Statens haverikommission
Swedish Accident Investigation Authority





Final report RL 2018:08e

Accident in Älvsbyn, Norrbotten County, on 26 September 2017 involving the helicopter SE-JVI of the model MDHI 369D, operated by First European Aviation Company (FEAC).

File no. L-114/17

20 August 2018

Statens haverikommission
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SHK investigates accidents and incidents from a safety perspective. Its investigations are aimed at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigations do not deal with issues of guilt, blame or liability for damages.

The report is also available on our website: www.havkom.se

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This document is a translation of the original Swedish report. In case of discrepancies between this translation and the Swedish original text, the Swedish text shall prevail in the interpretation of the report.

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General observations

The Swedish Accident Investigation Authority (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended to clarify, as far as possible, the sequence of events and their causes, as well as damages and other consequences. The results of an investigation shall provide the basis for decisions aiming at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigation shall also provide a basis for assessment of the performance of rescue services and, when appropriate, for improvements to these rescue services.

SHK accident investigations thus aim at answering three questions: *What happened? Why did it happen? How can a similar event be avoided in the future?*

SHK does not have any supervisory role and its investigations do not deal with issues of guilt, blame or liability for damages. Therefore, accidents and incidents are neither investigated nor described in the report from any such perspective. These issues are, when appropriate, dealt with by judicial authorities or e.g. by insurance companies.

The task of SHK also does not include investigating how persons affected by an accident or incident have been cared for by hospital services, once an emergency operation has been concluded. Measures in support of such individuals by the social services, for example in the form of post crisis management, also are not the subject of the investigation.

Investigations of aviation incidents are governed mainly by Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation and by the Accident Investigation Act (1990:712). The investigation is carried out in accordance with Annex 13 of the Chicago Convention.

The investigation

SHK was informed on 26 September 2017 that an accident involving a helicopter with the registration SE-JVI had occurred at Älvsbyn, Norrbotten County, the same day at 13:48 hrs.

The accident has been investigated by the Swedish Accident Investigation Authority, which is represented by Mikael Karanikas, Chair, Stefan Carneros, investigator in charge and operational investigator, Christer Jeleborg until the 27th of July, technical investigator, and Alexander Hurtig, behavioural science investigator.

The investigation team of SHK was assisted by Christer Magnusson and Kristoffer Danél as technical experts, Annika Wallengren as expert within the area of rescue services and Liselotte Yregård as medical expert.

Andrzej Pussak (State Commission on Aircraft Accidents Investigation, SCAAI) has participated as an accredited representative of Poland. He has appointed Boguslaw Trela (SCAAI) and Filip Krolak (First European Aviation Company, FEAC) as advisors.

Tim Sorenson (National Transportation Safety Board, NTSB) has participated as an accredited representative for the USA. He has appointed Joan Gregoire (MD Helicopters Inc.), John Hobby (Boeing) and Dave Riser (Rolls-Royce) as advisors.

The following organisations have been notified: The International Civil Aviation Organisation (ICAO), the European Aviation Safety Association (EASA), the European Commission, the Swedish Transport Agency, SCAAI and NTSB.

Investigation material

Interviews have been conducted with the pilot, officials with the operator, including the maintenance and airworthiness organisation. Interviews have also been conducted with participants and representatives of the various actors in the rescue operation. These interviews have involved employees of JRCC Göteborg, the Police Authority in Luleå, the Rescue Service in Älvsbyn, the pilots of the private aircraft that were involved in the search and the operator employee who located the helicopter. Statistics, including maintenance history from EASA, have been obtained.

Special technical tests on the helicopter engine have been carried out by an approved maintenance organisation, inter alia, by the Rolls-Royce Corporation. A contracted organisation has analysed fuel system and engine oil samples, as well as the fitting and pipe nut (B-nut) which the investigation concluded had come loose.

A meeting with the interested parties was held on 27 March 2018. At the meeting, SHK presented the facts uncovered during the investigation, available at the time.

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Aircraft:	
Registration	SE-JVI
Model	MDHI 369D
Class, airworthiness	Normal, Certificate of Airworthiness and valid Airworthiness Review Certificate (ARC)[1]
Serial number	300678D
Operator	FEAC, First European Aviation Company Sp. z o.o.
Time of the occurrence	26/09/2017, 13:48 hrs in daylight Note: all times are given in Swedish daylight saving time (UTC[2] + 2 hrs)
Location	Högheden, Västerbotten County, (position 65°38'23"N 21°2'27"E, 100 metres above sea level)
Type of flight	Specialised operations (aerial work)
Weather	According to SMHI's analysis: wind approximately southerly, 5 knots, visibility greater than 10 km, no clouds, temperature/dewpoint +16/+7 °C, QNH[3] 1040 hPa
Persons on board:	2
Crew including cabin	2
Passengers	0
Injuries to persons	1 dead and 1 seriously injured
Damage to the aircraft	Hull loss
Other damages	No damage
The pilot:	
Age, licence	28 years old, CPL(H)[4]
Total flying hours	207 hours, of which 67 hours on type
Flying hours previous 90 days	41 hours, all on type
Number of landings previous 90 days	85
System operator (commander):	
Age, licence	36 years old, CPL(H)
Total flying hours	893 hours, of which 658 hours on type
Flying hours previous 90 days	133 hours, all on type
Number of landings previous 90 days	103

[1] ARC – Airworthiness Review Certificate.
[2] UTC – Coordinated Universal Time.
[3] QNH – Atmospheric pressure at mean sea level.
[4] CPL (H) – Commercial Pilot Licence (helicopter).

SUMMARY

On 26 September 2017, a crew flying a helicopter of the model MDHI 369D was going to carry out a power line inspection on behalf of Vattenfall. Shortly after take-off from Älvsbyn/Högheden Airport, at a height of about 80 metres above the ground and a speed of 67 knots, they started to rapidly lose both altitude and speed. Twelve seconds later, the helicopter collided with the ground at the side of a grass field behind a building and near the edge of a forest. One crew member was killed and another was seriously injured. The helicopter sustained substantial damage, but no fire broke out.

The examination of the accident site has shown, among other findings, that the helicopter had a descent angle of approximately 70 degrees, close to zero forward speed and very low rpm in the main rotor and tail rotor, combined with an exceptionally large coning angle of the rotor disk at some point during the sequence. These findings indicated that the engine stopped supplying power during the flight. The technical investigation showed that a fitting to the gas generator fuel control unit had come loose during the flight, which meant that the engine did not supply enough power to actuate the rotor system. The fault occurred at such a flight position, and was of such a nature, that the crew was forced to immediately shift to flight in autorotation with a subsequent emergency landing. The surviving pilot has declared not to have any memories of the flight.

The site chosen for the emergency landing meant that the helicopter had to clear an obstacle in the final stage of the flight. The relatively low speed and altitude at the time when the fault occurred, in combination with a heavily loaded helicopter, entailed a shorter flight path than in the flight regimes that had been practised for autorotation landings during the type rating. For this reason, the crew did not reach the landing site without utilising the available rotor rpm at an early stage, which lead to a hard collision with the ground.

The rescue operation came to involve several units, and the helicopter was located by rescue services after approximately 1 hour and 40 minutes. The operator’s staff had then already been at the site of the accident for 15–20 minutes.

The accident was caused by an engine failure in flight where the possibilities for a safe emergency landing were limited by the low speed and altitude in combination with a heavily loaded helicopter.

The cause of the engine failure was that the pipe nut backed off and the pipe came loose resulting in a loss of engine power. The nut could back off due to the methods of securing the engine fittings with prescribed torque and the visual slippage inspections before flight was flawed.

