CIAIAC

COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

Report A-023/2012

Accident involving a Sokol PZL SWIDNIK W-3A aircraft, registration EC-JUN, operated by INAER, at Yátova (Valencia), on 2 July 2012

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COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

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Foreword

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

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.5 of Regulation (UE) n.º 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1, 4 and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it's not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

Consequently, any use of this report for purposes other than that of preventing 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.

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Abbreviations

00°	Degree(s)
00 °C	Degree centigrade(s)
00°00’00”	Degree(s), minute(s) and sexagesimal second(s)
AESA	Spain’s Aviation Safety Agency
AGL	Above Ground Level
ATPL (H)	Airline Transport Pilot License (Helicopter)
BRIF	Forest Fire Reinforcement Brigade
CIAIAC	Spain’s Civil Aviation Accident and Incident Investigation Commission
CPL(H)	Commercial Pilot License (Helicopter)
CVR	Cockpit Voice Recorder
EASA	European Aviation Safety Agency
FDR	Flight Data Recorder
ft	Foot
ft/min	Feet per minute
GPS	Global Positioning System
h	Hour(s)
HP	Horse Power
IAS	Indicated airspeed
KIAS	Indicated airspeed in knots
kg	Kilogram(s)
km	Kilometer(s)
km/h	Kilometers per hour
kt	Knot(s)
l	Liter(s)
LH	Left hand
m	Meter(s)
m/s	Meter(s) per second
MCC	Multi Crew Cooperation
min	Minute(s)
mm	Milimeter(s)
MOE-LIC	Special Firefighting Operations Manual
MTOW	Maximum Take-off Weight
N/A	Not applicable
N1	Compressor rpm’s
N2	Power turbine rpm’s
Nr	Main rotor rpm’s
OEI	One engine inoperative
OM	Operations Manual
RH	Right hand
rpm	Revolutions per minute
SB	Service Bulletin
TQ	Torque
UME	Military Emergencies Unit
V_1	Best climb speed
VHF	Very Hight Frequency
V_{toss}	Take-off Safety Speed

Synopsis

Owner and operator:	INAER
Aircraft:	Sokol PZL SWIDNIK W-3A
Date and time of accident:	2 July 2012; at 17:01 local time[1]
Site of accident:	Yátova (Valencia) – SPAIN
Persons onboard:	2 crew, seriously injured
Type of flight:	Aerial work – Commercial – Firefighting
Phase of flight:	Final approach
Date of approval:	12 November 2014

Summary of accident

On Monday, 2 July 2012, the helicopter Sokol PZL SWIDNIK W-3A, registration EC-JUN, suffered an accident when it was trying to land atop a mound in order to get its bambi bucket unloaded by the Forest Fire Reinforcement Brigade (BRIF in Spanish) of the Daroca Base (Zaragoza).

The helicopter was mobilized to take part in fighting a large fire in Cortes de Pallás (Valencia). After the helicopter crew sighted the BRIF personnel, they made a series of circles over two hills located next to each other, where the brigade's personnel were scattered. At one point during its last circling maneuver the helicopter experienced a partial loss of power. The crew made an emergency landing in an adjacent area where it impacted the ground.

Both people of the crew resulted seriously injured and the aircraft was seriously damaged.

[1] All times in this report are local.

1. FACTUAL INFORMATION

1.1. History of the flight

The helicopter, a Sokol PZL SWIDNIK W-3A, registration EC-JUN, was part of the Forest Fire Reinforcement Brigade (BRIF in Spanish) at the Daroca Base (Zaragoza).

On Monday, 2 July 2012, the helicopter and its brigade were mobilized to take part in fighting a large fire in Cortes de Pallás (Valencia). They took off from the base in Daroca at around 14:00 and reached the site of the fire after a one-hour flight. It was then that the crew was ordered to fly over the La Forata reservoir in the town of Yátova (Valencia) to search for a helicopter that had disappeared in the area just a short while earlier[2].

The crew of EC-JUN located the wreckage of the disappeared helicopter in the reservoir, and then set course for the Siete Aguas base in Valencia, where they landed at around 16:10.

They refueled[3] and at 16:50 the helicopter took off again en route to a location called Callembaja[4] (within the Yátova municipal limits), where the Daroca BRIF was cooling down the perimeter of the burned area.

The crew radioed a brigade technician, who told them to land in his vicinity so they could unload the bambi bucket and they could do water drops to support the brigade on the ground.

After the helicopter crew sighted the BRIF personnel, they made a series of circles over two hills located next to each other, where the brigade's personnel were scattered. At one point during its last circling maneuver, the helicopter experienced a partial loss of power. The crew made an emergency landing in an adjacent area where it impacted the ground.

During the event the coordination helicopter was circling and in contact with the crew of EC-JUN. The two crews were exchanging information on the upcoming tasks when the loss of power took place.

The crew in the coordination helicopter heard the MAYDAY distress call three times, and its crew saw how helicopter EC-JUN fell very rapidly.

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[2] A Bell 412 helicopter, registration EC-KSJ, had disappeared minutes before 14:00, as it approached the La Forata reservoir to take on water.
[3] They took on 1,200 l of fuel, enough to fly for two hours and return to base with a sufficient fuel reserve.
[4] The exact accident site was 0.8 km from CV-429, kilometer 9.6, in the direction of Arroyo de Ricastro, in the town of Yátova (Valencia).

When the BRIF personnel saw the helicopter dropping at a high rate of speed and heard it impact the ground, they quickly reported to the site to aid the crew.

1.2. Injuries to persons

The pilot under supervision, who was seated in the left side of the aircraft, suffered fractures of several vertebrae apophasis and inflammation of the neck.

The captain (supervisor), who was seated in the right side of the aircraft, had serious injuries to his chest, spinal column and his right leg and foot.

Injuries	Crew	Passangers	Total in the aircraft	Others
Fatal				
Serious	2		2	
Minor				N/A
None				N/A
TOTAL	2		2	

1.3. Damage to aircraft

The helicopter was seriously damaged.

1.4. Other damage

No other damage was made.

1.5. Personnel information

The operation was a single-pilot visual flight, though on this flight the crew consisted of two pilots, one acting as the pilot under supervision and seated in the LH seat in the cockpit, and another in the RH seat[5] who was acting as the captain supervising the former.

[5] In this helicopter model, the captain is seated in the LH seat.

1.5.1. *Pilot under supervision*

The pilot under supervision was a 36-year old Spanish national. He had a valid and in force Commercial Pilot License (Helicopter), a W3-Sokol rating and a firefighting-only agricultural rating. He had a medical certificate that was valid and in force until 20 June 2013.

He had a total of 1,139 flight hours, of which 140 had been on the type.

The language skills noted on his license were for Spanish and English.

He had not received Multi-Crew Coordination (MCC) training.

During the proficiency flight of 7 February 2012, he made two landings with a simulated engine failure before and after the decision point for the landing.

1.5.2. *Captain*

The captain was a 55 year old Polish national. He had a valid and in force Airline Transport Pilot License (Helicopter), a W3-Sokol type rating, an agricultural rating and a firefighting rating. He had a medical certificate that was valid and in force until 24 February 2013.

He had a total of 7,400 flight hours, of which 2,450 had been on the type.

The language skills noted on his license were for Polish and English. The post-accident interview was conducted in Spanish, where he demonstrated fluent speaking ability and was able to maintain a normal conversation.

He had not been trained on MCC or on flying in both piloting positions.

During the proficiency flight of 11 March 2012, he made two landings with a simulated engine failure before and after the decision point for the landing.

1.6. Aircraft information

1.6.1. *General*

The helicopter is a PZL SWIDNIK W-3A, registration EC-JUN, serial number 37.08.04. It was built in 1997.

It was entered in Spain’s Aircraft Registration Index on 30 October 2006.

It had a Certificate of Airworthiness that was valid and in force until 14 June 2013.

Its empty weight is 3977 kg and its maximum takeoff weight (MTOW) is 6,400 kg. The helicopter's weight and balance were within the limits specified in the Flight Manual for the entire flight.

Its landing gear features three non-retractable legs, one in the nose with two wheels, and two main landing gear legs with one wheel each.

It is equipped with two PZL KALISZ 10W engines, serial numbers 219963017A (engine 1, on the left side of the helicopter) and 219963018A (engine 2, on the right side of the helicopter).

The main rotor turns to the right as seen from above, that is, clockwise.

At the time of the accident the amount of fuel in the tanks is estimated to have been 1,100 l, thus making the aircraft's total weight an estimated 5,400 kg.

Aircraft EC-JUN started operations with INAER on 15 June 2012.

1.6.2. *System for transmitting power from each engine to the combined gearbox*

Each engine drives a shaft that comes out of its respective turbine.

In each engine the shaft that emerges from the turbine combines with an intermediate shaft that, in turn, joins the shaft that enters the combined gearbox via flexible couplings. The power of the two shafts that enter the combined gearbox is combined within the gearbox to drive the main rotor shaft. In order to connect them, the ends of the shafts terminate in a triangular face that is perpendicular to the shaft. This face has three drill holes, with their corresponding three bolts and nuts, which are used to attach it to the next shaft via a flexible coupling.

There is a component called the mounting cone (also known as a "pig's head") that is used to couple the engine and the combined gearbox. It spans the area from where the shaft exits the engine until it enters the combined gearbox, passing through the intermediate shaft. The mounting cone is attached to the combined gearbox via a Cardan-type coupling, which features extra clearance in two directions to prevent mechanical overloads. These clearances were the subject of a Service Bulletin issued by the engine manufacturer in September 2009 (Service Bulletin No. E-19W140/DOA/2009).

According to this bulletin, the clearances are not to exceed 0.6 mm axially in either of the two directions and must be inspected every 100 ± 10 h of operation.

