses on the last 2 minutes of the flight, in which the helicopter approached the southern part of the reservoir and carried out the operational test of the helibucket. The information relating to the previous flight has been included in section 1.

1.11.2 Fleet tracking system

20:02 Start of the approach to the reservoir on an easterly course. The helicopter was at 139 ft altitude, 32 kt GS and 250 m from where it would begin the operational tests of the helibucket.

20:03 The helicopter was hovering over the reservoir. This is assumed to be the point at which the tests, and therefore the event, began. The altitude and speed data recorded at this stage are not considered reliable, so the calculations obtained from the videos have been used.

20:04 Impact with the water.

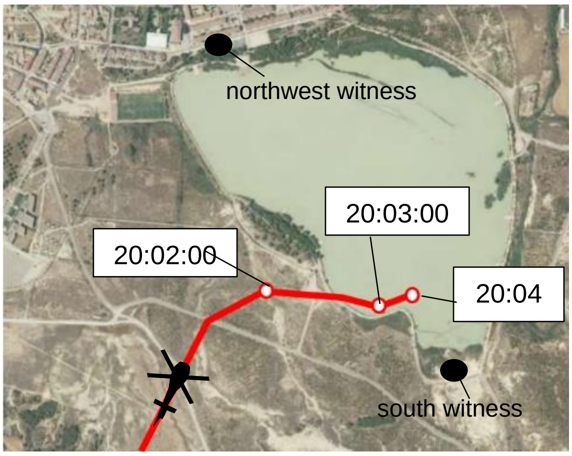

Figure 4. Last two minutes of flight (20:02-20:04)

1.11.3 Witness videos

t=+0 s 20:03:00. Start of video recording from the northwest. Estimated to coincide with the 20:03:00 fleet tracking time reference. The helicopter was hovering at a height of 6 m above the water. The helibucket was submerged and filling with water.

t=+28 s 20:03:28. Helicopter at a height of 6 m. It commences a forward and upward movement to remove the loaded helibucket from the water.

t=+29 s 20:03:29. The helibucket is emptied of water as the helicopter climbs to 8 m.

t=+32 s 20:03:32. Descent begins.

t=+35 s 20:03:35. Helicopter at a height of 6 m with the helibucket on the surface of the water. It remains in this position for a further 2 seconds before starting a new climb.

In this first ascent-descent cycle, the horizontal displacement was 32 m with an approximate GS of 1.7 kt.

t=+38 s 20:02:38. Start of video recording from the south. Helicopter at a height of 6 m. The helibucket is at water level. The helicopter commences a forward and upward movement. Filling the helibucket takes 10 s, but the video footage only shows the helibucket in the water for 3 s (from +35 to +38), which confirms that the helibucket was empty in this second cycle.

t=+45 s 20:03:45. Helicopter at a height of 9.5 m. End of climb. The helicopter continues moving forward maintaining its height above the water.

t=+48 s 20:03:45. The helicopter maintains a hover but begins a slight descent.

t=+50 s 20:03:50. Helicopter at 8.5 m.

t=+52 s 20:03:52. Helicopter at 7 m[7]. Start of yaw to the left and presence of a new sound in the audio (paragraph 1.16.2).

t=+53 s 20:03:53. Helicopter descending to 6 m. Helibucket in contact with the water. Coning of the main rotor can be seen.

t=+54 s 20:03:54. Helicopter impacts the water.

In this second ascent-descent cycle, the horizontal displacement was 30 m with a GS of 3.6 kt. The descent rate between 20:23:48 and 20:03:52 was 123 fpm. From 20:03:52 to 20:03:54, it was 690 fpm.

Figure 5 shows the first cycle of ascent and descent, recorded only by the witness positioned to the northwest. Figure 6 shows the second ascent-descent cycle from the two perspectives of the two witnesses.

Figure 5. Last minute: first ascent-descent cycle (20:03:00 to 20:03:35)

[7] This approximate height calculation shows that the helicopter remained within the safe zone of the height-velocity curve in the event of the failure of one of the two engines.

Figure 6. Last minute: second ascent-descent cycle (20:03:38-20:03:54)

1.12. Aircraft wreckage and impact information

Following the recovery of the helicopter from the reservoir on 14 July, a general inspection of the helicopter was carried out on 20 July. The results indicated the need for further specific tests, which have been included in section 1.16.

Figure 7. Aircraft EC-MTS after the accident

1.12.1 Exterior structure

The aircraft had minor exterior damage:

- The most significant damage consisted of a vertical and upward compression deformation of the lower fuselage, which was more pronounced on the right side than on the left, caused by contact with the helibucket during the impact with the water.
- Deformation of a door panel on the right side, which could not be opened, as a result of the previous deformation.
- Small compression deformation on the right side of the vertical stabiliser.
- The main and tail rotor blades and skids had no visible damage.

1.12.2 Cabin

The inspection of the cabin confirmed that the compartment had remained intact. With regard to the command and control systems, the following was found:

Miscellaneous:

- 5 tripped circuit breakers were discovered, which are not thought to be related to the event.
- The engine 2 fire extinguishing lever was pulled out. According to the pilot, it was used to shut down the engine when they were in the water.

Fuel system:

- Gov switches: in AUTO position, indicating that the fuel control units (FCU) were operating in automatic mode (AFCU). The circuit breakers of the gov switches were not tripped.
- Fuel switch: in normal operating position for both engines. This rules out cross-feed activation and confirms that the fuel system of the two engines was operating in the normal mode.
- Throttle: continuity between the throttle control and the engine fuel control units (FCU). The maximum and minimum FCU settings were correct.

Flight controls:

- Collective: continuity and coherence of movement between collective and rotor.
- Cyclic: continuity and coherence of movement between cyclic and rotor.
- Pedals: continuity and coherence of movement with the tail rotor.

1.12.3 Transmission and mast

- Indicators (cat eye) for chips in the upper transmission zone, intermediate (planetary) and sump: neither of the three were tripped.
- Metal chip detectors in the upper, intermediate and sump area of the transmission: no chips found. This ruled out mechanical faults in the transmission.
- Transmission filter check: free of particles.
- Mast overtorque indicator (cat eye): not tripped.
- A triple tachometer indication test was performed: The test confirmed that the connections between the tachometer generator and the cockpit indicator were intact and that the NR tachometer generator was reading 1.5-2% lower than the actual value but was within tolerances.