Safety recommendations

The FAA is recommended to:

- Evaluate whether the construction of the Rolls-Royce engine RR 250-C20 and other models using the same type of B-nut, without any other safety measures than the tightening torque and the prescribed nut checks, provides sufficiently secure protection against engine failure in single-engine configurations. *(RL 2018:08 R1)*

- Investigate whether there is a need to inform concerned sections of the industry that there may be deviating fittings (Filter Assembly) in circulation in international flight operations. *(RL 2018:08 R2)*

EASA is recommended to:

- Evaluate whether the construction of the Rolls-Royce engine RR 250-C20 and other models using the same type of B-nut without any other safety measures than the tightening torque and the prescribed nut checks in accordance with EASA AD 2004-0009R3, provides sufficiently secure protection against engine failure in single-engine configurations. *(RL 2018:08 R3)*

The Swedish Maritime Administration is recommended to:

- Review their procedures for how classification of emergency broadcasts on international emergency frequencies is applied. *(RL 2018:08 R4)*

- Evaluate and, if needed, develop their procedures to ensure a sufficiently quick dispatch of flying rescue units that are equipped, trained and have practised for search missions, including homing of emergency locator transmitters. *(RL 2018:08 R5)*

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Circumstances

The aim of the flight was to carry out an inspection of power lines on behalf of Vattenfall. The flight was the second one that day, and it was preceded by a stop for fuel and lunch at Älvsbyn/Högheden Airport. The weather was clear and sunny at the location and did not entail any limitations for the flight. The helicopter was equipped with a system to measure, photograph and present the status of the power line network and the surrounding terrain by means of advance data processing (see section 1.6.8). The system allows for flying at a higher altitude and greater speed than in traditional power line inspection, where the operator carries out an optical inspection while flying close to the power line at low speed.

The crew consisted of one pilot and one system operator, both of whom were pilots trained on the helicopter type with commercial helicopter pilot licences. The flight operator requires pilots to have 30 hours' experience of power line inspection using the measuring system before they can qualify as a commander. The pilot had 15 hours' such experience, and the flight was therefore carried out under the supervision of the system operator, who was an experienced pilot as well as the commander for the flight. The commander was sitting on the right side, tasked with handling the measuring system. When the measuring system is installed, the dual controls shall be uninstalled or disabled. However, during the pilot's qualifying period, it was installed and operational.

The first flight of the day was preceded by the daily maintenance check and a pre-flight check was carried out just before take-off from Älvsbyn/Högheden Airport.

1.1.2 History of the flight[5]

The take-off from Älvsbyn/Högheden Airport was normal, and the helicopter initially built up both speed and altitude. After approximately 47 seconds, when the helicopter was around 80 metres above the forest terrain flying at a speed of 67 knots, both altitude and speed started to fall rapidly. Twelve seconds later, the helicopter collided with the ground at the side of a grass field behind a building and near the edge of a forest (see figure 1). The helicopter sustained substantial damage. The system operator was killed and the pilot suffered serious injuries. SHK has not been able to determine how the crew worked together during the accident sequence.

[5] The information in this section is based on data from the registration equipment on board (see section 1.11.1). The pilot has no memory of the incident, and there were no witnesses.

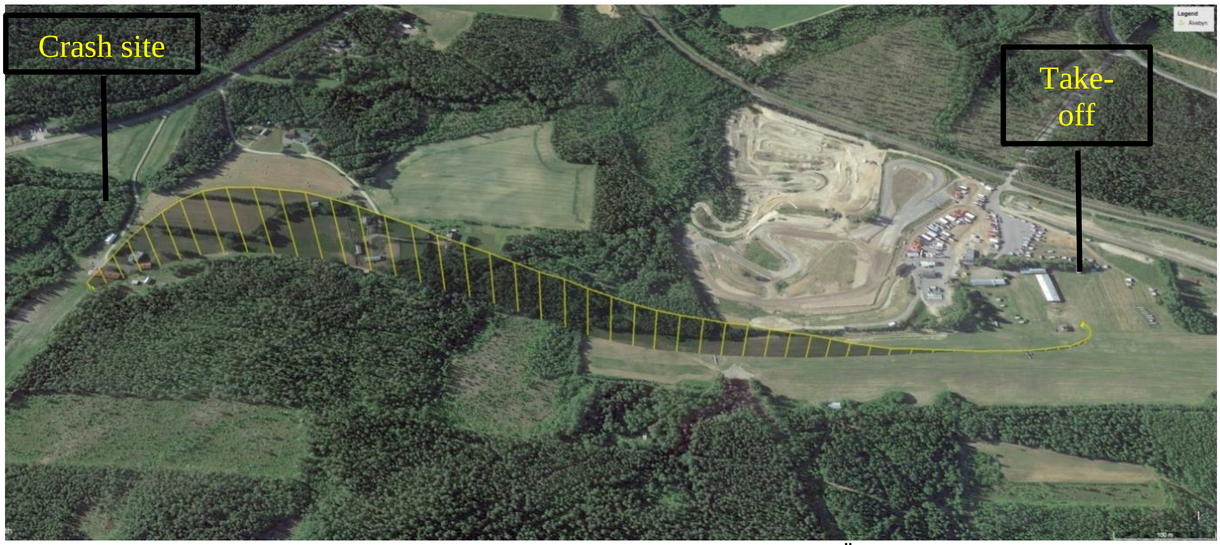


Figure 1. Flight path according to GPS data in the SkyDemo, presented in Google Earth. Älvsbyn/Högheden Airport can be seen on the right side of the image. The yellow columns show the approximate height above the terrain.

The accident occurred at position 65°38'23"N, 21°2'27"E, 100 metres above sea level at 13:48 hrs in daylight.

1.2 Injuries to persons

1.2.1 General

	Crew	Passengers	On board, total	Others
Fatalities	1	-	1	-
Persons with serious injury	1	-	1	-
Persons with minor injury	-	-	0	-
No injuries	-	-	0	-
Total	2	0	2	-

1.2.2 Injuries to those on board

The pilot, who was sitting on the left, sustained serious injuries mainly to the back and legs, but also head trauma. The pilot survived the crash. There are no indications that the pilot was under the influence of alcohol, drugs or medications prior to the accident.

The system operator, who was sitting to the right of the pilot, was killed in the crash. The operator suffered fatal injuries due to blunt trauma. The forensic examination revealed no presence of alcohol, drugs or medications.

1.3 Damage to the aircraft

Hull loss. The aircraft sustained substantial structural damage, inclu-ding to the skids and rotor system.

Figure 2. The helicopter, seen from the approximate track upon impact.

1.4 Other damages

Limited damage to the ground arose due to leaking fuel, oils and debris from the helicopter.

1.5 Crew/personnel information

1.5.1 The pilot

The pilot was 28 years old and had a valid CPL-H with the applicable operational and medical qualification. At the time, the pilot was PF[6].

Flying hours				
Last	24 hours	7 days	90 days	Total
All types	3	6	41	207
Type in question	3	6	41	67

Number of landings, type in question – last 90 days: 85.
Type rating conducted on 10 March 2017.
Latest PC[7] conducted on 22 May 2017 on type.

The pilot had completed training on the helicopter type in March 2017. In the two years before, he had primarily been flying as system operator in order to learn the measuring system that was mounted on the helicopter. During that period, he had only been flying as a pilot for the hours required in order maintaining his commercial pilot licence. These flight hours had been carried out on a different helicopter type.

[6] PF (Pilot Flying) – the pilot who is manoeuvring the aircraft.
[7] PC – Proficiency Check.

Pilot's training in emergency landing (autorotation)

The basic helicopter pilot training and further training for commercial pilots have requirements for the completion of certain exercises with full down autorotation, i.e., where the emergency landing exercise ends when the helicopter is standing still on the ground. The pilot had done this during his basic training as a commercial pilot between 2013 and 2015 on lighter helicopters of the types Robinson R 22 and R 44.