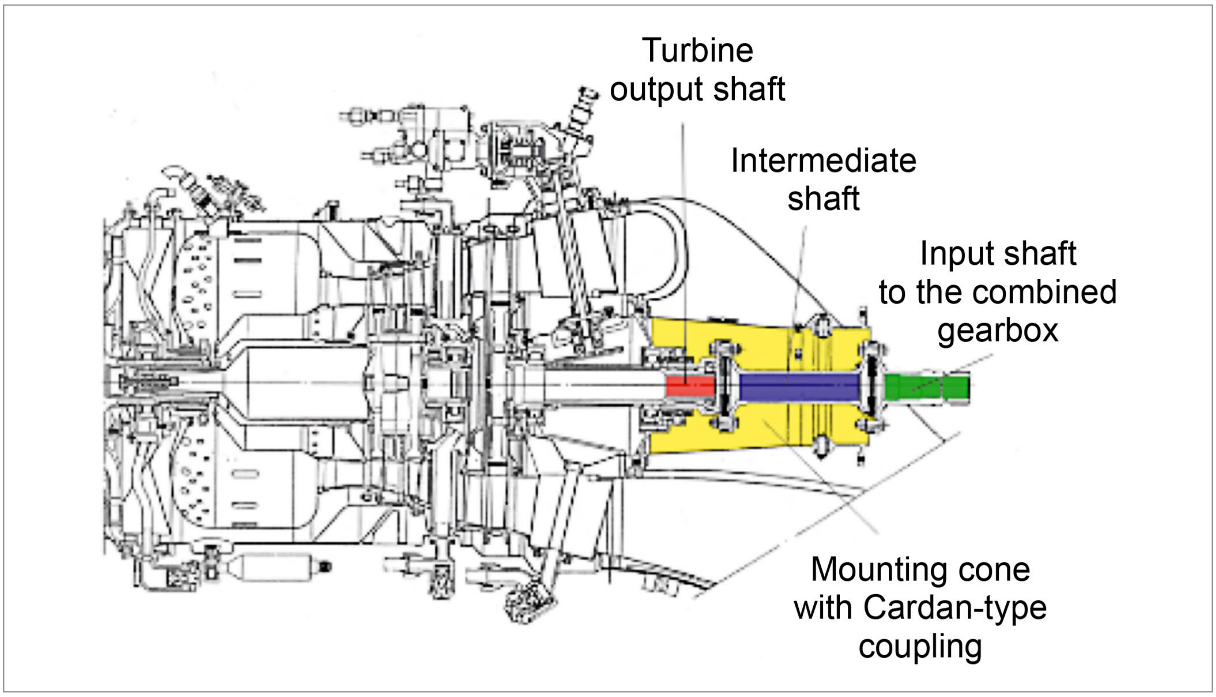

Figure 1. Cross-section of the engine to the entrance of the combined gearbox

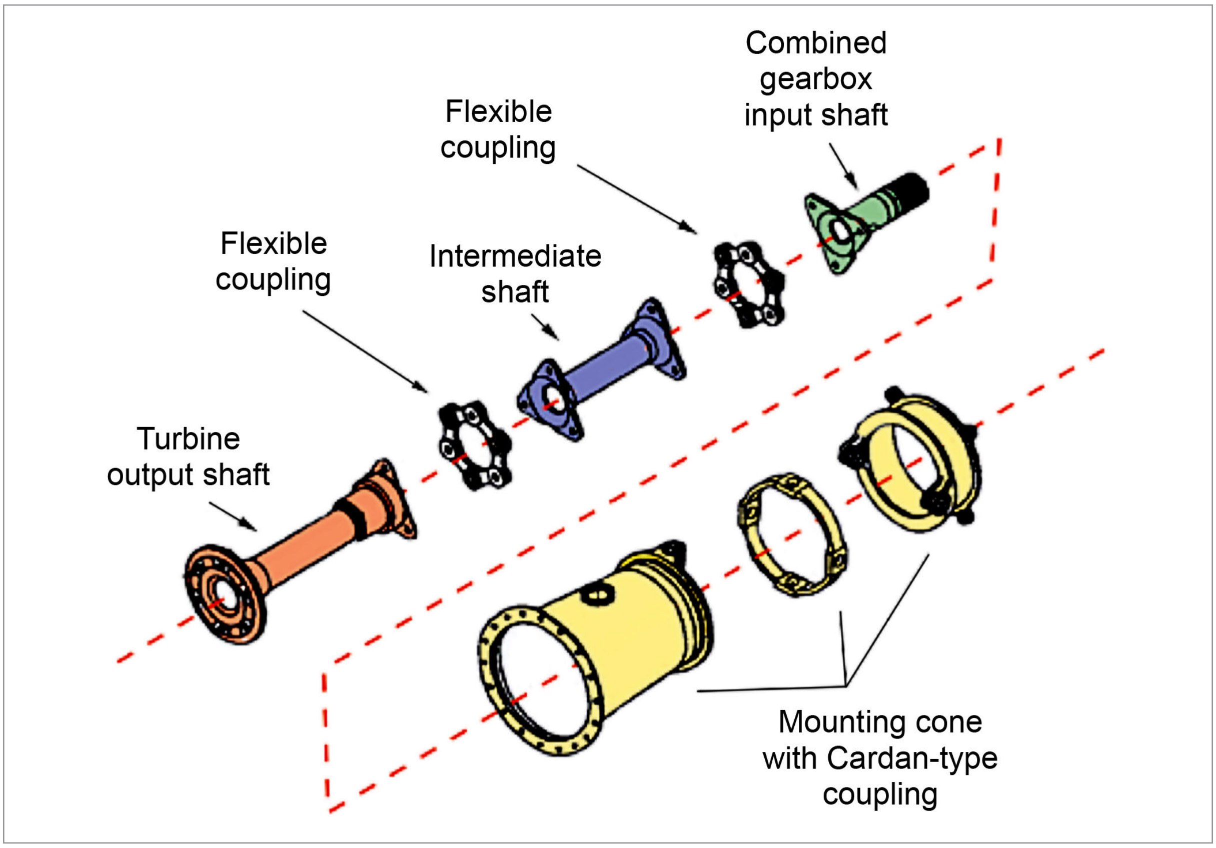

Figure 2. Exploded view of the parts that comprise the shaft, from the turbine to the combined gearbox, and its outer case (mounting cone)

The flexible couplings are hexagonal and consist of a set of metallic sheets joined together. They have six drill holes, three used to bolt the triangular plate at the end of one shaft and three used to bolt the plate from the other shaft.

The shaft that enters the combined gearbox from each engine features a system for detecting whether the shaft has been subject to torsional overloads. This system consists of two coaxial metallic parts that can move relative to each other if torsionally overloaded, causing a visible misalignment in two orifices.

1.6.3. *Maintenance*

Both engines were first overhauled in January 2006.

The maintenance records show that the overhaul was conducted as per the approved manual. On 24 January 2012 the last 300 h and 600 h checks of both the airframe and the engines were carried out. The last 25 h/15 day checks of the airframe and engines had been performed as per the planned schedule. No anomalies were detected during these checks.

On the day of the accident, before the flight from the base in Daroca, the aircraft and engines underwent a scheduled 25 h/15 day check, with 2,468 h on the airframe, 2,336 h on engine 1 and 2,338 h on engine 2. The clearances on the mounting cones of both engines were also measured for the first time by the current operator, giving values of 0.50 and 0.37 mm in engines 1 and 2, respectively (the clearances are measured in both directions for each mounting cone, and the larger one is recorded).

History of clearance checks for the mounting cones

The following information was gathered on the checks conducted of the mounting cones after the issuance of the service bulletin:

Date	Clearance (mm)		Hours of operation elapsed
	Engine 1	Engine 2	
11/11/2009	0.20	0.35	First time
26/02/2010	0.20	0.35	4
04/07/2010	0.20	0.35	40
22/09/2010	Not measured	0.36	64
18/01/2011	0.20	0.36	13
10/12/2011	0.35	0.35	287
02/07/2012	0.50	0.37	107

1.6.4. *Engine control and management systems*

This aircraft features three components that are essential to the control and operation of the engines: ALAE-2, ALRT-2B and ALRP-5. The functions and importance of each are briefly explained below.

ALAE-2

The nerve center of engine operations, there is one for each engine, located behind the RH seat in the cockpit.

This electronic device receives information on the engine's operating parameters, processes it and sends the signals needed to supply its corresponding engine with the right amount of fuel.

If one of the engines overspeeds[6], ALAE-2 cuts the fuel supply to that engine, which will then stop providing its thrust to the combined gearbox.

ALRT-2B

In the event of a fault in ALAE-2, there is a hydromechanical device, ALRT-2B, physically located next to the engine, which takes over the functions of ALAE-2. Once ALRT-2B goes into operation during a flight, the change cannot be undone to return to ALAE-2 in flight. This must be done on the ground by maintenance, which resets two buttons located on the engine to return ALAE-2 to service (there is one button on ALRP-5 and another on ALRT-2B, both of which trip).

The operation of ALAE-2 and ALRT-2B is mutually exclusive. They provide the same functions but they cannot both be in service at the same time.

ALRP-5

This unit controls the direct supply of fuel to the engine (as ordered by ALAE-2). Inside is WLP-3-5, which is an electrical actuator that governs the fuel valve.

There are no non-volatile memories in the engine control and operation systems. The parameters involving the control and operation of the engines are recorded on the flight data recorder (FDR).

[6] As determined by N_2 rpm's.

1.6.5. *Mode of operation with a fault in one engine*

With both engines operating normally, each one can supply a maximum power of 900 HP.

If, for whatever reason, N_1 (compressor rpm's) were to fall below 58% on either engine, the other would automatically increase its available power (without any action required by the crew) to 1,000 HP for a maximum of 30 minutes.

In addition, if commanded by the pilot by pressing a button (called 2.5 min-OEI) located on the collective control, the power on the operating engine is increased for an additional 2.5 minutes to 1,150 HP.

The 2.5 min-OEI button can also be pressed with no engine failures. This would not mean that either of the two engines that is operating normally will supply more than the rated 900 HP maximum; it would mean, however, that in the event of an engine failure, the 2.5 min OEI system would go into operation instantaneously.

1.6.6. *Flight Manual*

1.6.6.1. Operational limitations and restrictions

The operating limits for main rotor rpm's (N_r) are:

- With both engines running, the minimum and maximum limits for continuous use are between 100 and 105%. They can temporarily drop to 95%.
- With one engine inoperative (OEI), the continuous minimum is 95% and temporarily 85%, up to 15 seconds.

The engine torque limit with both engines running is:

- The maximum continuous engine torque is 85% for N_r = 105%.

The engine torque limits with OEI are:

- The maximum limit for 30 minutes of operation is 121% (with N_r equal to or less than 95%).
- The maximum limit for 2.5 minutes of operation is 139% (with N_r equal to or less than 95%).

1.6.6.2. Normal procedures

The take-off procedure in Section 2 of the Flight Manual recommends pressing the 2.5 min-OEI button (Sec. 2, pg. 2-22, Take-off). Likewise, the landing procedure recommends pressing the 2.5 min-OEI button (Sec. 2, pg. 2-24, Prelanding).

The takeoff procedure in Section 5A (category A operations)[7] of the Flight Manual requires keeping the 2.5 min-OEI button pressed. The landing is not described as a normal procedure. The landing maneuver following an engine failure (Emergency procedure) requires pressing the 2.5 min-OEI button.

Section 2 of the Flight Manual describes the procedures for landing in normal conditions until the aircraft is hovering (Sec. 2, pg. 2-24 Landing).

1. Establish approach to attain a 100 ft (30.5 m) altitude above the touchdown point at 38 KIAS (70 km/h) and at a descent rate of 600 ft/min (3 m/s).
2. At 100 ft (30.5 m) above the touchdown point, lift the nose of the helicopter to approximately +12°.
3. At 65 ft (20 m) above the touchdown point increase the collective gradually, as required to hover at 10 ft (3 m).

1.6.6.3. Overspeed light

Chapter 3 of the Flight Manual describes the emergencies associated with the danger and caution lights.