1.12.4 Main driveshaft

The connection between the main driveshaft and the transmission was in perfect condition. However, the coupling between the main driveshaft and the gearbox was detached:

- The joint between the main driveshaft coupling and the gearbox adapter had separated, and the shaft was resting on the fire bulkhead.
- The 6 bolt-washer-self-locking nut threaded joints that held the two parts together were missing from their housings.
- Six bolts (five fragments and one whole), five washers (three whole and two fragments) and two self-locking nuts (threaded onto two bolt fragments) were recovered.
- The abrasion marks on the contact surfaces were scarce and recent.

- The temperature monitoring stickers in the gear area had not changed colour, which ruled out overheating in the coupling, both at the joint with the transmission and at the joint with the combining gearbox.
- On the fire bulkhead, where the shaft was supported, there were two parallel perforations made by the flanges of the shaft coupling after it had disconnected. These perforations were located above engine 2. There were two parallel abrasion marks on the side of engine 1, but they had not perforated.
- The perforations had reached the exhaust nozzle of engine 2.
- Check of the free and frictionless rotation of the power transmission shaft.

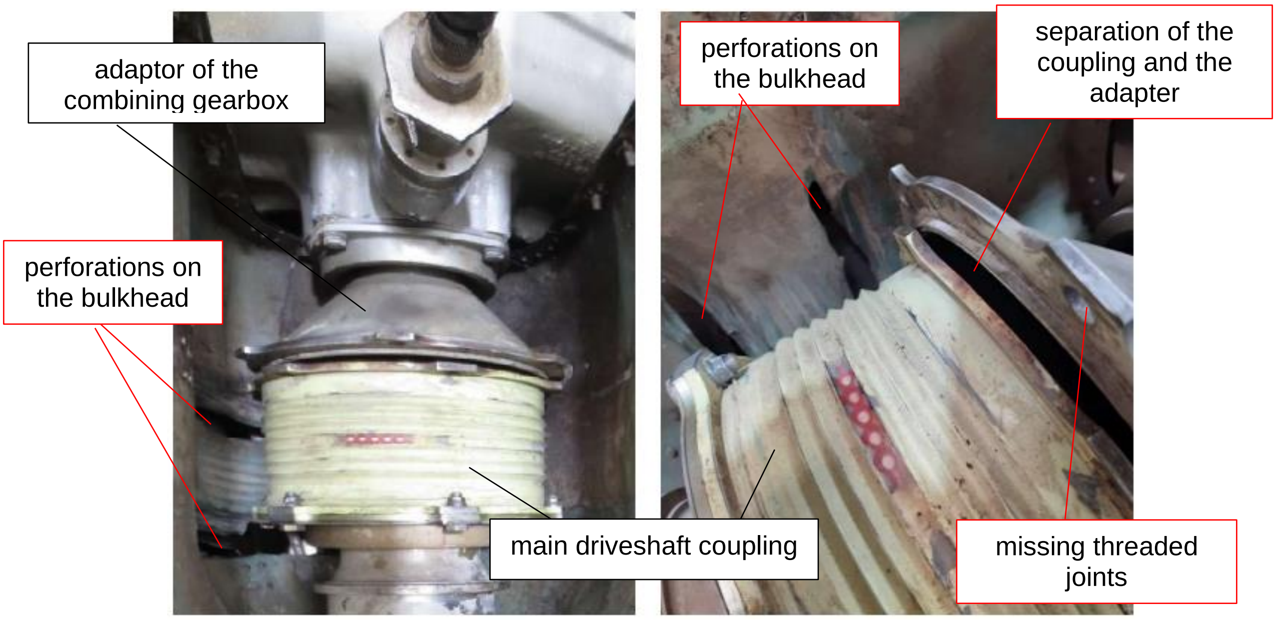

Figure 8. Separation of the shaft to gearbox coupling

Figure 9. Recovered bolts, nuts and washers

1.12.5 Gearbox

The combining gearbox had no oil leaks or deformations:

- Check of freewheel rotation of both engines and directions: correct.
- Check of air cooler blower rotation on both engines: no friction.

- Check of gearbox lubrication: 5 litres of water (as a result of being submerged) and 3 litres of oil were drained. The oil was filtered and confirmed to be free of metal particles.
- Check of condition of the gearbox oil filter: no particles.
- Check of gearbox metal chip detector: no particles.
- Check of the free rotation of the entire gearbox gear train, from the power output of the two engines to the power delivery to the main driveshaft.

1.12.6 Engines

The results were the same for both engines:

- Visual check of the power turbines through the exhaust nozzle: no damage.
- Check of the rotation of the power turbines: no friction.
- N2 metal chip detector: no particles.
- Disassembly, inspection and filtering of oil filters: no particles.
- Disassembly and inspection of fuel filters: correct condition.
- Boroscopic inspection of compressor turbine and stator area: no damage or abrasion.
- Check of the free rotation of the compressor turbine.

1.12.7 Fuel control unit (FCU)

The following checks were carried out:

- Disassembly and condition check of the P_3 filter: no blockages.
- Pressure test of the pneumatic fuel control system (P_G line): no bubbles or pressure loss throughout the circuit.

1.13. Medical and pathological information

It was not found evidence to suggest the actions of the flight crew were affected by any physiological or disabling factors.

1.14. Fire

There was no evidence of fire during the flight or after the impact.

1.15. Survival aspects

The harnesses and restraint systems worked adequately, and the cabin interior maintained its structural integrity. The second pilot, seated on the left side, which was the direction of the rollover, opened the door on his side immediately to secure his exit and was able to evacuate the cabin on his side once the rotor had stopped without waiting to hear the evacuation order, which was never issued. He swam around the nose of the helicopter until he reached the right side, where the commander was.

The commander remained in the cabin for longer to shut down both the engines, which had been running when they hit the water: one with the throttle and the other with the fire extinguishing lever. He evacuated the helicopter on the right side, and they both used the right skid to climb onto the fuselage and wait to be rescued. The commander described the cabin being flooded only to halfway up his body, with no more water entering because it wasn't a very deep area.

With regard to life-saving systems, they had life jackets in the cabin, which they were not wearing, and a breathing apparatus, which they did not need to take.

The rescue was carried out by a fire service boat that brought them to the shore, where a medical ambulance was on hand.

1.16. Tests and research

1.16.1 Helicopter performance calculation

To calculate the helicopter's performance, we used the charts used by the crew to prepare for the flight and the flight data: maximum authorised take-off weight 5,398 kg, helicopter empty weight 3,432 kg, payload weight (passengers, hook, bucket, baggage) 1,167 kg, fuel weight 740 kg, helicopter hover and low altitude consumption 340 kg/h, helibucket capacity 1,400 kg, temperature at the time of the accident 30.7°C, operating area altitude 341 m (base), 322 m (fire), 326 m (reservoir). This data provided the following results:

- Weight on take-off from the base: 5,339 kg
- Weight at the reservoir with the bucket loaded with 1,000 kg: 5342 kg
- Weight at the reservoir with the bucket loaded with 500 kg: 4842 kg
- Maximum hover weight with and without ground effect at the reservoir, fire and base at the time of flight: 5,398 kg.