When training on a new helicopter type (known as type rating), autorotation flight is included. This was also the case during the type rating for this type of helicopter. Those exercises were done towards the end of the flight, when the weight was low. The pilot has also stated that he, in conjunction with piloting on the left side, has felt comfortable making spontaneous turns to the left when manoeuvring next to power lines, as this affords him a better view on his side.

1.5.2 The system operator (commander)

The system operator (commander) was 36 years old and had a valid CPL-H with the applicable operational and medical qualification. At the time, the commander was PM[8].

Flying hours				
Last	24 hours	7 days	90 days	Total
All types	3	3	133	893
Type in question	3	3	133	658

Number of landings, type in question – last 90 days: 103.
Type rating conducted on 27 February 2015.
Latest PC conducted on 19 February 2017 on type in question.

The commander fulfilled his tasks as system operator of the measuring system on board, while he was also the commander and supervising the pilot who was flying to gain experience of flying for power line inspections. The commander was considered experienced on both the type and the mission profile and the two pilots had flown together before. For the flight in question, the commander had relieved the commander of the previous week according to a planned schedule, and this was the first day of the new work period.

1.6 The aircraft

1.6.1 General

Hughes H-6 is a family of small and versatile civilian and military helicopters that are used by several operators across the world. In the USA, the military version is called the OH-6A and the MDHI commercial designation is MD 500D.

[8] PM (Pilot Monitoring) – pilot who monitors and assists, but does not manoeuvre the aircraft.

The helicopter is 9.4 metres in length and 2.7 metres height at the main rotor. The width is the diameter of the main rotor, i.e., a little over 8 metres.

The helicopter structure is divided into three main parts: front, lower and rear. The front is constructed around a rigid framework structure. A centre beam forms the load-bearing structure of the helicopter. This beam is the mounting of several of the helicopter's structural components, including the landing gear.

Figure 3. The helicopter. Photo: Andrzej Rossa

1.6.2 The helicopter

Type certificate holder	MD Helicopters Inc. (MDHI)
Model	369D
Serial number	300678D
Year of manufacture	1980
Gross mass, lbs	Max. approved take-off mass 3,000/case in question 2,905
Centre of gravity	Within authorised limits. Case in question: 102.81 (permitted: 99–103.6)
Total operating time, hours	15,944
Flying time since last periodic inspection, hours	65
Number of cycles	14,873
Type of fuel loaded prior to the occurrence	Jet A-1

Engine	
Type certificate holder	Rolls-Royce Corporation
Engine type	250-C20B
Number of engines	1
Serial number	835608
Total operating time, hours	10,102

Flying time since last periodic inspection, hours	65
Operating time since last overhaul, hours	680

Deferred remarks
None relevant to the incident.

The aircraft had a Certificate of Airworthiness and a valid ARC.

1.6.3 Main rotor and tail rotor

The fully articulated main rotor is mounted above the helicopter's centre of mass. It provides lift that can be directed forwards, backwards and to both sides. The main components are the five blades, the hub and a special arrangement to control the angle of the blades. The collective lever in the cockpit is connected to the blades through different links and a swash plate. The collective adjusts all the blades equally over the full rotation, based on the position of the collective lever. The cyclic stick can be moved forwards, backwards and to the sides in order to steer the helicopter along the roll and pitch axes. Both control columns are used together with the pedals that control the tail rotor to enable coordinated flight.

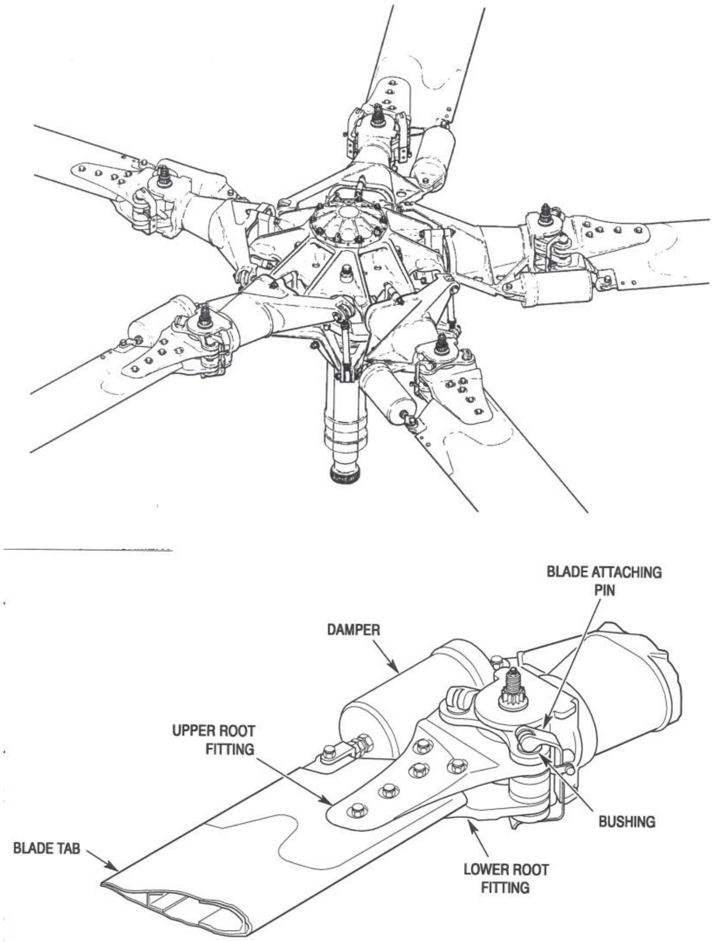


Figure 4. Main rotor hub (top) and detail (bottom).

The purpose of the tail rotor is to compensate for the main rotor's torque and to control the yaw of the helicopter.

1.6.4 Drive system

The engine produced torque is transferred to the rotors through a freewheel, gear boxes and drive shafts. The freewheel is mounted on the engine between the engine and the main drive shaft and acts as a releasing device. The purpose of the freewheel is to automatically disengage the engine from the main rotor if the engine drive system spools down. Instead, the inverse air stream is flowing up through the main rotor to maintain its rpm, which is referred to as autorotation. Also refer to section 1.18.2.

The main rotor drive shaft, which rotates inside the static mast, transfers torque from the main rotor transmission to the main rotor hub. The tail rotor is driven by a shaft from the same gear should be The tail rotor drive shaft is installed between the main rotor transmission and the tail rotor transmission. The tail rotor transmission is the attach point for the tail rotor.

The helicopter instrument and monitoring system includes an audio warning, “engine out”, which indicates engine failure. This warning activates at an rpm (55 % N1) that is below the engine’s idling speed, or when the main rotor speed is less than 98 %. A circuit breaker on the centre console is used to avoid setting off the alarm in conjunction with turning the engine on and off. In the examination of the accident site, the circuit breaker was found to be pushed in, which indicates that the warning was armed during the event.