When the overspeed No. 1 light turns on, this means that the no. 1 engine has stopped due to the action of the engine's overspeed protection system when the engine's N_2 (power turbine rpm's) exceeded 120%. This light requires carrying out the engine emergency procedures.

1.6.6.4. Partial loss of power

Chapter 3 of the Flight Manual describes the emergency associated with a partial loss of power in flight.

- Engine failure in flight:
  - If the engine failure occurs at an altitude at or above 65 ft (20 m), proceed as follows:
    1. Adjust the descent rate to 600 ft/min (3 m/s), the main rotor rpm's (N_r) to above 95% and the speed to 38 KIAS (70 km/h).

[7] Category A refers to multi-engine helicopters, with performance information in the Flight Manual based on the critical engine failure concept, which ensures an adequate designated surface and a performance ability that is suited to the safe continuation of a flight in the event of an engine failure.

2. At an altitude of 65 ft (20 m) above the touchdown point, decelerate the helicopter by pulling back on the collective to lift the nose of the helicopter to between 15 and 20°.
3. Between 23 and 16 ft (7 and 5 m) gradually increase the collective to the maximum at the point contact is made with the ground.
4. Lower the nose to a 10° nose-up angle between 10 and 7 ft (3 and 2 m) above the touchdown point.

– If the failure occurs below 65 ft (20 m) above the touchdown point, proceed as follows:

1. Establish a 10° nose-up attitude.
2. Increase the collective to the maximum at the point of contact.

• After touching down, the procedure describes how to stop the helicopter's speed using the flight controls and the wheel brakes.

1.6.6.5. Helicopter performance following a partial loss of power

Assuming a total aircraft weight of 5,400 kg, an altitude of 1,700 ft and an outside air temperature of 35 °C, the Flight Manual was used to calculate the climb rate that could be achieved with one engine inoperative in two power demand conditions: 30 min OEI and 2.5 min OEI.

• In the case of 30-min OEI at a V_y (best climb speed) of 65 KIAS, with the engine de-icing system off and an N_r of 95%, a positive climb rate of 500 ft/min was calculated.

The calculation was based on the information contained in Section 4 (Performance Data) of the helicopter's Flight Manual; specifically, on the "Single engine rate of climb" graphs.

• In the case of 2.5-min OEI at a V_{toss} (take-off safety speed) of 40 KIAS, with the engine de-icing system off and an N_r of 95%, a positive climb rate of 550 ft/min was calculated.

The calculation was based on the information contained in Section 5A (Category A operations) of the helicopter's Flight Manual; specifically, on the "Single engine power failure during approach" graphs.

1.7. Meteorological information

The weather information was obtained from data recorded at the automatic station in Buñol (Valencia), about 8 km away from the accident site at an elevation of 600 m, and from BRIF personnel at the crash site.

1.7.1. *Data recorded at the Buñol weather station*

At the time of the accident, winds were weak (between 7 and 9 kt) from the southeast, gusting to 16 kt.

The air temperature was 26 °C and there were few high clouds.

1.7.2. *Data provided by BRIF personnel at the accident site*

Three BRIF firefighters at the crash site reported that winds locally were weak, and from the east. They estimated the temperature in the area as high, at around 35° C, considering that the burned area was adding to the ambient temperature.

1.8. Aids to navigation

Not applicable.

1.9. Communications

The accident helicopter, callsign "Daroca 1", had VHF radio communications equipment to communicate with other aircraft in flight.

Communications in the flight area were directly between air stations or from air to ground.

Outside communications were handled by the pilot under supervision, who was also the pilot flying.

What follows is a brief summary of the communications that took place between the accident helicopter and the air resources coordination aircraft, as well as between the accident helicopter and the BRIF.

After helicopter EC-JUN took off from the Siete Aguas base, the pilot under supervision made several unsuccessful attempts to contact the coordination helicopter.

He later made contact with the BRIF teams that were fighting the fire, reporting his arrival at the fire zone. The supervisor in charge of the BRIF instructed him to land nearby so they could deploy the bambi bucket and start cooling down the area via water drops.

The coordination helicopter, callsign "V1", contacted Daroca 1 to remind its pilot of the need to contact V1 before entering the fire zone. Daroca 1 replied that he had tried to call V1, but had not received a reply. V1 then instructed him to assist the BRIF as planned and to inform V1 if he sighted any fire sources.

Ten seconds after V1 completed its final message to Daroca 1, the latter made a distress call, repeating the word MAYDAY three times. The coordination helicopter asked what was happening, with Daroca 1 replying that they were going down.

The BRIF supervisor reported on the radio that helicopter EC-JUN was going down.

1.10. Information on the BRIF work area

The members of the BRIF were scattered along two small hills that rose to elevations of 587 and 553 m. They were next to each other but separated by a ravine (see figure below).

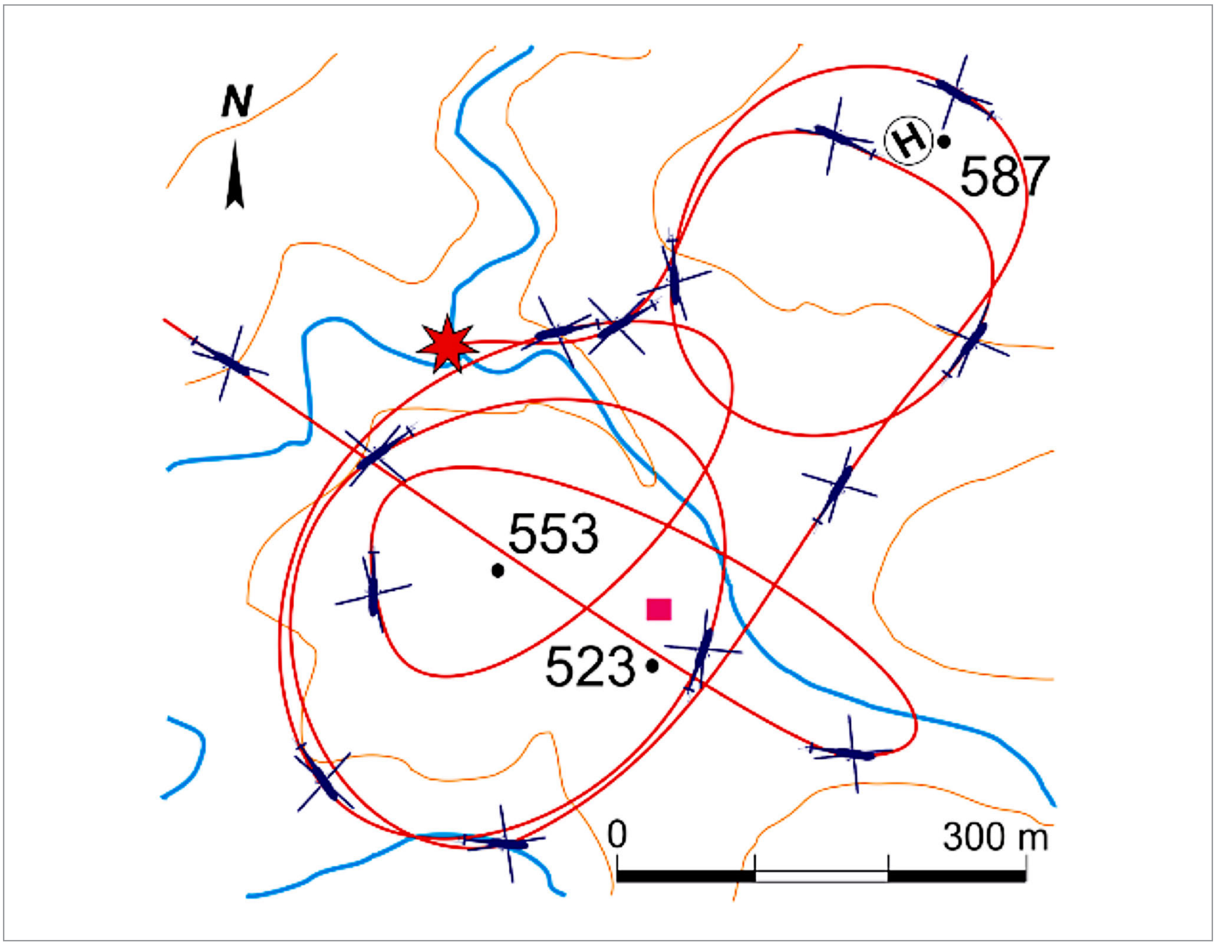

Figure 3. Planned landing site, circling area and impact site

The supervisor in charge of the BRIF informed the helicopter crew that they could land in the hill to the northeast, where other helicopters had landed previously. The hill was at an elevation of 587 m and its summit was covered in rocks and shrubs.

The emergency landing site was at the junction of two ravines, flanked by the steep sides of the hills on either side. The hillsides and ravines were enveloped by shrubs and scattered trees.

1.11. Flight recorders

The helicopter was equipped with a flight data recorder for engine and main rotor parameters (FDR) and with a cockpit voice recorder (CVR). Both recorders had an Authorized Release Certificate (EASA Form One), issued in December 2011 by Poland's Civil Aviation Authority.

The FDR was a ZBN-1-1 model, serial number 60108. It is a magnetic tape recorder that can record up to 50 flight hours and a total of 20 analog and 48 digital parameters.

The cockpit voice recorder was a MARS-BM 70A-10M model, serial number 355013. It is a magnetic tape recorder that records the voice of the pilot in the LH seat on channel 1, the voice of the pilot in the RH seat on channel 2 and cockpit sounds on channel 3.

Recorded on the CVR were the voices of both pilots, the voices of the radio operators on the BRIF and the voice of the pilot on coordination helicopter V1.

Investigators also obtained the computerized records of the GPS data used by the fleet monitoring system installed on the helicopter. These data provide information at geographic coordinates with a time stamp, heading, ground speed and altitude.

The data from this system were extracted in two formats:

a) Data sent telephonically during the flight to the operator and recorded approximately every 30 seconds.
b) Data taken from the volatile memory on the GPS unit onboard the helicopter. The first data point is from 16:58:49 and the last from 17:02:07.

The time reference used was that from the GPS[8] at the time that the GROUND signal was activated on the FDR. This signal is activated when the landing gear strut on the helicopter is compressed.

[8] The report uses local time, obtained by adding two hours to those provided by the GPS.

1.11.1. *Flight data recorder (FDR)*

The FDR had recorded 754 seconds from the last flight made by the helicopter. It did not record data between seconds 683-690 or 742-743, all inclusive, or on seconds 745, 748, 752 and 753.

The GROUND signal was recorded in second 754 on the FDR, corresponding to 15:01:36 GPS time and 17:01:36 local time (which is the time used in this report).

At no time during the flight is there a record of the 2.5 min-OEI button being pressed.

At 17:01:20 (second 738 on the FDR) two events were recorded after which the helicopter became unstable:

1. a sudden drop in the engine 1 torque (TQ_1), which went from 95% to 2.5%, and
2. the activation of the overspeed protection system on engine 1.