For the flight that morning, the maximum hover weight with and without ground effect over the areas of operation and at the temperature at the time was also 5,398 kg. The weight data for the morning operations would be similar to those calculated for the accident flight.

The data shows that the operating weight for the water loads on the day of the fire were very close to the maximum hover weight in and out of ground effect (56 and 59 kg margins). At the time of the accident, the load was partial (500 kg), which does provide a more significant margin with respect to the maximum operating weight (556 kg). On the day of the accident, the relative humidity was 41%, and although this is not included in the performance tables, it is a factor that negatively affects performance.

1.16.2 Acoustic analysis

The videos recorded by the witnesses were submitted for an acoustic analysis to obtain more information on the helicopter's operating regime during the event. Information could only be obtained from the second ascent-descent cycle, between the time references 20:03:38 to 20:03:54.

- The revolutions of the main rotor NR (and associated tail rotor) and N1 (indicated as NG in figure 10) were constantly maintained at around 95% throughout almost the entire manoeuvre, until 20:03:52. The N1 revolutions of both engines remained the same. The speed of the power turbine N2 could not be identified in the video.

- In the last half of second 20:03:52, a high amplitude sound can be heard, which is not associated with any component under normal operating conditions. The frequency of this sound rapidly increases and then decreases, and its appearance coincides with the helicopter's descent at 690 fpm until it hits the water.
- Within one second of the onset of the sound, the NR decreases instantaneously, and the N1 of both engines momentarily increases and then decreases drastically.

Figure 10 shows the acoustic analysis. Graphs showing the percentage rotational speeds of the main rotor, the compressor turbines and other elements with frequencies have been included. The time references of the graphs have been marked with respect to the beginning of the video taken from the southern part of the reservoir.

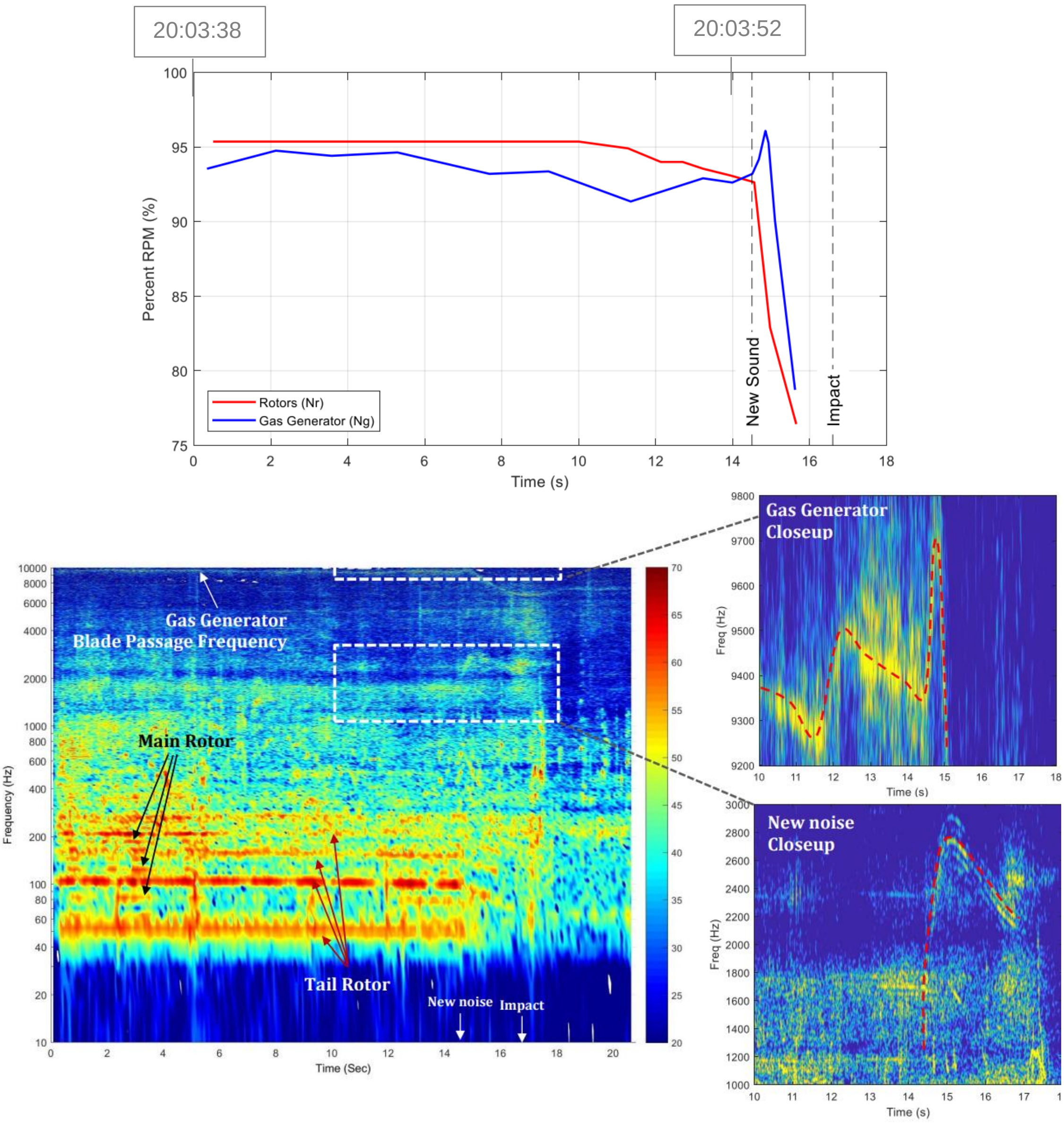

Figure 10. Acoustic analysis of the flight between 20:03:38 and 20:03:54

1.16.3 Investigation of the joining elements: bolts, nuts and washers

The flange where the disconnection of the main driveshaft occurred is connected to the gearbox by 6 bolts, 6 washers and 6 self-locking nuts. Of these, the following were recovered after the accident:

- Bolts: 3 fragments from the head area, 2 fragments from the end with screwed-on nuts and 1 whole bolt without the nut or washer.
- Washers: 2 loose whole washers, 1 whole washer attached to the head of a bolt fragment and 2 fragments.
- Self-locking nuts: 2 screwed onto the two bolt fragments.