1.6.5 Engine

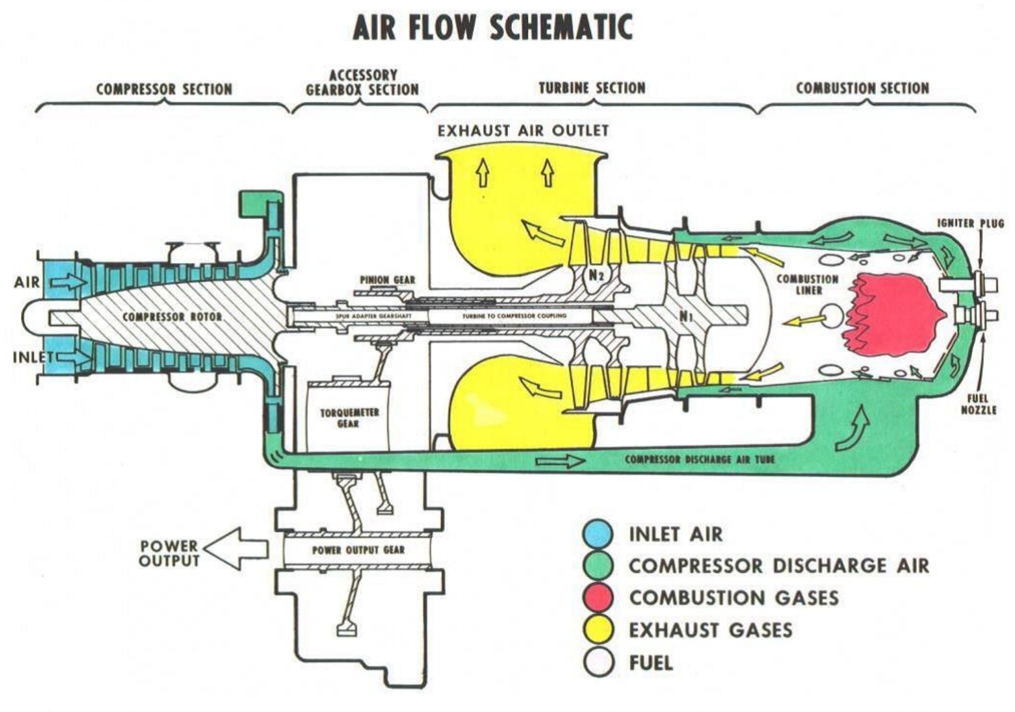


Figure 6. Schematic of the engine.

Rolls-Royce Model 250 is a turboshaft engine with a gas generator and a free turbine. The engine has an axial compressor with six stages, and then a single centrifugal compressor and a single flame tube in the combustion chamber. Downstream is the turbine section, which contains a two-stage gas turbine mounted on the compressor N1[9]. The free turbine also has two stages N2[10], and finally there is the outlet. The auxiliary unit gearbox contains the gear box function of the gas generator and the free turbine, which has an output shaft that is in turn connected to the rotor system gear box.

[9] N1 – Abbreviation of low-pressure compressor, or in this case, gas generator speed.
[10] N2 – Abbreviation of high-pressure compressor, or in this case, free turbine speed.

1.6.6 *The engine fuel system*

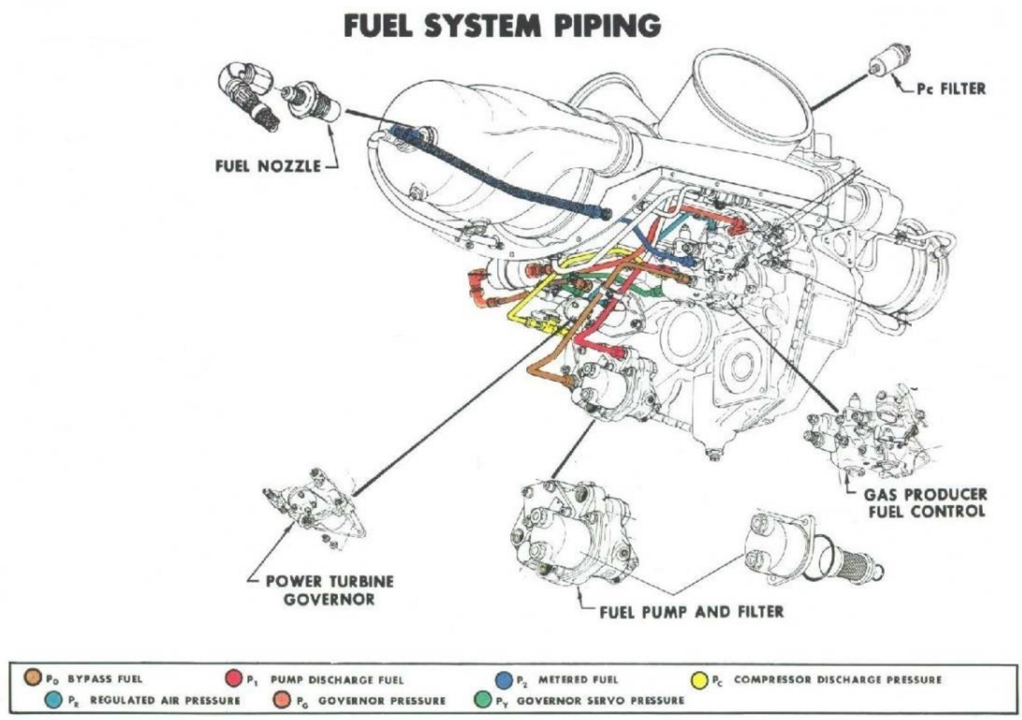


Figure 7. Engine fuel system.

The fuel control unit (FCU[11]) of the gas generator is the central component of the Bendix fuel system. This hydro mechanical unit controls the flow of fuel to the engine in order to achieve optimal acceleration during the engine start sequence and to give the correct output during operation. An increased or decreased fuel flow will have a direct impact on the gas generator (N1) speed. The unit is mechanically operated by the engine's auxiliary unit, the rpm of which is proportional to that of the gas generator. The flow of fuel is affected, for example, by the cockpit throttle, by incoming fuel pressure, by the compressor outlet pressure and by regulated air pressure from the free turbine regulator. The fuel control unit feeds fuel to the fuel nozzle, which distributes the fuel evenly in the combustion chamber where the combustion takes place.

When the throttle is turned from off to idle during an engine start, the fuel control unit automatically regulates the flow of fuel as a function of compressor discharge pressure and N1 speed. Combustion is initiated in the engine and it accelerates and stabilises at idle running speed (approx. 60–65 % of N1). The fuel flow during this sequence is controlled by the fuel control unit.

The free turbine regulator is used when rpm is above idle, in order to prompt the fuel control unit to maintain N2 speed as constant as possible. The free turbine regulator and the fuel control unit are connected through a system of tubes, so that the compressor discharge pressure controls the fuel control unit and thereby the N2 speed via the

[11] FCU (Fuel Control Unit) – unit that regulates the flow of fuel in a jet or turboshaft engine.

free turbine regulator. The free turbine drives this regulator with gearwheels. During normal operation, the flow of fuel is controlled to maintain N2 constant. There is fine-tuning of the rpm and a system to reduce the risk of variations in N2 in the event of large movements of the collective lever.

If the reference pressure from the compressor outlet to the FCU is not reached during flight, the FCU will immediately reduce the fuel flow to a minimum value, which corresponds to an N1 speed below idle.

1.6.7 B-nut fittings in the engine system

A number of steel pipes with AN couplings are used to transfer oil, fuel and reference air pressure to different parts of the engine. The coupling is fastened with a pipe nut, specifically a B-nut (see figure 8). In this type of coupling, appropriate material stress is very important for the coupling to maintain a tightly sealed connection between nipple and pipe during the flight. The correct material stress is achieved when the friction between nipple and nut is in accordance with the design requirements, the thread geometry is correct and the prescribed tightening torque is applied.

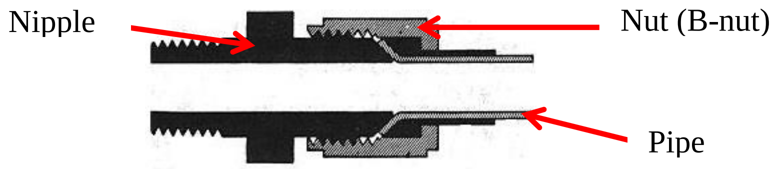


Figure 8. Example of AN coupling.

In SHK's examination of the engine following the accident, it was discovered that the pipe that supplies reference pressure (reference pipe) from the engine compressor to the free turbine regulator and the fuel control unit had come loose from its fitting (see figure 9). The threads of the pipe nut and the fitting were intact, which indicates that these had come apart prior to impact. The investigation noted that another pipe nut in the same pipe system was also loose, but it had not been completely dislodged. The last known maintenance on the fuel control unit, when the connection unit (Filter Assembly) was fitted, was carried out on 29 September 2015 according to the identification plate on the fuel control unit. The safety wire on the connection unit was sealed with the marking H S P.