So as to facilitate a study of the FDR, the flight was divided into three phases, prior to, during and subsequent to 15:01:20 (second 738 on the FDR).

The figures below show the changes in various parameters of interest during the final 25 seconds of the flight. Note the dashed red vertical line at time 15:01:20, which marks the partial loss of power in engine 1.

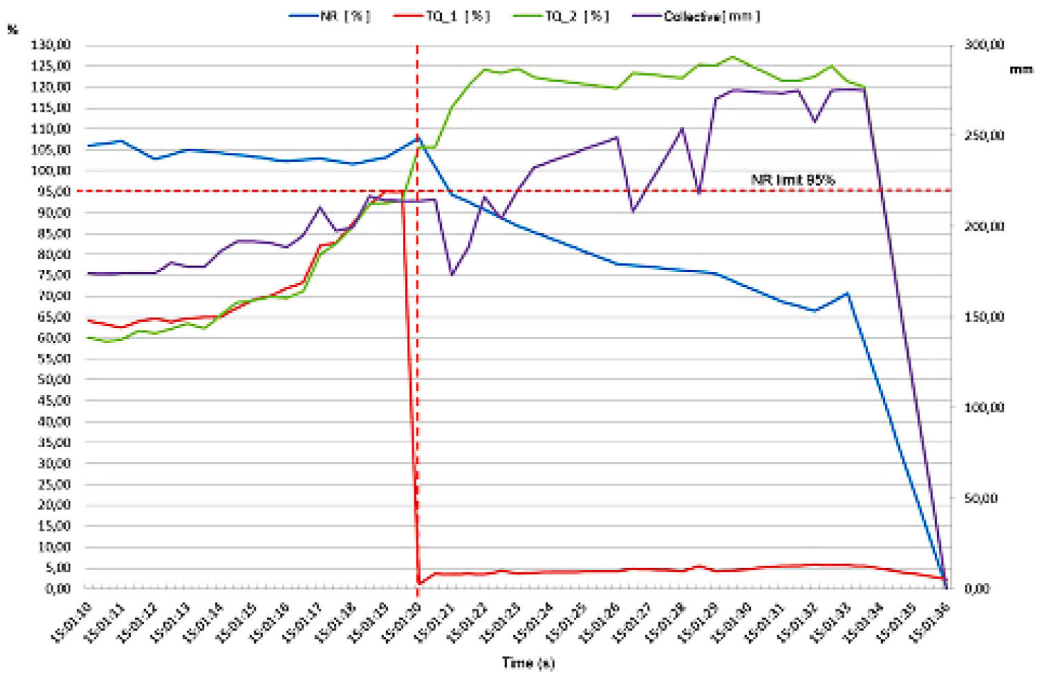

Figure 4. Input to the collective control lever, torque readings for both engines and main rotor rpm's

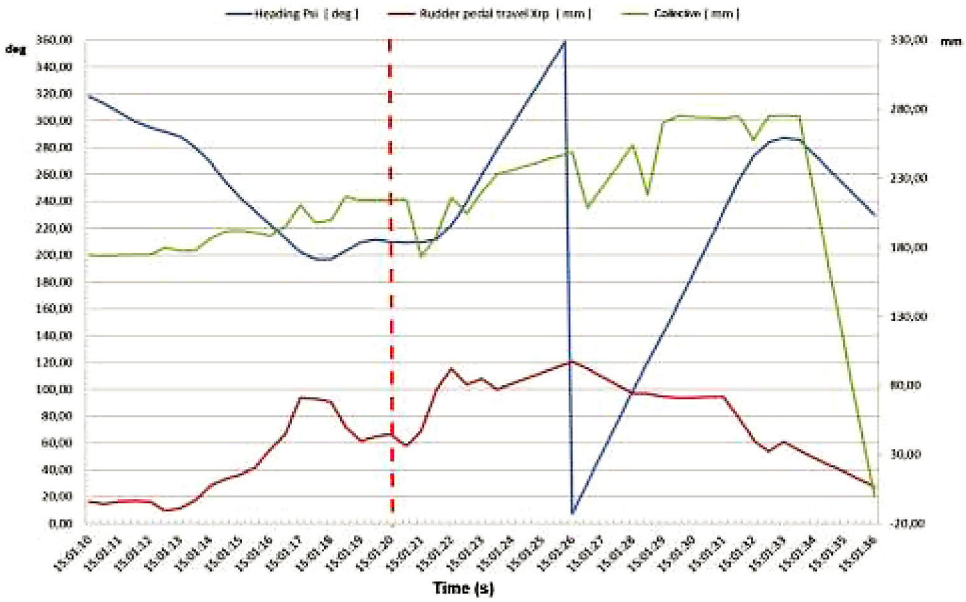

Figure 5. Right pedal travel, displacement of the actuating rod that changes the pitch angle on the tail rotor blades, and heading readings

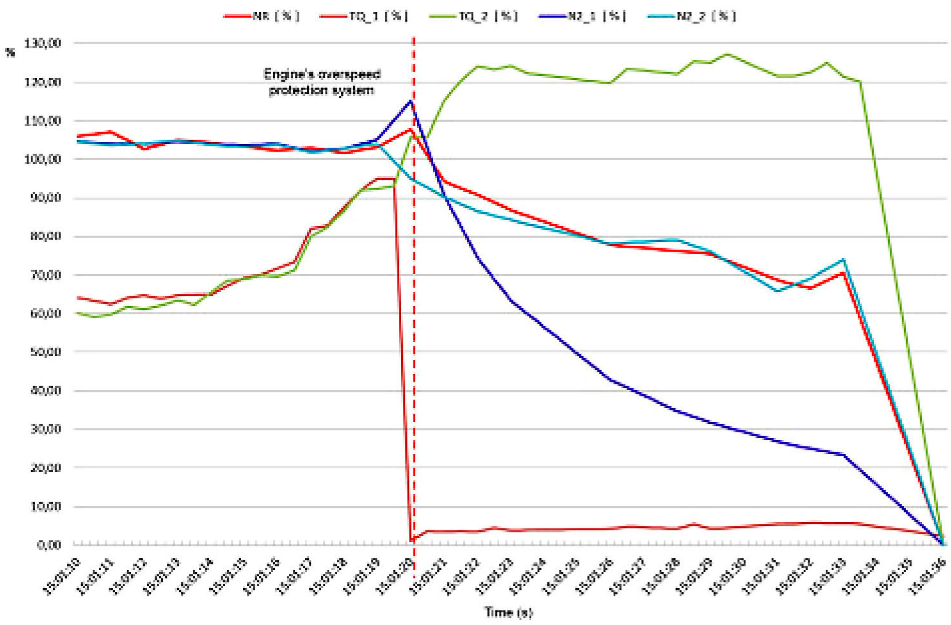

Figure 6. Torque (TQ) and N_2 values for both engines, and main rotor rpm's

A) Prior to 15:01:20

This period spans from the time when the helicopter entered the BRIF work area, at approximately second 520, and started a series of circling maneuvers around the hill to the west, continuing these maneuvers over the hill to the northeast, until second 738.

- *Altitude, AGL and speed*

The helicopter entered the BRIF work area from the northwest at an IAS of approximately 75 kt. On its first circle it was at a pressure altitude of between 1,650 and 1,775 ft, an altitude it maintained until 15:01:20.

The helicopter flew over the summit of the hill to the northeast twice (near which the accident would later take place) from south to north. On its first pass it was at a pressure altitude of 1,775 ft and a radio-altitude of 71 ft (21.6 m). After clearing the hill it descended to 1685 ft before climbing to 1,714 ft and flying over the hill a second time at an AGL of 25 ft (7.6 m).

The IAS during the circling maneuvers fell to values between 40 and 60 kt, except during the last and second-to-last circles, when it fell below 40 kt to as low as 28 kt.

- *Heading*

The headings recorded on the FDR reflect the left turns made by the helicopter as it circled to the left over both hills, as recorded on the GPS.

Seven seconds before 15:01:20, there was a significant forward deflection of the right pedal, causing a proportional decrease in the length of the actuating rod that changes the pitch angle of the tail rotor blades. Three seconds later, the heading stabilized between 199° and 210° and the right pedal was kept at the same forward-most position as before.

- *Engines 1 and 2*

At the start of this phase of the flight, the torque parameters for both engines, whose values oscillated between 45 and 60%, were consistent with the flight conditions of the helicopter.

In the final 18 seconds of this phase, these values rose to 70% before rising even more in the final seconds, reaching values of 95% and 92% in the two engines before time 15:01:20.

The travel recorded for the collective lever was consistent with the increased torque values noted above.

The values for the power turbine rpm’s (N_2) on both engines remained between 102 and 105%.

- *Main rotor rpm's (N_r)*

The value for the main rotor rpm's remained between 101 and 105%, peaking briefly at 107%.

- *Helicopter attitude*

The FDR records data on the travel of the longitudinal cyclic and lateral cyclic flight controls, which determine the pitch and roll angles, respectively. During the left circling turns the pitch angle was kept near 0° and the roll angle was kept steady.

Eight seconds before 15:01:20 the longitudinal cyclic was moved forward, resulting in the pitch angle increasing downward to a value of –10°. There was also a movement of the lateral cyclic to the right that stopped the left turn.

B) At 15:01:20

The values for the helicopter's attitude and for the engine and main rotor parameters at 15:01:20 are shown in the table below, along with the values in the second immediately prior.

Time	Helicopter						Engine 1		Engine 2		Main rotor
	Pitch	Roll	IAS	Collective Lever	Right pedal	Heading	TQ	N_2	TQ	N_2	N_r
15:01:19	–10°	6°	41 kt	High position	Forward position	210	95%	105%	92%	104%	103%
15:01:20	–4°	6°	31 kt	High position	Forward position	209	2.34%	115%	106%	95%	107%

The red color in the cells associated with engine 1 at 15:01:20 highlight the overspeed event that occurred. The 115% reading for N_2 is assumed to have taken place fractions of a second after the 120% that triggered the overspeed.

C) After 15:01:20

Below is a summary of the change in the helicopter's attitude, engine and main rotor parameters between the first second after 15:01:20 and the end of the FDR recording.

- Engine 1:

  - The torque remained between 2.34 and 6.1%,
  - N_2 fell gradually from 91 to 23%,
  - and the low oil pressure light turned on two seconds after the event.

- Engine 2:

  - The torque rose to 124% in two seconds and stayed at around this value until the end.
  - N_2 dropped to 86% in two seconds and continued falling to around 65%.