Given that the helicopter was submerged and overturned for 4 days in the reservoir, it is assumed the unrecovered joining elements were lost in the water.

<u>Bolt fragments from the head area (p/n NAS6604-4)</u>

The three bolt fragments that included the head also had the non-threaded (grip) area. The heads were engraved with "NAS6604-4 LFC". The fracture surfaces were examined with a stereo-microscope and scanning electron microscopy (SEM), confirming breakage due to overload on the fracture surfaces. With regard to material and hardness specifications, all three fragments met the specifications of the NAS6604 standard, but the diameters of the non-threaded areas at some points were below the design minimum. The non-threaded areas of the bolt showed signs of wear and abrasion.

<u>Bolt fragments from the end area (p/n NAS6604-4) with screwed-on nuts (p/n 90-132L4)</u>

The two nuts that remained screwed onto the bolt fragments were engraved "90-132", indicating compliance with the manufacturer's service bulletin ASB412-14-160 and EASA directive AD2014-0118. The fracture surfaces of the bolts were examined with a stereo-microscope and scanning electron microscope, also confirming breakage due to overload. It was also confirmed that these fragments completed two of the three bolt heads that had been found.

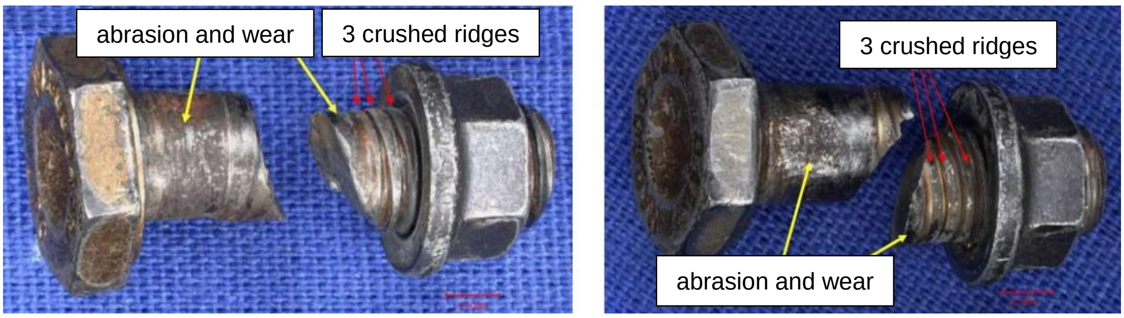

Figure 11. Bolt fragments

In addition to abrasion and wear on the non-threaded section of the bolt, the fragments exhibited crushing of the first three thread ridges (the ones closest to the head). In the case of the bolt that was found with the washer installed, the washer was completely warped and deformed towards the bolt head.

Whole bolt (p/n NAS6604-4) without nut or washer

The bolt recovered in one piece did not have the self-locking nut fitted. Its dimensions indicated that it was intact. The inscriptions on the head of the bolt were "NAS6604-4 OHIO". With regard to the specifications for length, the diameter of the non-threaded area, material and hardness, the length, material and hardness specifications were met, but the diameter was below the NAS6604 requirement (0.62992 cm compared to the minimum diameter of 0.63119 cm).

The bolt exhibited three types of damage:

- Impact dents in some areas of the last threads, which is where the nut should be, as well as on the head.
- Crushing of the first 6 thread ridges, corresponding to the area where the bolt passes through the main driveshaft coupling.
- Abrasion and wear on the non-threaded area of the bolt, the area where the bolt passes through the gearbox adapter.
- The last threads had no signs of crushing or shearing on their ridges, although they did exhibit contact marks (the dents mentioned previously).

These damages confirmed that the threaded joint to which it belonged had no counterweight installed to balance the shaft.

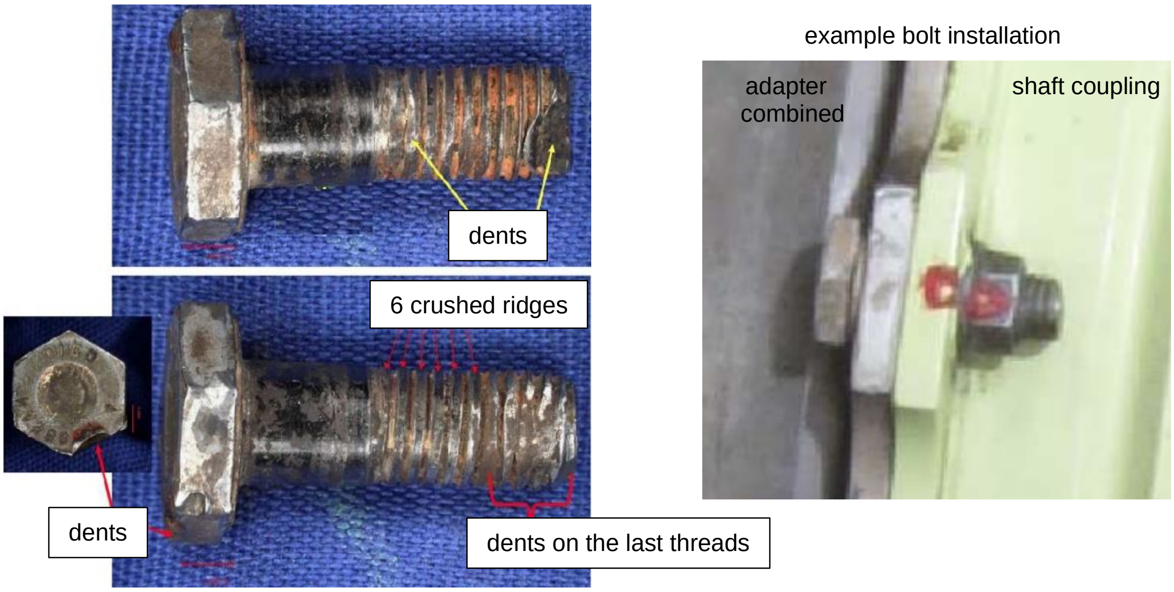

Figure 12. Whole bolt and example of contact areas

Washers (p/n NAS1149F0432P)

The two loose whole washers had a step-shaped concavity caused by contact with the bolt head. Both had a reduced cross-section due to wear and erosion. The two washer fragments recovered had been subjected to excessive wear, which had reduced their thickness, and they were visibly warped. The washer attached to the bolt showed obvious signs of deformation and warping similar to the other fragments found. In terms of material and hardness, the washers complied with the specifications of the NAS1149 standard.