The last known maintenance carried out that had an impact on the pipe nut that dislodged from the fitting was a replacement of the free turbine regulator on 18 July 2017.

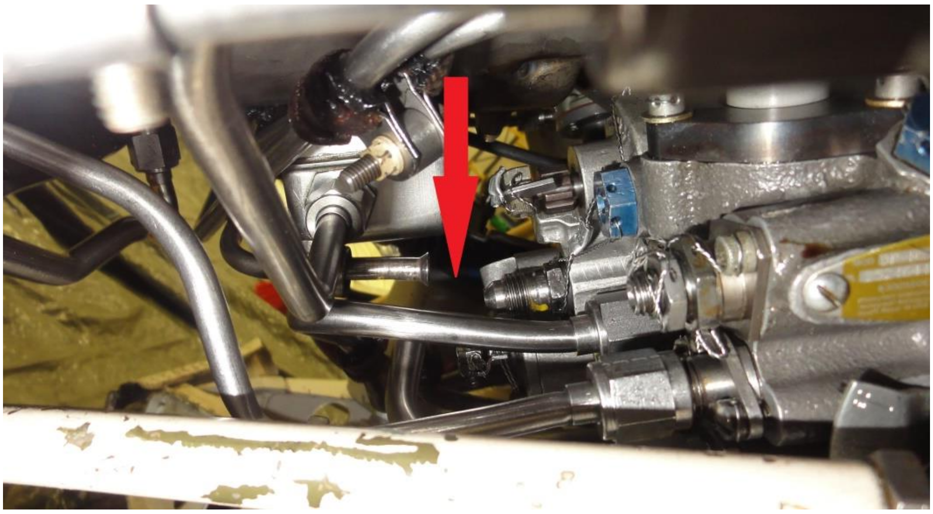
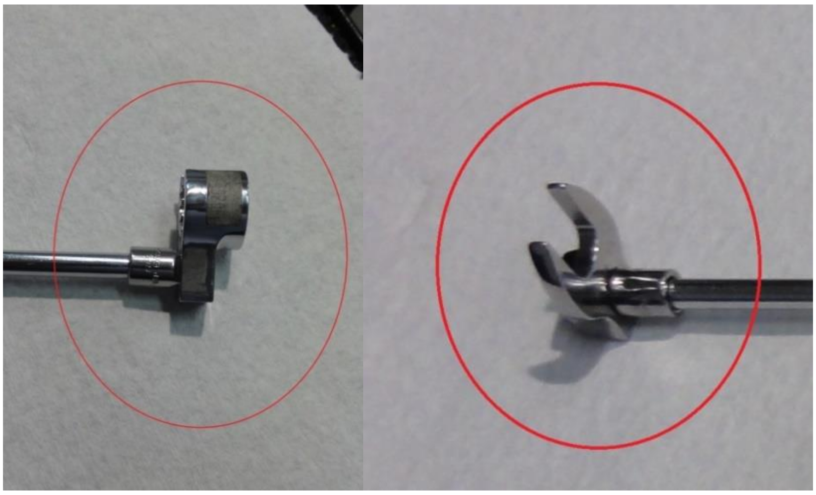


Figure 9. The image shows the fuel control unit fitting that had come loose.

When torqueing a pipe nut, the torque wrench needs to have either an open-end or a flare-end extension. The centre of rotation for both of these adapters is offset in relation to the centre line of the torque wrench (see figures 10 and 11).



Figures 10 and 11. The flare-end and open-end (Also known as Crow foot) adapters used to install the pipe nut.

When working with an offset torque measuring point, the torque needs to be configured, taking into account the length of the offset as well as the point where the force impacts on the torque wrench (see figure 12). At the time of SHK's visit, the operator maintenance organisation had access to both types of adapters. However, the open-end adapter (see figure 11) can cause an unwanted movement of the tool, meaning that the torque wrench extension is not parallel to the pipe and the nut, which in turn can lead to an incorrect torque. If the torqueing is carried out in a narrow space, there is also the risk of the adapter not turning freely, which results in the torque wrench indicating the achievement of a set torque before this is actually the case.

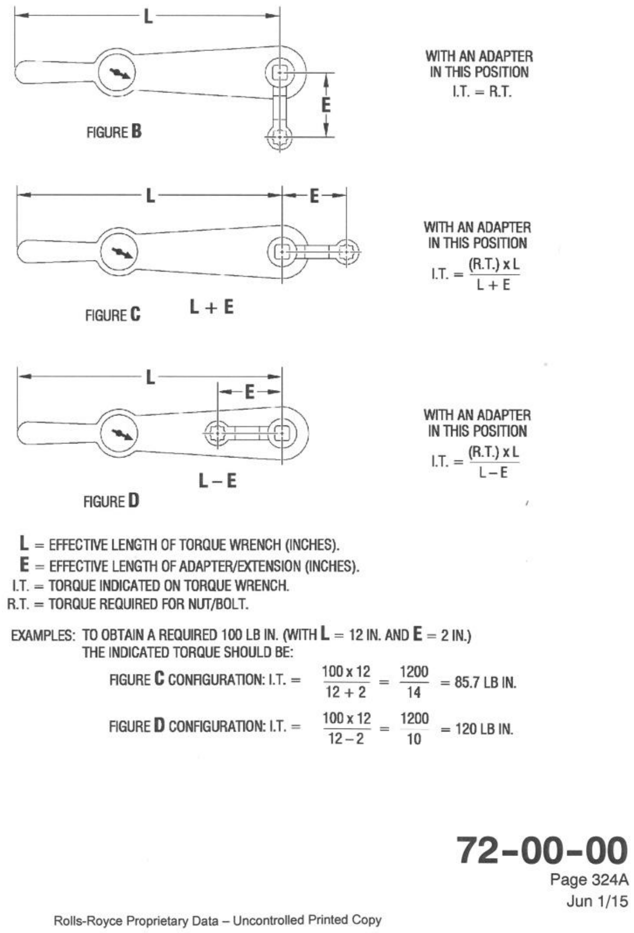


Figure 12. Torque calibration for offset measuring point. Graphics: Rolls-Royce

1.6.8 Measuring system Visimind (DAM-H Vision Mount Module)

The Visimind measuring system has been approved for installation in the helicopter type by an STC[12] and a supplement to the helicopter flight manual (RFM). Before flying with the system, the cyclic, collective and pedals on the right side of the cockpit shall be removed or blocked (RFM supplement). It is also stated that the installation shall be carried out in accordance with Visimind's installation documents. However, these documents do not indicate which authorisation is required to make the installation, or that the manoeuvring devices on the right side shall be removed or blocked.

A screen and keyboard were fitted on the right side of the cockpit in order to operate the system during power line inspections (see figure 13). These are not included in the STC, and SHK has been unable to find a description of how this installation is to be carried out or by whom.

[12] STC (Supplemental Type Certificate) – document for special approval of modification to aircraft.

The Visimind system was weighed by SHK in connection with the technical investigation, and it weighted approx. 89 kg. This corresponds well to the description in STC.


Figure 13. The field of view to the right and downwards as seen from the pilot's position, with the screen of the measuring system in place.

1.6.9 Airworthiness directives and type certificate holder's maintenance requirements

An airworthiness directive is a document issued by the EASA or another aviation authority which prescribes measures to be taken in an aircraft in order to restore an acceptable level of aviation safety when there is evidence to suggest that the aviation safety of that aircraft can otherwise be jeopardised. These measures can include requirements for modifications, replacement of parts, inspections, maintenance actions or changes to operative limitations and procedures, etc., which may be deemed necessary. If the directive is not complied with, the aircraft is not airworthy. Airworthiness directives often refer to regulations or recommendations from the type certificate holder, which in this case is Rolls-Royce Corporation in regard to the engine.