- N_r fell to 95% in two seconds and continued falling to around 67%.
- The collective lever was moved slightly downward in the first second before being moved upward. In the next second its value was already higher than it had been at the time of the event and it continued rising to a maximum value some eight seconds later.
- The barometric altitude was constant for the following four seconds before falling until the time of impact.
- The radio altitude held at 200 ft for two seconds and then increased to 285 ft three seconds later before it started to decrease until the time of impact.
- The IAS went from 31 kt to 8 kt in one second and remained at 0 kt until the impact.
- The pitch angle remained at –4° for two seconds after the time of the event, after which it increased to –23° in four seconds before decreasing once more to –3°.
- The helicopter's heading, which had been 210° at 15:01:20, increased until the helicopter made one full turn. It then continued to increase to heading 287°, at which time the direction of rotation changed, with the helicopter eventually laid on the ground on a heading of 230°.
- The displacements of the pedals and the actuating rod that changes the angle of attack on the tail rotor blades were in keeping with the changes in heading described above.

1.11.2. *Cockpit voice recorder (CVR)*

Continuing with the same phases of flight noted earlier, the details of the CVR are described next (figure 7).

A) Prior to 15:01:20

After taking off, the crew planned to head to the area where the BRIF was working to help them and to have them put the bambi bucket in its working position.

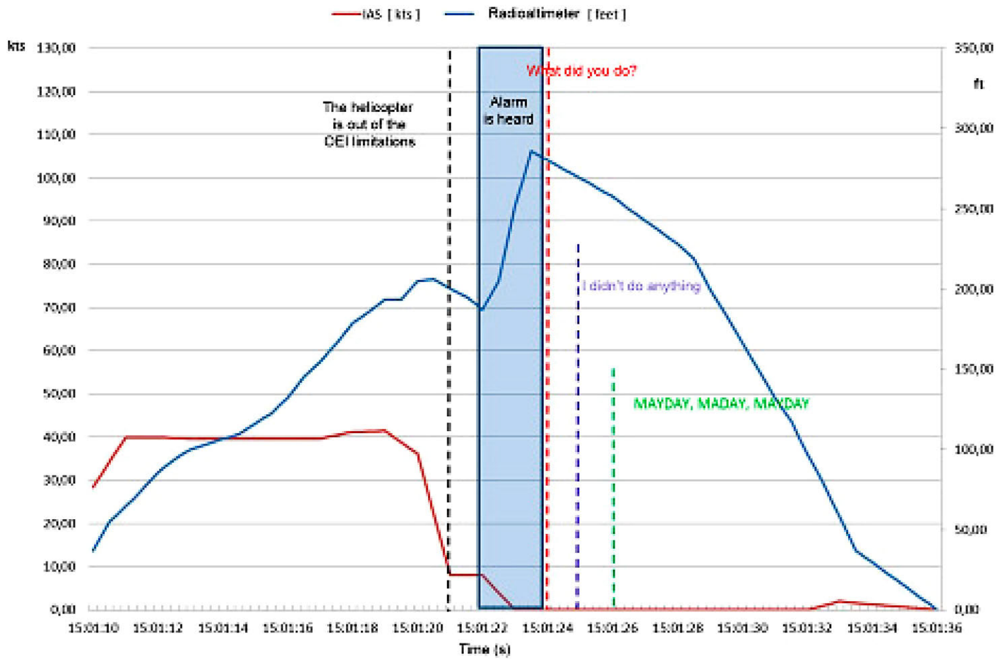

Figure 7. IAS, radio altimeter reading, and voices in the cockpit after the emergency

Upon entering the fire area, the pilot under supervision radioed the coordination helicopter in the fire area without receiving a response. He tried repeatedly but with the same result.

Seconds later he called the BRIF supervisor, which also required making several calls before establishing contact with him. The supervisor told him the area where they were working to cool down the perimeter of the fire. After identifying the area, the pilot under supervision started a series of circling maneuvers.

The BRIF supervisor told him that the area where he was located, on the hill to the southwest at an elevation of 553 m, was not suitable for landing since the area was burned, and he instructed the pilot to proceed to the other hilltop, which was then at the pilot's 12 o'clock position.

Seconds later the helicopter received a call from the flight coordinator at the scene, which the pilot under supervision answered. The coordinator reminded him of the need to contact the coordinator first, to which the pilot under supervision replied that he had tried unsuccessfully to radio him. The coordinator then proceeded to give them instructions on what to do if they saw the fire reflash. Four seconds before the event, that is, at 15:01:16, the captain (who was supervising the other pilot) said "You don't pull out" while they were completing the coordinator's instructions.

No aural alarms were heard.

B) At 15:01:20

A high-pitched sound is heard on the CVR.

C) After 15:01:20

Two seconds after the high-pitched sound, an alarm is heard lasting two seconds. The captain then asked the pilot under supervision "What did you do?" to which the pilot under supervision replied "I didn't do anything."

At 15:01:26 the pilot under supervision is heard saying "MAYDAY MAYDAY MAYDAY," immediately after which the flight coordinator asked "What's wrong? What's wrong?" The pilot under supervision replied, "Daroca 1, we're going down."

The BRIF supervisor is then heard saying "The Sokol is coming down here," followed a second later by the aircraft impacting the ground, at which point the CVR recording ended.

1.11.3. *Fleet tracking (GPS)*

The helicopter's coordinates, heading, ground speed and altitude were extracted from the memory of the fleet tracking unit for those points that had been recorded. The recorded data were used to determine the helicopter's approximate flight path.

A) Before 15:01:20

The flight path shows that the helicopter entered the area from the northwest and circled three times, holding its altitude above the hill to the southwest.

After completing the third circle, the aircraft proceeded northeast to the other hill, where it circled one and a half times before the accident (15:01:20, or second 738 on the FDR).

The recorded ground speed indicated that it approached the circling area, gradually reducing its speed[9] from 91 kt to 50 kt by the time it started circling. It then continued to reduce its ground speed to around 43 kt during the circling maneuvers. At 15:00:05 its speed was 45 kt, dropping to 23 kt 15 seconds later. The speed remained more or less constant at this latter value until the last data point before the event, at 15:01:16, when the speed was 23 kt.

[9] The speed obtained from the GPS unit is the aircraft's absolute speed, that is, its ground speed.

B) At 15:01:20

There is no GPS data point for this exact time.

C) After 15:01:20

There are only two data points after the event:

- one in the second immediately following, at 15:01:21, recording a ground speed of 25 kt and an altitude of 1,896 ft (578 m), and
- another 15 seconds later, at 15:01:36, recording a ground speed of 0 kt and an altitude of 1,653 ft (504 m).

Time stamp	Time	Ground speed	Altitude
Emergency	15:01:20	No reading	
1 second later	15:01:21	25 kt	1,896 ft
16 seconds later	15:01:36	0 kt	1,653 ft

1.12. Wreckage and impact information

The speed at the time of the impact was mainly vertical, with very little pitch angle and a slight roll to the right. The altitude of the impact point is 485 m (1,591 ft), and the helicopter did not move from this impact point, coming to rest on the lower part of the fuselage, which was slightly tilted to the right.

The forward gear leg bent backward and broke, becoming lodged in the opening where the leg folds into and is attached to the helicopter fuselage.

Figures 8 and 9. Aircraft after the impact

The two legs on the aft gear and their respective wheels retracted backward until they touched the lower part of the fuselage.

The right side of the airframe was more damaged due to the way in which the impact with the ground took place. The roof of the airframe (weighed down by the mass of the engines and transmission) also gave way as a result of the impact, noticeably reducing the clearance in the passenger cabin, especially on the right side.

There was damage to the aft end of the tail cone. The tail skid, consisting of two levers attached to the tail cone structure and a third attaching arm, consisting of a damper, had both levers bent backwards. The skid itself had been displaced until it contacted with and impacted the bottom rear of the tail cone.

The vertical stabilizer was broken where it attaches to the tail cone and it had fallen on its right side. It remained attached by a piece of fiber sheathing and a series of electrical cables. The driveshaft was disconnected and the tail rotor blades had lost about half their surface area. The missing parts of the tail rotor blades were found near the impact site. There were no signs that the blades had impacted against the ground or trees.

The main rotor blades showed evidence of damage from impacting against objects, primarily a couple of trees located near the helicopter on the ground. One blade segment was behind the helicopter halfway down the hillside, located behind the tail of the helicopter.

The right pedal was displaced fully forward and jammed in place.

1.13. Medical and pathological information

Not applicable.

1.14. Fire

The aircraft did not catch fire after the accident.

1.15. Survival aspects

The first people to arrive at the impact site were the members of the BRIF, who reached it two or three minutes after the helicopter impacted the ground. When they arrived the main rotor blades were still rotating, so they waited outside the turn radius of the main rotor blades. Before the main rotor stopped turning, they were asked by the pilot seated in the LH seat to help evacuate the pilot in the RH seat.

While they were extracting him from the cockpit, the main rotor blades impacted the ground, as a result of which the people who were aiding the injured pilots stopped this activity, dropping to the ground. Once the main rotor stopped turning, they resumed the evacuation of both pilots.

The pilot in the RH seat was more severely injured than the one in the LH seat, mainly because the impact with the ground was absorbed to a greater extent by the right side of the aircraft. In fact, this pilot's right leg was pinned against the fuselage.

It would have been difficult or impossible for the two pilots to have exited the cockpit unaided.

1.16. Tests and research

1.16.1. *Eyewitness interviews*

Crew

- *Pilot under supervision*

He was in the LH seat and was being supervised by an experienced Sokol captain, a Polish national who, in the opinion of the pilot under supervision, spoke and understood Spanish well. He knew him from the pre-season campaign in Tineo (Asturias), a month and a half before the accident. They had been together in Daroca for 15 days.

They had taken off from Daroca and flown for an hour to reach the fire area, and then spent another hour over the La Forata reservoir looking for a downed helicopter (which had also taken off from Daroca, was operated by the same company and whose pilot was a colleague and friend of his). Upon reaching the reservoir the first thing they saw was a fuel slick in the water. Then, when they saw parts of the fairing on the shore of the reservoir, they reported that the helicopter they were looking for was very likely at the bottom of the reservoir, and they assumed that the pilot had not survived the accident.

He stated that this realization affected him, and that he was upset by the loss of his colleague in the subsequent hours. He said that he was worried "about other things" during the flight and was not fully focused on the flight. The pilot in the RH seat did not seem to him to be as affected.

After flying for two hours they went to Siete Aguas to refuel and to rest for 40 minutes. He did not recall how much fuel they took on, but it was standard to refuel up to 1,200 l, enough for two hours of flight plus a reserve.

They took off from the base at Siete Aguas and headed for the area where the Daroca BRIF was located, which they eventually reported to the air coordinator (V1) after trying unsuccessfully a couple of times due to high radio traffic.

He stated that he was the pilot flying for the entire flight, until just after 15:01:20.

Once in the area where the BRIF was, he circled the first hill and then proceeded as instructed by the supervisor to the adjacent hill to the northeast, where the BRIF was, so they could deploy the bambi bucket.

Over this hill and after circling once, he made something akin to a crosswind leg and lined up on final to land atop a mound at his 10 o'clock position. Seconds later, while on short final, he heard a noise and transferred control to the other pilot before immediately making a distress call. The other pilot (the Polish captain) took the controls then, and the pilot under supervision did not touch them after that (except at the end, when both were pulling on the collective). It seemed normal to him to have the other pilot take the controls so quickly, given his own role as a pilot under supervision.