1.16.4 Investigation of the disconnected parts

The main driveshaft coupling and the gearbox adapter were the two parts found separated. As a result, they were subjected to a specific inspection.

Driveshaft coupling (p/n 214-040-659-005)

The contact area with the adapter exhibited drag marks and deep, circular scratches believed to have been caused by contact between the two surfaces after their separation. There were no signs of excessive wear or ovalisation in the bolt holes; in fact, they were measured and complied with the design requirements. Contour marks made by the nuts were clearly identifiable around the bolt holes.

The opposite surface of the part consists of a serrated inner area that is in contact with the rest of the driveshaft. This serrated surface showed typical wear marks, which are not considered to be relevant. The centre spring (p/n 204-040-685-1) was in perfect condition and met the design specifications for unloaded length.

Gear box adaptor (p/n 209-040-618-1)

Drag marks made by contact between the two parts after their separation were identified on the coupling contact surface. The contact area has a small lip or step that helps the two parts fit together, extending all the way around. A 3.8 cm arch was missing from this step due to shear stress. Two of the six bolt holes were elongated, and it was confirmed that their diameter measurements exceeded the design maximum. Around the bolt holes, the contour markings made by the washers on which the bolt heads rest were clearly identifiable.

The opposite surface of the part, in the form of a funnel, consists of a serrated inner area that is in contact with the gearbox. This serrated surface did not exhibit any evidence of excessive wear. The exterior surface surrounding this area showed a 0.5 cm shiny mark extending to the middle of the contour, indicating rotational friction. This mark is believed to have been produced after the driveshaft dislodged while the gearbox was still rotating.

1.16.5 Investigation of the fuel control system

The fuel control unit (FCU), consisting of the automatic fuel control unit (AFCU), the manual fuel control unit (MFCU) and the fuel pump, as well as each engine's N2 governor and torque limiting unit (TLU) were removed from the helicopter for investigation. The two N2 governors and the TLU were models installed before the issuance of service bulletin PT6T-72-5511 in 2010-2011, which was optional and issued to eliminate torque fluctuations.

Between 22 and 24 November 2021, the 9 elements were subjected, in this order, to an external visual inspection, performance tests in accordance with the maintenance manual for each component and an internal visual inspection after disassembly. The discrepancies identified for each component are described below.

Joint test of the fuel control system of engine 1

Before disassembling the various components, an attempt was made to test the AFCU-MFCU-pump assembly of engine 1, but because the pump would not even allow manual rotation of the shaft, it could not be carried out. The steel parts of the assembly showed signs of corrosion, and it was noted the presence of a powder similar to sand/soil on the surface of the components. The external inspection of the entire assembly identified three missing lockwires.

AFCU engine 1 (p/n 3244883-8)

There was a deviation in the maximum setting of the N_G stop screw. The tests prescribed in the CMM 73-20-71 component maintenance manual were carried out without changing the position of this screw, revealing some differences in some of the settings. The differences have been marked with the sign (+), when the fuel flow was higher than the maximum and (-) when the fuel flow was lower than the minimum allowed by the CMM. The acronym TP, used in the CMM, refers to a test point:

- Metering valve orifice and bypass valve differential pressure: TP 1.04 (+)
- Enrichment spring: TP 2.02 (-)
- Governor spring: TP 3.01 (+), TP 3.03 (+) & TP 3.04 (+)
- Idle speed stop and pick up angle: TP 4.02 (-)
- Governor reset check: TP 6.06 (+)

Some of these settings can be adjusted on wing according to the AMM, but others cannot and can only be changed by the manufacturer according to its CMM. Most of the deviations found in the tests performed provided fuel flows above the maximum value indicated by the CMM.

MFCU engine 1 (p/n 3244884-3)

The tests stipulated in the CMM 73-20-72 component maintenance manual were conducted, and deviations were found in the following settings:

- Cut-off leakage: TP4 (+)
- Fuel schedule: TP9 (-)

Fuel pump engine 1 (p/n 025277- 300-8)

The shaft could not be turned manually, so the performance test could not be performed. The disassembly of the pump revealed extensive corrosion on all components.

Joint test of the fuel control system of engine 2

In this case, it was possible to test the operation of the entire fuel control assembly of engine 2. The steel parts in the assembly showed signs of corrosion, and it was note the presence of a powder similar to sand/soil on the surface of the components. The external inspection identified three missing brake cables. Performance tests of the AFCU were carried out in accordance with CMM 73-20-71, and deviations were found in the following settings:

- Metering valve orifice and bypass valve differential pressure: TP 1.03 (+) & TP 1.04 (+)
- Enrichment spring: TP 2.02 (-) & TP 2.03 (+)
- Governor spring: TP 3.01 (+) & TP 3.03 (-).
- Idle speed stop and pick up angle: TP 4.01 (-)

AFCU engine 2 (p/n 3244883-8)

The exterior inspection confirmed that there was a deviation in the maximum setting of the N_G stop screw. After removing the automatic fuel control unit from the pump/pack assembly, its performance was again bench-tested in accordance with CMM 73-20-71, and deviations were found in the following settings:

- Metering valve orifice and bypass valve differential pressure: TP 1.03 (+) & TP 1.04 (+)
- Enrichment spring: TP 2.02 (+) & TP 2.03 (+)
- Governor spring: TP 3.01 (+) & TP 3.03 (-).
- Idle speed stop and pick up angle: TP 4.01 (-)

The disassembly revealed a partial blockage of the P_Y bleed caused by a deposit.

MFCU engine 2 (p/n 3244884-3)

As no deviations were detected in this unit during the general test of the assembly, no further disassembly or additional testing was deemed necessary.

Pump engine 2 (p/n 025277-300-8)

The pump was tested according to the manufacturer's CMM 73-10-11 with a satisfactory result.

N2 governor engine 1 (p/n 3244885-4)

The entire assembly showed a presence of a powder similar to sand/soil on the surface of the components. An exterior inspection of the entire assembly confirmed that all seals and gaskets were in good condition. The governor shaft could be moved by hand. Performance tests were carried out in accordance with the manufacturer's CMM 73-20-69, with the following deviations:

- P_R-P_G differential pressure: TP3 (+) & TP4A (+).
- Maximum stop angle: TP9 (+, 1º above the limit)

The disassembly revealed the presence of deposits and internal dirt.