On 23 March 2016, the EASA issued an airworthiness directive for the engine type in question (AD 2004-0009R3). The directive replaced an earlier directive from the EASA and the initial directive that was issued in March 1995 by the British Civil Aviation Authority (CAA).

The issued directives show that both the type certificate holder and the regulating authorities that issue permits have been aware of the occurrence of nuts that have come loose during flight. The current directive contains special procedures and inspections for the reference pipes and nuts specified above, in order to prevent them from dislodging during flight. It also contains initial and repetitive maintenance measures, such as detailed instructions for inspection of pipes and nuts before assembly; instructions for torqueing and the establishment of maintenance records showing which tightening torque is applied on each disturbed

B-nut. In order to enable visual inspection to verify that these nuts have not come loose, a colour marking is used to indicate the position of the pipe nut and the nipple in relation to one another following installation through torqueing. This colour marking is to be inspected in-between each flight and at every 100-hour inspection. There are a total of 31 pipe nuts to be checked at each inspection.

1.7 Meteorological information

According to SMHI's analysis: wind approximately southerly, 5 knots, visibility greater than 10 km, no clouds, temperature/dewpoint +16/+7 °C, QNH 1040 hPa. The accident occurred in daylight and sunny weather.

1.8 Aids to navigation

Not applicable.

1.9 Radio communications

There is no known radio communication from the flight in question.

1.10 Aerodrome information

Not applicable.

1.11 Flight- and audio recorders

There were no requirements for recorders, but the helicopter had two different types of equipment registering data from the flight; an iPad with the navigation application SkyDemon (GPS[13] data), and the measuring system Visimind, which was used on board to document power line status (laser and GPS data). SHK has analysed the available data.

1.11.1 SkyDemon

The pilot was using an iPad with the application SkyDemon to plan the flight and to navigate. The application had saved the following data:

- Earlier flight plans.
- Performance of the helicopters SE-JVI and another of the company's helicopters, in two versions each – "FERRY" and "INSPECTION".
- Log files relating to a large number of previous flights.
- Files of the types .gpx and .kml, which can be uploaded to Google Earth to show flight paths.

[13] GPS (Global Positioning System) – often referred to as satellite navigation system.

SkyDemon uses positioning data from the iPad, for example using GPS. As no correction signals (reference signals) are used, the horizontal accuracy is considered to be within some ten metres, vertical accuracy within several ten metres. SHK has not found any specifications from the manufacturer Apple.

According to data from the Visimind equipment, the take-off point at Älvsbyn/Högheden Airport is at 76 metres above sea level. Prior to take off, SkyDemon registrated altitudes between 76 and 85 metres. A map from Lantmäteriet at a scale of 1:10 000 indicates that the take-off point is between the contour lines for 75 metres and 80 metres.

Data from SkyDemon has been entered into an Excel spread sheet and thereafter presented as a diagram where the vertical speed has been calculated based on registered altitude data (see figure 14).

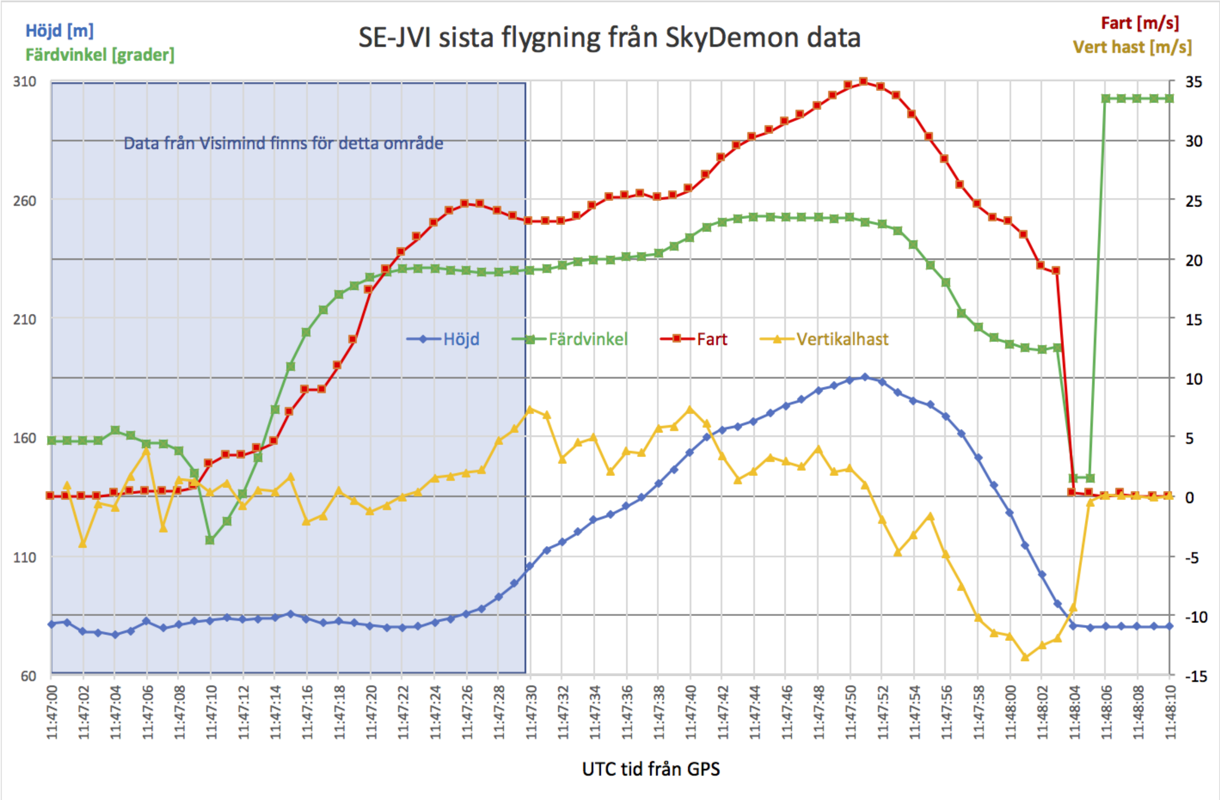


Figure 14. Diagram indicating altitude [m], bearing [degrees] and speed [m/s] based on registered data in SkyDemon. Vertical speed [m/s] has been calculated based on changes in altitude between each point. All times are given as UTC (Coordinated Universal Time). Local time = UTC + 2 hours. Note that speeds are relative to the ground (ground speed) as they are based on GPS data.

The diagram shows that the speed is 0 (and the bearing is stable) up until 11:47:03 hrs, to then increase to a maximum of 35 m/s (68 knots) and an altitude of 185 m at 11:47:51 hrs, which corresponds to an altitude above the surrounding forrest of about 80 metres. Then the speed reduces and the altitude dropped rapidly up until 11:48:04 hrs, when the registered speed was close to 0 and the altitude 80 m. The point of impact is at an altitude of 95–100 metres according to the Lantmäteriet map at a scale of 1:10 000, which is within the margin of error for SkyDemon. This means that the collision with the ground occurred between 11:48:03 and 11:48:04 hrs according to SkyDemon, and that the flight lasted for approximately one minute. However, it is of course possible that the helicopter was hovering before the speed and altitude started to increase.

Considering the actual winds (wind approximately southerly, 5 knots) and the topographical conditions on the site, SHK has considered the GPS speed data as corresponding to indicated air speed during the flight.