He reported a power failure in one or both engines, he could not recall exactly, and that he did not hear any aural warnings in the cockpit or see any danger or caution lights. He did not recall hearing the "Engine out" alarm.

He could not recall the wind direction, but he noted it was weak.

When asked why he circled so low at such a low speed, he explained that in the Sokol he makes approaches at an slight incline because of the airplane-style cockpit and the low forward visibility, and that he even makes the final approach at a slight right nose angle so as to increase the visibility out the left side.

When asked if they moved the throttle levers at the time of the event, he said no.

When informed that the torque demand was very high at the time of the accident, he replied that he was unaware of this and informed that between piloting, the radio and landing, he was saturated. He reasoned that perhaps the speed was low, hence the high torque. He said his workload was high and did not notice the torque.

When asked if the pilot flying during the emergency reported the emergency, he said no.

When asked if he pressed the 2.5 min-OEI button, he said no. He did not know if the other pilot had pressed it or not.

In a subsequent interview he was told that there were no signs that the crew had selected a landing point, to which he replied that he had selected one, though he had not communicated it to the other pilot.

When asked about the use of checklists, he stated they usually do the items from memory and that they do not use them, even to start up the engines.

He stated that during the descent trajectory, he did not recall the helicopter making any turns. He did not recall impacting anything before hitting the ground. Once on the ground, BRIF personnel and other people nearby quickly responded. He signaled them to keep away until he was able to reach the engine levers and stop the engines, at which point he told them to help the other pilot, whose injuries were more serious.

- *Captain*

In addition to the usual details already noted regarding that day's operations, he added the following in relation to the emergency that took place.

He stated that when the event happened, they were both at the controls applying thrust to climb a little, and then he heard a noise and the number 1 engine stopped (he is sure that it was the engine further away from him). He did not recall how engine 2 responded. He thinks they reduced the helicopter's forward speed by lifting its nose, and that they made two or three clockwise turns while they descended sharply.

When the loss of engine power occurred, their indicated airspeed was, in his words, "reduced", at approximately 40 kt, and their heading was N-NE. He thinks it may have been around 060°.

They had not yet decided where they would land.

When asked about the wind he said it was gusting and swirling, but he could not specify the directions. He said that the outside air temperature was above 30 °C.

He did not recall any impacts prior to the one with the ground.

After hitting the ground his right foot became trapped. He said that all engine levers were retarded and that the main rotor was still turning.

The personnel who had reported to help them extracted him from the helicopter.

Witnesses outside the helicopter

There were BRIF and other specialized personnel from the UME[10] who were also helping to extinguish the fire.

Regarding the left circling turns and the helicopter's altitude near the tops of the two hills, the accounts of the various eyewitness interviewed were all in agreement.

One of them, a UME member who was working as an air controller in helicopter operations, reported that he heard a noise like an engine stopping, that the helicopter made a 360° turn about its vertical axis as it fell rapidly.

None of the eyewitnesses was able to see the moment of impact due to the narrow terrain where it impacted.

1.16.2. *Hangar inspection of the wreckage*

The aircraft wreckage, in particular the engines and its auxiliary systems, were inspected in detail on 25 and 26 July 2012. It was carried out in the hangar where the helicopter was under custody after being removed from the field. Involved in the inspection were representatives from the manufacturer of the aircraft[11], the operator and the Polish accident investigation authority. The inspection was led by CIAIAC investigators.

Auxiliary systems

The two ALAE-2 were removed and a digital multimeter was used to check the relevant pins on a connector at the rear of the units to reveal that engine 1 had oversped, something that did not happen with engine 2.

Both ALAE-2 units were also verified to have been working in automatic mode (later it was also verified that the buttons on ALRP-5 and ALRT-2B were not tripped, indicating that ALRT-2B did not switch to hydromechanical mode while in flight).

The fuel pumps on each engine's ALRP-5 were removed, and in both it was noted that:

- The shaft was in good condition and turned freely.
- The filter was clean and in good condition.
- The untripped button indicated that ALAE-2 was in operation, meaning that the electronic control mode was in effect.

[10] Military Emergencies Unit.
[11] Of the engines, engine management and control system and of the helicopter.

The ALRT-2B units on each engine were removed. In both it was noted that:

- The shaft was in good condition and turned freely
- The untripped button indicated that ALAE-2 was in operation, meaning that the electronic control mode was in effect.

Engine 1

The shaft on both the compressor and the turbine rotated freely.

There was a dent at the front of the engine on a silver-plated metal cylinder with a semispherical base that is protected by the air intake covers, which had been previously removed. The technicians attributed the dent to the movement of these covers during the impact with the ground (the same thing was observed in engine 2).

The flexible coupling that joins the shaft exiting the turbine with the intermediate shaft was fractured in a way that it decoupled the transmission (the fragments that were found were recovered). Such a decoupling would leave the output of the turbine unloaded, causing an immediate overspeed in N_2 as the turbine goes from having a load (and a high one at that moment) to having zero load. In addition, the flexible coupling that joins the intermediate shaft with the shaft that enters the combined gearbox exhibited partial fractures.

Figure 10. Intermediate shaft decoupled from the engine 1 turbine output shaft. Around it is the mounting cone, which was fractured by the ejected fragments of the flexible coupling. At the rear, in blue, is the combined gearbox

Figure 11. Same assembly seen from another angle, showing the partially broken flexible coupling between the intermediate shaft and the shaft entering the combined gearbox

Figure 12. Partially broken flexible coupling between the intermediate shaft and the shaft entering the combined gearbox

The clearances between the Cardan coupling on the mounting cone and the combined gearbox were also found to be excessive in both directions where this clearance exists to avoid mechanical overloads. In the opinion of the Polish experts, these clearances were not caused by the same impact that caused the dent (in fact, they were not found in the other engine). Moreover, the fracture of the flexible coupling between the turbine output and intermediate shafts had ejected its components at a sufficiently high radial speed to break the metallic plating in the area where the shaft rotates (mounting cone).

Figure 13. Broken mounting cone. Note the fracture caused by the fragments of the flexible coupling projected radially

Figure 14. Broken mounting cone showing a close-up of the Cardan coupling

Engine 2

The shaft on both the compressor and the turbine rotated freely.

The mounting cone's shape, appearance and clearance were normal, as were the output shaft and the flexible couplings for the shaft entering the combined gearbox.

Combined gearbox

The shaft that is driven by the turbine output shaft on engine 2 was disassembled to see if it too had been subjected to an overload.

An inspection revealed that the two orifices drilled in the system to check for such a defect were misaligned, indicating that engine 2 was subjected to an excessive torsional load, which was transmitted to the combined gearbox.

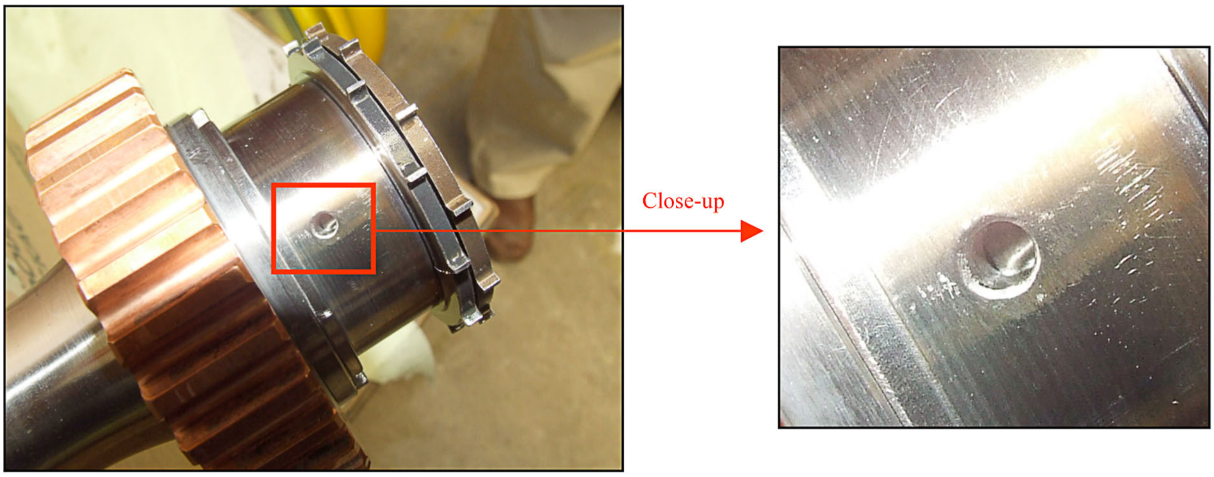

Figure 15. Orifices to check for excessive torsion and close-up

1.16.3. *Laboratory inspection of the broken turbine shaft on engine 1*

Samples were taken of the broken coupling materials and sent to a specialized metallurgical laboratory for analysis of the fractures. These samples are as shown on the following two figures:

Figure 16. Pieces of the destroyed flexible coupling that attached the turbine output shaft to the intermediate shaft

Figure 17. Intermediate shaft coupled to the shaft that enters the combined gearbox via its partially broken flexible coupling

A fractographic study of the breaks in the flexible coupling joining the turbine output shaft and the intermediate shaft revealed that these breaks were produced by fatigue mechanisms that started in the central part of the sheets and advanced outward. The small size of the area of the final tear indicates that the fracture took place with little stress forces. The areas where the fault in the material started did not show signs of cracking produced by any mechanism other than fatigue in the material.

The broken sheets of the flexible coupling between the intermediate shaft and the one that enters the combined gearbox, however, failed due to ductile tearing under shear stress, exhibiting plastic deformation indicative of fracture from overloading.

The evidence compiled during this analysis shows that the flexible coupling between the turbine output shaft and the intermediate shaft broke before the other one.

1.17. Organizational and management information

1.17.1. *Selection of landing point*

The operator's Special Firefighting Operations Manual (MOE-LCI) specifies that *"the special characteristics of firefighting (LCI) flights can result in operations that approach the limitations of this manual and of the helicopter itself. However, the safety of individuals, be they crewmembers or not, or of materials, equipment, or helicopters, be they involved with the flight or not, must not be jeopardized"*.

This same manual defines the landing point as the *"site that fulfills the safety conditions required for a helicopter to take off and/or land in firefighting flights and allows firefighting crews to embark and disembark"*.

It also stipulates that *"the pilot flying during takeoffs and landings must reduce the risk to the helicopter, persons and things as much as possible in the event of a failure of the powerplant(s)"*.

The MOE-LCI regards the descent and pick-up of crews outside their home base as a basic maneuver that requires special attention and skills during its execution and when deciding where to carry it out.

The following factors must be analyzed when selecting the landing point:

- When over the chosen site:
  - Do a high reconnaissance run above 300 ft to evaluate the area around the site,
  - Do a low reconnaissance run above 100 ft to check for obstacles on the chosen approach and takeoff paths, and
  - Do a final reconnaissance run during the approach fly-by at > 60 kt to reconnoiter the ground.
- Wind direction and strength.
- Landing site elevation.
- Nearby obstacles.
- Approach and takeoff path.
- Helicopter weight and reserve power.
- Condition and gradient of the terrain.