N2 governor engine 2 (p/n 3244885-2)

The entire assembly showed a presence of a powder similar to sand/soil on the surface of the components. The P_G setting line had water in it. The governor shaft could be moved by hand. The external inspection confirmed that the eccentric shaft and maximum-stop adjustment screw Teflon back up ring was missing on the Pg fitting. Performance tests were carried out in accordance with the manufacturer's CMM 73-20-69, with the following deviations:

- P_R-P_G differential pressure: TP 3 (+) & TP 6 (+)
- Maximum stop screw: TP 7 (+, 7º above the limit)

The disassembly revealed the presence of deposits and internal dirt.

Torque limiting unit (TLU) (p/n 3244881-2)

The external check confirmed that the lockwire seals were missing on the fine and coarse servo valve adjustment cap. Performance tests were carried out in accordance with CMM 73-20-68, revealing the following discrepancies:

- Flow restrictor bleed test: TP1.01 (-)
- Multilimiter adjustment check: TP 4.01, TP 4.02, TP 4.03, TP 4.04 & TP 4.08 (-)
- Differential pressure check: TP 4.09 (- y +)

The disassembly revealed the presence of sand inside the component, probably from water ingress.

1.17. Organisational and management information

Any relevant information about the organisation has been included in the appropriate sections.

1.18. Additional information

During the investigation, meetings were held with the operator to share the conclusions reached. Rotorsun decided to include in the maintenance work order for the main driveshaft, which is carried out every 600 h or 12 months, the use of new fasteners (bolts, washers and self-locking nuts) every time the shaft is disassembled. As of the date of issue of this report, the operator has confirmed that this modification has been implemented in their procedures. The results of the initial changes showed that some bolts were found with marks but that in other maintenance tasks, the components were found to be in good condition. It should be noted that the maintenance is carried out once per calendar year (12 months) because the aircraft's annual operating hours are approximately 100 hours, nowhere near 600 hours.

The engine and aircraft manufacturers were also involved in the investigation from the outset. Regarding the inquiries made to Bell about how the shaft would operate if one of the joints deteriorated, it advised that the shaft is designed to work with 6 joints, not 5, and that, logically, if one of them were to fail, the remaining joints would be subjected to increased overload. No driveshaft performance tests were carried out with just 5 joints, so it's difficult to assess how long the shaft might operate without one of its threaded joints.

The only experience of this potential scenario comes from the directives issued to replace nuts that had fractured due to brittleness, which revealed that some in-service helicopters had been operating with a fractured nut without experiencing transmission problems.

1.19. Useful or effective investigation techniques

N/A.

2. ANALYSIS

The accident occurred to the twin-engine Bell412 EP helicopter (registration EC-MTS) on Sunday, 11 July 2021, involved an in-flight loss of control during a hover manoeuvre over the Estanca del Gancho reservoir (Zaragoza), due to the disconnection of the driveshaft.

The fact that the hover manoeuvre and shaft breakage occurred sequentially in time initially influenced and steered the investigation to believe that the two factors were related and, therefore, to seek the origin of the first in the second. However, the conclusions reached during the investigation process and the analysis carried out have ruled out this initial approach, leading to the following general conclusions about the accident:

- The two events were unrelated, even though they occurred sequentially in time.
- With regard to the inability to maintain a hover, the origin of the problem could not be determined, although technical problems have been ruled out.
- With regard to the loss of control, its source appears to have been the disconnection of the main driveshaft from the gearbox following the loss of integrity of the threaded joints that hold them together. This loss of integrity originated in at least one of the threaded joints, which was operating without a self-locking nut as a result of inadequate maintenance instructions and practices. These maintenance instructions and practices had also affected the other threaded joints, degrading them and eventually contributing to the complete failure of the transmission.

The analysis in this section is structured in two parts, each focusing on analysing one of the two events that occurred during the flight, but this time without following the chronological order in which they happened.

2.1. General

2.1.1 The flight

The entire flight lasted 14 minutes and comprised an intermediate approach and landing to drop off the brigade and an approach to hover over the water, at which point the helicopter began to experience problems. The hover manoeuvres lasted less than two minutes and consisted of two ascent-descent cycles: the first with the helibucket loaded and the second with the helibucket empty.

2.1.2 Crew

The description given by the crew is broadly consistent with the information that has been confirmed from the flight. Their physical condition and the aspects related to their experience and knowledge, both of the flight and the area of operation, do not appear to have contributed to the accident. The pressure issues characteristic of large fires were not present in this case, nor did the area where the loading was being carried out present any orographic difficulties; therefore there have been ruled them out as influencing factors.

2.1.3 Aircraft

The external damage consisted of compression deformations, with an exclusively vertical component, consistent with the impact against the water after an uncontrolled 2-second descent from an altitude of 7 m. These deformations are consistent with the lower fuselage coming into contact with the helibucket, confirming the absence of translational velocity.

By contrast, the damage to the main driveshaft, unlike the external damage, was caused by a pre-existing maintenance issue and not by the impact against the water.

2.2. In-flight loss of control

The in-flight loss of control occurred at 20:03:52 as a result of a complete disconnection of the main driveshaft from the gearbox.

This disconnection occurred when the helicopter was 7 m above the water level of the reservoir, attempting to maintain a hover that it had started seven seconds earlier and in which it had failed to maintain altitude. Four seconds earlier, it had initiated a gentle, controlled descent at 123 fpm, which suddenly transformed into the helicopter dropping at 690 fpm until it hit the water. The sudden descent was accompanied by a yaw to the left, which is to be expected in the event of a loss of transmission.

This drop coincided with the changes in the NR values, which, in less than 1 second, decreased from 95% to 76%. The behaviour of the rotor was the result of it being disconnected from the engines and, therefore, being without power. The N1 values for the engines at 20:03:52 show an initial acceleration of the turbines due to the fact that they lost power when the shaft disconnected. This acceleration is believed to be the origin of the sound that can suddenly be heard in the video. It was immediately reversed by the governors, which, in an attempt to compensate, had to reduce the fuel flow without shutting down the engine, confirming that they were functioning correctly. This was evidenced by the N1 value dropping to 79% within one second and the fact that the engines were running when the helicopter hit the water.

In conclusion, the operation of the engines and rotor and the helicopter's fall and yaw were consistent with a sudden and complete disconnection of the main driveshaft.

2.2.1 Management of the emergency

The phase of flight in which the helicopter was operating (hovering) and the proximity to the ground (7 m) left the crew with little room for manoeuvre and only two seconds (the duration of the descent) to react. The recovered footage shows the main rotor coning before the impact. This might indicate the initiation of an autorotation manoeuvre from a hover, which would be the procedure to follow to manage a transmission failure. The time lag between the shaft breakage and the evidence of rotor coning is between one and one and a half seconds. This amount of time falls below even the threshold for human reaction to a stimulus[8], which leads to the conclusion that the emergency management was adequate given the proximity to the ground.