The diagram shows that the vertical speed oscillated up and down around 0 m/s up until 11:47:22 hrs, when it turned positive. From 11:47:51 hrs, the vertical speed turns into a negative figure (the helicopter is descending) and reaches its maximum of over 12 m/s, i.e. around 2,400 ft/min, at 11:48:01 hrs. Between 11:48:03 and 11:48:04 hrs it fell slightly (to 9.4 m/s, close to 2,000 ft/min), which may be due to the pilot successfully reducing the speed of descent, or that the impact occurred at this point in time. The large oscillations in registered vertical speed are likely due to a limited accuracy in the iPad’s estimated altitude values based on GPS (and GLONASS). Also see figure 1 and figure 15, where data has been entered in the flight path from SkyDemon in Google Earth.

1.11.2 Visimind measuring system

The helicopter was equipped with the measuring system *Visimind* for video photography and laser scanning of power lines. GPS-based equipment was used for positioning, which had an accuracy of a few centimetres both horizontally and vertically, with the recording frequency 1 Hz, as well as an inertial measurement unit with the recording frequency 100 Hz.

Data from both sensors has been used to estimate the position and orientation in 3D at 100 Hz. Data has then been saved with time, position, yaw, pitch and roll at 100 Hz. Note that yaw is the direction of the nose (heading) and not the track over the earth.

The recording begins at 11:42:02 hrs UTC and ends at 11:47:30 hrs. This means that the recording ended 34 seconds prior to impact, when the helicopter was still over the airport, i.e., when the flight appears to have proceeded as normal.

The equipment is fitted with battery backup, which is to supply it with power for up to 30 minutes after the regular power supply is gone. A likely reason why this has not functioned as intended is that the batteries were destroyed on impact, and that the equipment consequently could not transfer data from the volatile memory to the non-volatile memory, which retains data even with no power supply.

The analysed data from the Visimind system before it stopped corresponds to the compared data from SkyDemon for the same period of time.

1.11.3 Cockpit Voice Recorder (CVR[14])

Not installed.

1.12 Accident site and aircraft wreckage

1.12.1 Accident site

The accident site is located at the edge of a slightly sloping grass-covered meadow next to a group of buildings at the edge of a forest (see figures 15 and 16).

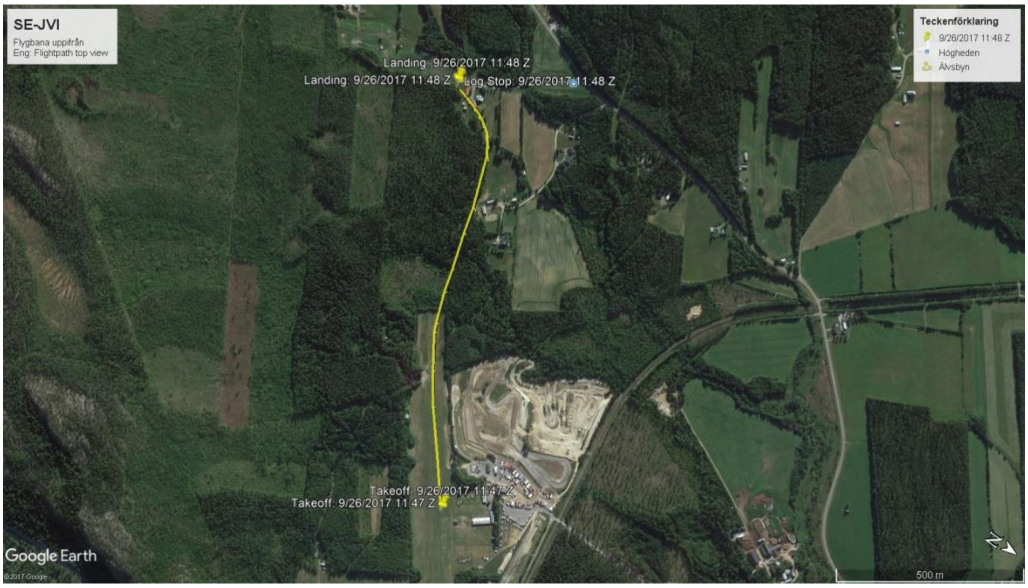


Figure 15. Satellite image with the flight path seen from above. Source: Google Earth


Figure 16. The accident site seen from above with an illustration of the probable flight path.

[14] CVR – Cockpit Voice Recorder.

1.12.2 *Aircraft wreckage*

The examination of the accident site showed that, when it collided with the ground, the helicopter had a high vertical speed and hit the ground tail rotor guard first (see figure 17), followed by the landing gear, which collapsed in the collision.

Figure 17. Ground contact with tail rotor guard and fin.

The damages to the helicopter, ground and nearby trees indicate that the helicopter had a descent angle of approximately 70 degrees, close to zero forward speed and very low rpm in the main rotor and tail rotor, combined with an exceptionally large coning angle[15] of the rotor disk at some point during the sequence (see figure 18).

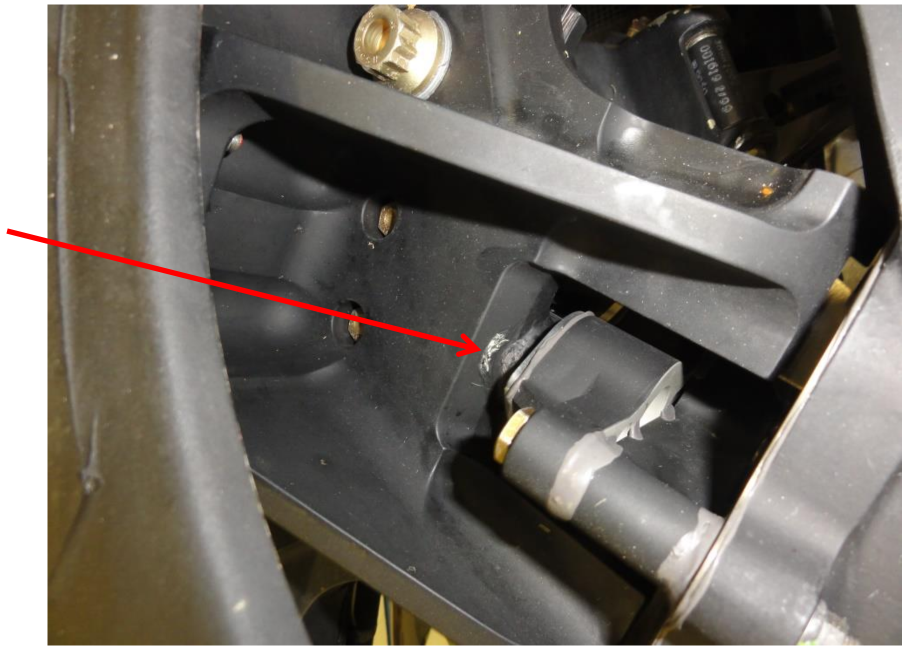


Figure 18. Damages to the main rotor hub following a high coning angle.

[15] Coning angle – the rotor blades turn upwards at an angle in relation to the plane of rotation.

After the first contact with the ground, the helicopter has rotated approximately 45 degrees to the left before coming to a stop.

1.13 Medical information

There is nothing to indicate that the mental and physical health of the pilot was impaired before or during the flight.

1.14 Fire

There was no fire.

1.15 Survival aspects and rescue operation

1.15.1 General

Provisions on rescue services are found primarily in the Civil Protection Act (2003:778) and the Civil Protection Ordinance (2003:789), in the following referred to by use of their acronyms in Swedish, LSO and FSO respectively.

The term "rescue services" denotes the rescue operations for which central government or municipalities shall be responsible in the event of accidents or imminent danger of accidents, in order to prevent and limit injury to persons and damage to property and the environment (Chapter 1, Section 2, first paragraph of LSO). The air rescue services are responsible for searching for missing aircraft (Chapter 4, Section 2 of LSO). Pursuant to Chapter 4, Section 2 of FSO, the Swedish Maritime Administration is responsible for air rescue services. These activities are coordinated from the Swedish Maritime Administration's sea and air rescue centre (JRCC[16]) in Gothenburg. Each municipality is responsible for rescue services within the municipality insofar as it is not a matter for central government rescue services (Chapter 3, Section 7 of LSO). In this case, the responsibility for rescue services was with central government air rescue services and the municipal rescue services.