1.17.2. *Pilot under supervision*

The company's Operations Manual defines a pilot under supervision as one *"having a valid license and who must always fly with a Captain or instructor designated by the Company so as to increase the experience needed to operate a helicopter type or carry out a specific type of operation".*

It also stipulates that in supervised flights, *"the captain must also demonstrate his ability to direct the operation and make appropriate decisions".*

This manual does not refer to the qualifications needed, either by the captain in order to be designated as a supervisor, or by the pilot under supervision. It also does not explain what the supervision consists of (how it is programmed, planned or executed, the functions of each pilot, number or duration of flights, evaluations, types of operations, etc.).

1.17.3. *Operations Manual approved by AESA*

The seventh revision of the Operations Manual (OM) was approved by AESA on 14 July 2011.

According to information provided by AESA, if checklists are located in an external document, these lists must be properly referenced in Part B of the OM, after which they shall be regarded as accepted as part of the acceptance process for the OM revision that references them. When the OM in question was approved, the reference in Part B to the Flight Manual was approved despite no explicit mention being made of said checklists.

1.17.4. *Checklists and MCC training*

Part D of the company's Operations Manual stipulates the following in relation to Multi-Crew Coordination (MCC) training:

- *"The purpose of MCC training is to optimize the decision making, the communication, the division of tasks, the use of checklists, mutual oversight, teamwork and assistance in every phase of flight under normal, abnormal and emergency conditions.*
- *The use of checklists is particularly important to the orderly and safe execution of flights.*
- *Part B of this Operations Manual contains different checklists based on the helicopter model, phase of the operation, make-up of the flight crew and procedures in the Flight Manual."*

A review of the company's Operations Manual revealed that Part B does not contain any checklists.

Furthermore, Part A of the company's Operations Manual stipulates that *"helicopters shall have procedure lists that shall include the emergency procedures".*

A review of the documentation onboard the helicopter revealed that the emergency procedures were in the aircraft's Flight Manual in bound A4-size sheets that occupied a large amount of space.

Part B of the company's Operations Manual stipulates that *"all operational aspects involving the aircraft type, such as: general information and units of measure, limitations, normal, abnormal and emergency procedures, performance, pre-flight and flight planning, weight and balance, cargo, minimum equipment lists and aircraft systems are specified in the Flight Manual for each helicopter type operated by the company. Each aircraft's documentation includes a properly updated copy of its corresponding Flight Manual."* It does not, however, explicitly reference the checklists.

1.18. Additional information

Not applicable.

1.19. Useful or effective investigation techniques

Not applicable.

2. ANALYSIS

2.1. Handling of the flight workload in the cockpit

In general, the accident flight took place with the pilot under supervision flying at all times (except in the final moments of the flight following the engine failure). The pilot under supervision also handled the radio communications with the BRIF personnel and with the coordination aircraft.

The pilot under supervision's workload was high, his emotional status after learning of his colleague's death was compromised and the operation he was involved in required the maximum performance from the aircraft and from the crew. The monitoring of the flight, however, given the lack of planning for the operation that was being carried out (landing at the top of a hill) and the absence of communications between the crew, was far from satisfactory.

As evidenced by the statements from the two pilots, and corroborated by the information taken from the cockpit voice recorder, the communications between the two pilots were practically non-existent throughout the accident flight, even during its most critical phase, involving the decision to land (and the execution of the landing itself) atop a hill and the circling maneuvers that were being made. They did communicate their intentions upon entering the area where the BRIF was, or regarding how to circle, or the site selected to land or how to make the approach.

They also did not read any checklists.

2.2. Crew training for operating a supervised flight

MCC training

Neither pilot had received MCC training. The helicopter company's Operations Manual (Part D) notes the importance of receiving said training, which, as this same manual states, optimizes *"decision making, the communication, the division of tasks, the use of checklists, mutual oversight, teamwork and assistance in every phase of flight under normal, abnormal and emergency conditions".*

Decisions during the accident flight were made without the exchange of technical opinions between the pilots and without the pilot flying verbalizing his decisions as he made them. Furthermore, as evidenced from the pilot interviews and from the CVR recording, there was no division of tasks, mutual supervision or teamwork.

There is a clear discrepancy between the importance given in the company's Operations Manual to MCC training and the reality demonstrated by this accident; namely, the crew had not received any MCC training, meaning they could hardly achieve the objectives intended for a flight under supervision.

Flight under supervision

The aircraft's captain, who was supervising the pilot under supervision, was not trained to fly in both piloting positions. A pilot accustomed to always flying while seated in one side of the cockpit will not react the same when seated in the opposite side.

In addition, as a Polish national, his license did not record any Spanish language skills.

With regard to the qualifications needed to supervise a flight, the company's Operations Manual does not specify anything, and as a result investigators could not analyze whether he fulfilled the requirements or not.

A company's criteria for designating one of its captains as a supervisor of other pilots must be clearly listed in its Operations Manual.

2.3. Use of available information

The crew did not adhere to the instructions in the operator's Special Firefighting Operations Manual (MOE-LCI) regarding the selection of the landing site. They also did not perform the approach maneuver as specified in this manual or in the aircraft's Flight Manual.

Use of checklists

The helicopter operating company's Operations Manual (Part D) notes the importance of using checklists, stating that they are *"particularly important to the orderly and safe execution of flights"*. It also states, on the one hand, that these lists are contained in Part B of the Operations Manual, while on the other, Part A stipulates that *"helicopters shall have procedure lists that shall include the emergency procedures"*.

These lists, however, were not used during any phase of the accident flight, not even on takeoff. What is more, the lists were not contained in the Operations Manual, meaning they were not available either in the manual or, logically, onboard the aircraft.

The emergency procedures were also not in a proper format for use, since while they were included in the aircraft's Flight Manual, they were inside a large volume with A4 sheets that are complicated to use in practice inside a cockpit, particularly during an emergency situation.

Flight under supervision

The fact that the operating company's Operations Manual does not go into detail on what a flight under supervision entails (how it is programmed, planned or executed, the functions of each pilot, number or duration of flights, evaluations, types of operations, etc.) makes it difficult to conduct such a flight within the theoretical parameters required or for the objectives of the supervision to be achieved. It also hampers the division of tasks in the cockpit, the communications between crew members and the decision-making process.

2.4. Conduct of the flight

Weather conditions at the time of the accident were suitable for the operation being conducted. Winds were weak, there were practically no clouds and visibility was optimal[12]. The temperature, though high, was reasonable for the flight since they were flying at a low altitude. The combination of these two factors with the aircraft's weight meant that the aircraft's performance was not significantly affected.

The helicopter entered the BRIF work area from the northwest. Its pressure altitude before starting the first left circling maneuver was approximately 2,000 ft, meaning that it was about 300 ft above the tops of the nearby hills.

Thirty seconds later it reached an altitude of around 1,700 ft, which it would maintain throughout the circling maneuvers. The helicopter's altitude was thus similar to that of the two hills it was circling.

In the last circling turn before the accident, and while flying on an approximately northerly heading, the helicopter flew over the top of the hill to the northeast at a radio altitude of 25 ft (7.6 m). Seconds before flying over the top, the pilot commanded an increase in the position of the collective control, which raised the torque on both engines. This resulted in a 29 ft increase in the helicopter's barometric altitude, which underscores the fact that they were circling at too low an altitude above the ground. Without that 29 ft climb, the aircraft would have been flying at practically the same elevation as that of the hill they wanted to fly over.

The IAS recorded on the FDR during the last fly over the hilltop was 29 kt, well below that specified in the MOE-LCI. Once past the hilltop, the IAS increased to values near 40 kt.

The low IAS at which the circling maneuvers were being made required a high power demand, with high positions of the collective control. This resulted in equally high torque and engine demands as well.

[12] Although the flight was over an area that was practically burned, there was no longer any smoke or flames.

Once the helicopter flew over the hilltop on a 330° heading, the pilot continued turning left while lowering the pitch angle and keeping a stable altitude.

While flying toward the intended hilltop landing site, the right pedal was applied to near maximum values[13] three seconds before 15:01:20, at which time the captain said "You don't pull out."

The exact intentions of this comment could not be ascertained, but everything indicates that the captain thought that the conditions in which the flight was being conducted in terms of AGL, speed and power demand were insufficient and difficult to recover from.

Neither pilot pressed the 2.5 min-OEI operation button. This action, recommended by the aircraft's Flight Manual when landing with two engines operational and required for an engine failure in category A, would have been of great benefit in the situation leading up to the loss of power that followed, especially because the conditions of the flight had become critical, as evidenced by the captain's "You don't pull out" comment, and because the MOE-LCI specifies reducing the risk to the helicopter, persons and things as much as possible in the event of a failure of the powerplant.

The pilots also did not press the 2.5 min-OEI button after engine 1 lost power.

The pilot continued to apply more collective during the ten seconds leading up to the loss of power, at 15:01:20, when the values of engine torque were 95% and 92% (for engines 1 and 2, respectively). Under these conditions, the pitch of the main rotor blades is very high (and increasing as the collective lever is raised), and thus their drag is also very high. This could be why N_r only managed to climb from 105% at 15:01:10 to 107% at 15:01:20.

Two factors explain why N_r do not increase as quickly (or may even decrease) as demanded by the input made to the collective lever: a high angle of attack in the blades and right yaw commanded by the right pedal. This is because the power demanded by the tail rotor to yaw takes power away from the main rotor, whose blades were in a high angle of attack position (high drag and high power demand as well). The lift drops if more power is not supplied to the main rotor, a condition that is further aggravated by further pulling on the collective lever, as this would increase the angle of attack on the main rotors blades even more. Under these circumstances the operating engine may not be able to supply the power needed to maintain N_r above the value required for OEI 95% or higher.

[13] Since the main rotor turns clockwise as seen from above, the power demand needed by the tail rotor to yaw right as commanded by the pilot (when applying right pedal) is to the detriment of that applied to the main rotor, and hence to the lift.

At that time the helicopter's attitude was dictated by the fairly high position of the collective lever. The barometric altitude was 1,714 ft, the radio altitude was 193 ft[14], the right pedal was heavily depressed, the IAS was 41 kt, the pitch angle was 7° down and the roll angle was slightly to the right.

The maneuver was not being executed in keeping with the procedures specified in the aircraft's Flight Manual or in the MOE-LCI.

At 15:01:20 the torque on engine fell suddenly and sharply to 2.34%, while its N_2 increased to 115% (this is expected since removing the mechanical load on the engine causes the turbine to freewheel and accelerate). Although the N_2 reading for engine 1 on the FDR do not reflect this value reaching 120%, this must have been the case since the engine overspeed system stopped the number 1 engine.

This fact is consistent with the pilots' statements in which they reported hearing the change in engine sound (winding down).