2.2.2 Survival

The only noteworthy aspect in terms of survival is the fact that when they evacuated the helicopter, neither of the two crew members took their lifejackets or breathing devices. While this decision did not have any consequences for their survival, as the area into which they fell was shallow, it is considered an aspect that merits reinforcement, and to this end, a safety recommendation is issued to the operator in this regard.

2.2.3 Disconnection of the main driveshaft

The disconnection of the main driveshaft was caused by the loss of integrity of the threaded joints securing it to the combining gearbox. All 6 joints came out of their housings, causing the combining gearbox and shaft to separate completely, interrupting the power supply to the rotors and resulting in the loss of control.

<u>Origin: loss of one of the threaded joints</u>

The disconnection originated in at least one of the six threaded joints. This joint was the one corresponding to the bolt that was found intact, with neither nut nor washer in place. The damage to this bolt has confirmed that:

- The bolt was installed in one of the housings.
- At some point, it came out of the housing, and the nut was not attached when that happened. It was assessed three scenarios as the potential cause of this situation:
  a) That the nut had not been installed the last time the shaft was serviced, i.e. 8 months and 67 hours earlier.
  b) That the nut had been installed but had come loose due to a loss of tightening torque.
  c) That the nut had been installed but subsequently fractured.

Of these three options, the investigation considers option b) as the most likely, given that latent conditions resulting from maintenance instructions and practices that could lead to a loss of tightening torque in the assembly have been identified. Option c) is considered unlikely as the nuts were as specified in the EASA directive and, therefore, were not affected by brittleness issues. With regard to option a) a lack of similar events and information on how the transmission would perform with the loss of any of the threaded joints makes it difficult to assess whether it's possible that it could have lasted for 67 hours at rotational speeds of 6,600 rpm. The erosions and ovalisations found indicate that the joint had been working with a lack of solidarity between the two parts for a period of time that cannot be estimated.

[8] According to EASA RMT.0246, a pilot's reaction time to a power failure in a twin-engine helicopter would be between 0.5 and 1.4 seconds.

In any case, what has been confirmed with certainty is that this threaded joint was the origin of the accident: the self-locking nut was either not installed or was lost, the bolt came out of its housing because nothing was holding it in place and it ceased to perform its function of holding the shaft and gearbox together in that area.

Early deterioration and overloading of the remaining threaded joints

In addition to the complete loss of one of the joints, the remaining joints were in a deteriorated state of operation, and it was the combination of these two circumstances that led to the complete failure of the transmission. Ovalisation, erosion and extensive abrasion marks were evident on all the recovered parts, which, for example, in the non-threaded area of the bolts, had reduced the cross-section to below specification. Under these conditions, the tightening torque of the joints is affected, and the ability to hold the elements together is compromised.

In this context, when the first joint lost its integrity, the remaining joints, which had already deteriorated, were subjected to higher loads than the design loads, accelerating the deterioration process. The loss of integrity of the remaining joints increased until, in the final phase, the joints broke due to overload. The breakage mechanism of the two joints that were not recovered is unknown, and they could belong to either of the two groups.

Although investigation has been unable to determine the deterioration period, it has been able to confirm that the rupture due to overload of the recovered joints occurred instantaneously and simultaneously at 20:03:52, resulting in the complete separation of the shaft.

After the rupture of all the connecting elements, the shaft separated from the adapter. The recent sparse marks on the contact surfaces and the perforations in the fire bulkhead confirm circular movements after the disconnection due to the rotation of both shafts: the gearbox rotating at 6,600 rpm and the shaft rotating due to inertia. This damage occurred a posteriori during the helicopter's fall, there being no evidence of damage caused before the disconnection.

2.2.4 Threaded joint maintenance instructions: reuse and torque tare

Three latent conditions arising from maintenance instructions and practices have been identified as being conducive to the loss of torque on the threaded joints of the main driveshaft and which, consequently, are thought to be responsible for what transpired in the accident:

- The reuse of the threaded joint elements.
- The absence of tare torque information in the maintenance procedure, as a necessary step prior to the reuse of the nuts.
- The operator's tare torque verification practices.

The maintenance instructions for the threaded joints of the main driveshaft installation allowed the indefinite reuse of all its components: bolts, washers and self-locking nuts.

In the case of the EC-MTS helicopter, some of the bolts had been reused for more than 9 years, all the nuts for 1 year, and when the washers were initially installed is unknown. Every year, as a minimum, these joints have to undergo a cycle of disassembly and assembly and, therefore, torque applications. These cycles increase the wear and tear on the components and accelerate the loss of the threaded joint's properties, especially in an assembly rotating at 6,600 rpm and subjected to constant vibrations. All the elements recovered after the accident evidenced a deteriorated condition that is indicative of this long-term reuse. The wear was particularly noticeable on the washers.

Furthermore, the requirement to measure the tare torque was not included in the procedure provided in the Maintenance Manual. Checking this torque is a preliminary step that should be performed before applying the assembly torque and has a critical safety objective, which is to ensure that the nut has not lost its retention capacity and can be reused. This essential safety information is not included in the Maintenance Manual but is included in the Standard Maintenance Practices document, which impedes its application during maintenance. In the case of the EC-MTS helicopter, this tare torque was not checked with a torque meter but was assessed qualitatively in terms of its resistance to twisting.

The maintenance instructions should contain all the data and information necessary to perform the task, avoiding, as far as possible, the need to use additional documents or including a clear citation or referral to any such documents, especially for safety-critical tasks involving essential elements such as power transmission. To this end, two recommendations are issued to the manufacturer, Bell Helicopters, recommending it improve its maintenance instructions, and one to the operator, recommending it improve its tare torque measurement practices.

2.3. Helicopter's inability to maintain a hover

The inability to maintain a hover prior to the driveshaft disconnection was confirmed by the main rotor rotational speed at 95%. This speed, being below 97%, generated the LOW RPM acoustic warnings described by the crew and made it impossible to use the collective's INCR/DECR RPM control to adjust the NR.

By design, the helicopter is intended to maintain constant rotor revolutions in the region of 100%, and this is achieved through a series of systems, components and actions commanded by the crew from the cockpit. In the analysis of this event, it is significant that the NR and N1 values were maintained at 95% over time, which rules out the possibility of a loss of power and instead seems to suggest that a limit was set by one of the system's elements or commanded from the flight deck.

2.3.1 Systems and components

The systems and components review is two-fold: on the one hand, focusing on the functionality of the components and, on the other hand, on a possible torque limitation.

The review of the functioning of systems and components involved in the fuel control and engine management of the EC-MTS helicopter did not identify any technical problems that would prevent the engines from generating power and, therefore, explain why NR and N1 were kept at 95%. The N2 governors, which aim to keep the N2 and NR at the value commanded from the cockpit, were functioning correctly. On the contrary, the review of the systems identified variations in settings in some components that were intended to deliver more fuel and, therefore, more power, not less.

In this respect, these modifications are the result of maintenance practices which have not been permitted by the manufacturer for 20 years and were probably carried out in line. These component modifications were not documented, so it has been unable to identify whether they were made by Rotorsun. In any case, the fact that the lockwire seals were missing should have been identified by the operator's maintenance staff, and therefore, a recommendation is issued to the operator.

Regarding the possibility of a torque limitation, the only system capable of doing so would be the TLU, and only when the torque reaches 108%. The crew did not describe any action on the controls that would have justified its activation, such as a pull on the collective and, at any rate, this feature would not leave the system at the low values recorded.

2.3.2 Settings configured by the crew

In terms of the possible contribution of operating settings configured from the cockpit by the crew, their statements are the only source of information, and they indicated that the positions of the collective and throttle were appropriate. In this regard, the absence of any recorded data makes it impossible to verify this aspect. However, even if the throttle or collective control had been inadvertently lowered, it's difficult to believe that the crew would have allowed it to remain in that position for long without correcting it.

2.3.3 Performances

Lastly, the investigation mentions the helicopter's performance under the operating conditions present on that day. The data shows that the helicopter's weight, with partial helibucket loading, as appears to be the case in the accident, would not pose any operational limitations since it could safely carry another 500 kg before reaching the maximum. If, on the other hand, the water load had been closer to the norm (1,000 kg), this would explain the problems in maintaining flight.

Operations with a full helibucket are carried out with a weight very close to the maximum hover weight, both in and out of ground effect, which, together with the relative humidity, could have affected the helicopter's ability to maintain the necessary power when loaded with water. In this context, the crew's description of the need to use the INCR/DEC control during the morning flight is deemed to be consistent with this performance limitation.

3. CONCLUSIONS

3.1. Findings

Loss of control:

- The helicopter lost control during a hover manoeuvre over the Estanca del Gancho reservoir after 14 minutes of flight.
- The loss of control was caused by the complete and instantaneous disconnection of the main driveshaft from the gearbox.
- After the shaft rupture, the engines and the rotor reacted as expected.
- The engines remained operational until the impact.
- The 6 threaded joints holding the main driveshaft to the combining gearbox had lost their integrity and were missing from their housings.
- One of the 6 threaded joints had been operating without a self-locking nut.
- Three of the 6 threaded joints showed evidence of operating below the appropriate tightening torque. These joints eventually ruptured due to excessive stress.
- The manufacturer’s maintenance instructions permitted the reuse of all the elements (bolts, washers and self-locking nuts) that formed the threaded joints of the main driveshaft.
- The manufacturer's maintenance instructions did not include in the MM but did include in the SPM the need to check the tare torque as a requirement for the reuse of the self-locking nuts.

Impact:

- The impact with the water followed an uncontrolled descent from a height of 7 metres, which lasted 2 seconds.
- The impact had a marked vertical component.
- The external damage to the helicopter was caused by contact with the water.
- The damage to the main driveshaft was sustained before the impact.

Inability to maintain a hover prior to the driveshaft rupture:

- The helicopter experienced problems maintaining stationary flight before the rupture of the main driveshaft.
- During the last ascent-descent cycle, the NR and N1 of both engines were stable and equal at 95%.
- No anomaly was found in the helicopter's power and fuel control system that could have contributed to the power problems. On the contrary, the modifications that had been made allowed the delivery of more fuel than the manufacturer's limits.
- Variations in the settings of certain components of the power and fuel control system, not permitted in the manufacturer's instructions, aimed at providing more fuel and, thus, more power were confirmed.
- The inability to maintain a hover was not related to the rupture of the driveshaft.

3.2. Causes/contributing factors

The cause of the accident was an in-flight loss of control of the helicopter following the disconnection of the main driveshaft from the combining gearbox due to a loss of integrity in the six threaded joints that held them together. This, in turn, occurred because at least one of them had been operating without a self-locking nut, and the remainder were in a deteriorated state due to loss of tightening torque.

The following main driveshaft maintenance instructions and practices are considered possible contributing factors to the accident:

- The reuse of threaded joint elements.
- The lack of a tare torque check, as a requirement for the reuse of the nuts, in the maintenance procedure.
- The operator's tare torque verification practices.

4. OPERATIONAL SAFETY RECOMMENDATIONS

The investigation has determined that the maintenance instructions and practices for the main driveshaft of the BELL412 helicopter result in conditions that may lead to loss of torque in the threaded joints that connect the shaft to the gearbox and transmission. These conditions are related to the indefinite reuse of the threaded joint elements and the application of tare torque to the self-locking elements. In order to minimise these conditions, the following safety recommendations are issued:

> REC 34/23. It is recommended that Bell Helicopter Textrom consider amending the Bell412 Helicopter Maintenance Manual to include, in the main driveshaft maintenance procedures, the replacement of all the components (bolts, washers and self-locking nuts) of the threaded joints each time they are disassembled and assembled.

> REC 35/23. It is recommended that Bell Helicopter Textrom consider modifying the Bell412 Helicopter Maintenance Manual to include alerts concerning the need to check tare torque on self-locking elements.

> REC 36/23. It is recommended that ROTORSUN remind its maintenance personnel of the need to check the tare torque when performing maintenance on threaded joints using self-locking elements.

The investigation identified maintenance actions on certain components of the EC-MTS helicopter's fuel control system consisting of modifying the settings to provide more fuel and, therefore, more power. These modifications have not been permitted by the manufacturer for more than 20 years. Although the investigation has not been able to determine in which period these actions were carried out (i.e., by the current or former owner), the following safety recommendation is issued:

> REC 37/23. It is recommended that ROTORSUN take the necessary measures to ensure that the components installed on its helicopters comply with the maintenance specifications defined by their manufacturers.

The investigation established that when the crew evacuated the helicopter in the reservoir, they did not use their lifejackets or the portable breathing devices. Although this had no impact on the crew's survival, the following safety recommendation is deemed necessary:

> REC 38/23. It is recommended that ROTORSUN remind its pilots to use portable life-saving devices in the event of impacts on water.