After 15:01:20 and the subsequent emergency situation, the pilot under supervision gave the controls to the captain, though the CVR does not reflect the exact moment when this took place.

N_r fell to 86% in three seconds, and continued falling to a value of 66%.

Initially there was a small drop in the position of the collective lever for about a second. This was immediately followed by an increase that would last for the entirety of the helicopter's descent. The right pedal was depressed and reached its maximum travel six seconds later, with the associated decrease in the effectiveness of the main rotor.

Two seconds after the loss of torque from engine 1, the helicopter made a 360° right turn over the course of nine seconds. The pilot then lowered the right turn rate by pushing the left pedal forward. He continued applying left pedal until the right turn was stopped on a heading of 287°. The helicopter then started turning slowly to the left. Three seconds later the helicopter impacted the ground while on a heading of 235°.

As for the loss of altitude after the loss of power, in the first four seconds the barometric altitude held at 1,600 ft. Five seconds later it had decreased by 58 ft, and in the next five seconds it dropped a further 67 ft. Three seconds later the helicopter impacted the ground.

As concerns the IAS, it went from 41 kt to 0 kt in two seconds, coinciding with the application of right pedal and the start of the helicopter's rotations about its vertical axis.

[14] This figure, though precise, is of relative importance since they were flying over ravines and river beds, which made it vary quickly. Thus, it does not reflect a stable value on which to base the maneuver.

2.5. Handling of the emergency

After the loss of power in engine 1, the emergency was handled inadequately for several reasons.

First, the situation in which the emergency occurred was in and of itself an improper flight situation, as it was in violation of the stipulations in the MOE-LCI concerning the selection of the landing site and reducing the risk to the helicopter, persons and things as much as possible in the event of a failure of a powerplant.

Second, according to the aircraft's Flight Manual, the calculations made in Section 1.6.6.5 of this report indicate that the helicopter had sufficient lift available (on the order of 500 ft/min) after an engine failure to have gained height without ending the flight catastrophically. This would have required the aircraft not getting to time 15:01:20 in the power, speed and altitude situation that it did. It would also have required carrying out the emergency procedure as stipulated.

The right yaw commanded by the pilot also did not help; it only made the situation worse. It was a bad choice (for the reasons noted earlier) that might have been motivated by the proximity to the hillside, resulting from the slight inclined approach.

As for the communications, these are underscored by their scarcity or even by the lack of a response (even a physical one) to the situation as it unfolded. For example, four seconds before the loss of power the captain said "You don't pull out", with no reply from the pilot under supervision. The comment is serious, and more so in the phase of flight when it was made, and yet the captain did not include a proposed solution nor did he make any physical inputs to the flight controls to correct the situation.

When the loss of power occurred, neither pilot said anything out loud in an effort to find out what was happening or how to resolve the situation until four seconds later, when the captain asks "What did you do?" to which the pilot under supervision replies "I didn't do anything." This was the sole exchange between the pilots prior to the impact. In addition to being insufficient, it did little or nothing to address the emergency.

There was also no explicit transfer of control from the pilot under supervision to the supervisor (nor a request for said transfer from the latter). It was the captain who piloted the aircraft after the emergency. Therefore the required "mine" or "yours" verbalization was not made when giving or taking control of the aircraft.

Once on the ground the crew acted correctly despite their injuries by disengaging the aircraft's systems. Crucial to the survival of both pilots is the fact that a fire did not break out after the impact with the ground (there were about 1,100 l of fuel onboard). Finally, the aid rendered by BRIF personnel and the early reporting of the accident to medical and rescue personnel also contributed significantly to the pilots' receiving medical assistance as quickly as possible.

2.6. Failure of engine 1

The loss of power of engine 1 was caused by the fatigue failure of the flexible coupling between the turbine output shaft and the intermediate shaft, which resulted in a sudden interruption of the power transfer between the turbine and the combined gearbox.

Engine 1 subsequently stopped as a result of the overspeed protection that is designed into the engine.

When the turbine freewheeled (due to being uncoupled from the combined gearbox), it caused its N_2 to overspeed. This, in turn, caused the electronic control for the propulsion system to stop the number 1 engine.

During the approach the turbine output shafts on both engines[15] were under high mechanical load due to the high power that was being demanded to remain aloft. Under these conditions, the high stress was such that the flexible coupling (which already exhibited symptoms of fatigue that had not been detected earlier) could resist no further and it broke.

No existing problems had been reported with the mechanical assembly that failed, nor with engine 1 nor with the combined gearbox.

The analysis of both engines and their auxiliary components revealed that at no point did any of them fail, beyond the aforementioned fatigue fracture of the flexible coupling.

The damage exhibited by the flexible coupling that joins the intermediate shaft to the shaft entering the combined gearbox occurred after the fracture of the flexible coupling between the turbine output shaft and the intermediate shaft, and resulted from the excess stress that was transmitted to it.

An analysis of the maintenance performed on the aircraft in general and on the engines in particular, did not reveal any discrepancies in its execution, which indicates that it was neither incorrect nor defective. Moreover, the periodic checks of the clearance of the Cardan-type coupling on the mounting cone were being conducted, as per the engine manufacturer's service bulletin no. E-19W140/DOA/2009, despite these checks not being required. In fact, the last 25-hr/15-day check was conducted on the day of the accident. This included a check of the clearances, which were found to be within tolerance.

An excessive clearance of the Cardan-type couplings on the mounting cone would have contributed to excessive stress being placed on the couplings between the turbine output shaft and the combined gearbox input shaft, though this does not seem to have occurred.

[15] The input shaft to the combined gearbox on engine 2 was also subjected to excessive torsional loading, though investigators were unable to determine if this was a result of the high load before the failure of engine 1 or afterwards, when it had to bear all of the propulsion demand.

3. CONCLUSIONS

3.1. Findings

- Weather conditions at the time of the accident were suitable for the operation being conducted.
- The aircraft had the valid and in force documentation required to carry out the operation.
- The helicopter's weight and balance were within the parameters specified in its Flight Manual throughout the flight.
- The maintenance records showed that all maintenance was carried out in keeping with the approved manual.
- The periodic inspections required by the manufacturer's Service Bulletin No. E-19W140/DOA/2009, on the clearance for the Cardan couplings on the mounting cone, were being carried out despite not being obligatory.
- The last 25-hr/15-day inspection, during which these clearances were checked and verified to be within limits, was carried out on the day of the accident.
- On this type of helicopter the captain sits in the LH seat in the cockpit.
- The operation was conducted as a single-pilot flight in visual flying conditions, although the crew consisted of two pilots, one of them acting as the pilot under supervision and sitting in the LH seat, and the other acting as a supervising captain and sitting in the RH seat.
- Such a supervised operation is considered in the Operations Manual, though the manual does not detail, among other things, what it consists of, how it is conducted or what is expected from a supervised flight.
- The company's Operations Manual contains no details regarding the qualifications needed to be a pilot supervising a flight.
- The accident flight took place with the pilot under supervision at the controls at all times (except for the final moments, after the engine failure). This pilot also handled the radio communications.
- Both pilots had valid licenses and ratings for the activity being performed. They also had valid medical certificates.
- The captain was not trained to fly from both piloting positions.
- The captain, a Polish national, did not have any Spanish language skills noted on his license.
- The loss of power in engine 1 was caused by the fatigue failure of the flexible coupling between the turbine output and the intermediate shafts.
- The subsequent stoppage of engine 1 occurred as a result of the design overspeed protection.
- After engine 1 lost power, the emergency was not handled as stipulated in the aircraft's Flight Manual.
- There was no explicit transfer of control from the pilot under supervision to the supervisor (nor a request from the latter to the former).
- The landing approach maneuver was not executed as per the procedures either in the aircraft's Flight Manual or in the MOE-LCI.

- The 2.5 min-OEI button was not pressed during the approach nor after the loss of power in engine 1, despite this being recommended in the Flight Manual in the first case and required for a category A landing in the second case.
- The calculations done using the accident conditions indicate that the aircraft could have climbed at a rate of 500 ft/min, sufficient to have gained height and not end the flight catastrophically had the approach and emergency been handled properly.
- The helicopter fell to the ground as a result of the loss of power in the engine and of the way in which the approach maneuver was executed.
- No previous problems had been reported involving the mechanical assembly that failed the no. 1 engine or the combined gearbox.
- The checklists had not been defined in the Operations Manual, and thus they were not available either in the manual or onboard the aircraft. As a result the crew did not read the lists, having to perform them from memory.
- The emergency procedures, which were in the Flight Manual, were not available in a format that was conducive to their use in the cockpit.
- The company's Operations Manual lists MCC training as required for flights with more than one pilot.
- Neither pilot had received MCC training.
- Communications between the two pilots were practically non-existent throughout the accident flight, even during its most critical phases.

3.2. Causes

The accident was caused by the improper handling of an in-flight emergency resulting from the loss of power on engine 1, which failed when the shaft from the turbine to the combined gearbox fractured, causing the helicopter to fall and then impact the ground.

The following factors contributed to the accident:

- The practically non-existent teamwork between the two-pilot flight crew.
- The flight crew's lack of training in MCC.
- The flight crew's failure to adhere to the normal and emergency procedures contained in the aircraft's Flight Manual, in the Operations Manual and in the MOE-LCI of the helicopter operator.
- The absence of certain important content in the Operations Manual of the helicopter operator.
- The insufficient number of checklists and procedure and emergency lists onboard the aircraft.

4. SAFETY RECOMMENDATIONS

REC 53/14. It is recommended that INAER Helicópteros, SAU, as the operator of the flight, include in its Operations Manual all of the operational and other aspects involved in conducting supervised flights.

REC 54/14. It is recommended that INAER Helicópteros, SAU, as the operator of the flight, include in its Operations Manual the requirements, qualifications and training needed to be a supervising pilot.

REC 55/14. It is recommended that INAER Helicópteros, SAU, as the operator of the flight, provide MCC training to any pilot who takes part in any type of multi-crew operation.

REC 56/14. It is recommended that INAER Helicópteros, SAU, as the operator of the flight, include in its Operations Manual control and procedural checklists, including emergency checklists, in a format that facilitates their use onboard the aircraft.

REC 57/14. It is recommended that INAER Helicópteros, SAU, as the operator of the flight, ensure that the necessary documentation involving control and procedural checklists is present on the aircraft and is consistent with the requirements of the company’s manuals.

REC 58/14. It is recommended that Spain’s National Aviation Safety Agency (AESA) ensure that the operating manuals of INAER Helicópteros SAU it approves contain all of the required information and that said contents are not inferior to those the manual claims to contain.

REC 59/14. It is recommended that Spain’s National Aviation Safety Agency (AESA) ensure that the crews of INAER Helicópteros SAU receive proper training on adhering to operating procedures.

REC 60/14. It is recommended that Spain’s National Aviation Safety Agency (AESA) ensure that the crews of INAER Helicópteros SAU have the documentation they need onboard the aircraft to carry out operations.