Special provisions on air rescue services are found in the Swedish Transport Agency's regulations and general advice (TSFS 2015:51) on alerting services and air rescue services.

As soon as the Air Rescue Coordination Centre is informed that an aircraft is in a critical situation (uncertainty phase[17], alert phase[18] or distress phase[19]), the air rescue coordinator shall assess the information and judge the extent of the measures required (Chapter 5, Section 10 of

[16] JRCC – Joint Rescue Coordination Centre.
[17] Uncertainty phase – a situation wherein uncertainty exists as to the safety of an aircraft and its occupants (international designation: INCERFA).
[18] Alert phase – a situation wherein apprehension exists as to the safety of an aircraft and its occupants (international designation: ALERFA).
[19] Distress phase – a situation wherein there is a reasonable certainty that an aircraft and its occupants are threatened by grave and imminent danger and require immediate assistance (international designation: DETRESFA).

TSFS 2015:51). If the information is from any source other than an air traffic control unit, the air rescue coordinator shall also determine which emergency phase they are dealing with. (Chapter 5, Section 11 of TSFS 2015:51).

In the *uncertainty phase*, the Air Rescue Coordination Centre shall as far as possible cooperate with air traffic control units and other suitable agencies and organisations in order to quickly assess incoming reports and take necessary measures.

In the *alert phase*, the Air Rescue Coordination Centre shall immediately inform suitable rescue units and take necessary measures.

In the *distress phase*, or on the assumption of this phase, the Air Rescue Coordination Centre shall, among other things:

- immediately alert rescue units in accordance with suitable instructions
- determine the last known position of the distressed aircraft, assess the accuracy of this position and, based on this information and the circumstances, determine a possible search area
- based on the available information, make a detailed plan to lead the air rescue operation and communicate this plan to the agencies, organisations and others who are involved in the rescue operation.

The Air Rescue Coordination Centre shall have access to airborne SAR units[20] and other airborne rescue units that are suitably located and equipped for air rescue operations in the air rescue region (Chapter 2, Section 10 of TSFS 2015:51).

1.15.2 Air rescue services

At 13:48 hrs, the COSPAS-SARSAT[21] system received an emergency signal from SE-JVI's ELT[22] of the type Artex 406; without position for the helicopter. At 13:52 hrs, a report was submitted to JRCC, which then began to search for information about the helicopter. After a call to the ELT contact person, the situation was deemed to be in the uncertainty phase. At 14:05 hrs, JRCC received another report from COSPAS-SARSAT regarding SE-JVI, which also included information that the position of the emergency transmitter had been established as close to Älvsbyn. Through information linked to the emergency transmitter, JRCC was quickly able to make contact with the company associated with the helicopter.

[20] Airborne SAR unit – aircraft with special equipment and crew trained and exercised to search for and locate distressed aircraft and to home in on emergency locator transmitters.

[21] COSPAS-SARSAT is an international, intergovernmental organisation with the task of receiving and localising emergency signals on international emergency frequencies for aviation and shipping. The organisation, which meets the requirements set by the International Civil Aviation Organization (ICAO), has an emergency alert system consisting of both satellites and ground stations.

[22] ELT – Emergency Locator Transmitter.

At 14:11 hrs, JRCC contacted the air traffic control at Luleå/Kallax and was then informed that they had recently been in contact with SE-JVI, which was carrying out power line inspection, and that the helicopter with its two-man crew was then on its way to land at Älvsbyn/-Högheden Airport.

At 14:16 hrs, JRCC received information from the operator flight coordinator that the latter had attempted to contact the people on board the SE-JVI without receiving a response. The flight coordinator also provided the information that the helicopter had refuelled at Älvsbyn/-Högheden Airport and thereafter taken off at around 14:00 hrs. The person who had filled up the helicopter was asked to go by car from Älvsbyn/Högheden Airport along the route where SE-JVI was meant to carry out a power line inspection.

JRCC made a new assessment of the situation at 14:20 hrs, and at 14.22 hrs the situation was raised to the alert phase. Immediately thereafter, JRCC adopted a concept of operations (CONOPS) to the effect that units were to be dispatched to help locate the helicopter.

JRCC requested airborne resources via air traffic control in Luleå/Kallax at 14:31 hrs. There was a surveillance flight (Bluestar 12) and a private operated helicopter (SE-JDS) in the air, which was directed to the site indicated in the COSPAS-SARSAT reports.

At 14:34 hrs, JRCC received corrected information from the operator flight coordinator regarding the point in time when the latter last spoke to the pilots in the helicopter. The time of contact was now approx. 10 minutes prior to the first report from COSPAS-SARSAT.

At 14:38 hrs a police patrol in Älvsbyn, which was asked to go to the site. The police officer was alone in the patrol car.

At 14:41 hrs, following renewed assessment at JRCC, the incident is moved to the distress phase. A minute or so later, the surveillance flight stated that they had picked up the ELT and that they would be initiating a search in the area.

The rescue helicopter in Umeå (*airborne SAR unit*) was alerted at 14:43 hrs, and at the same time, JRCC asked the police whether there was any police helicopter available (*other airborne rescue unit*). The municipal rescue service and ambulance were then alerted via SOS Alarm.

The surveillance flight arrived to the area at 14:46 hrs and searched for approx. 10 minutes (see figure 19), but did not see the helicopter.

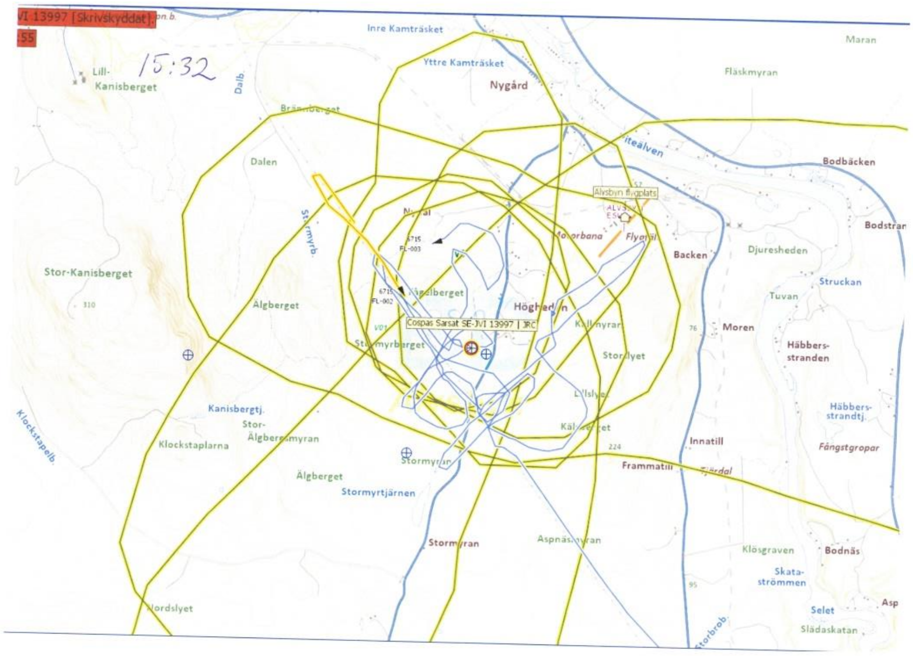


Figure 19. The tracks show the flight paths of Bluestar 12 (yellow) and SE-JDS (blue) during their participation in the search for the crashed helicopter. Source: JRCC

At 14:48 hrs, the police operations centre stated that a police helicopter was en route from the area of Östersund and was estimated to arrive at around 16:00 hrs.

The police patrol car arrived at 14:54 hrs and also made contact with the operator employee who had fuelled up the helicopter.

At 15:01 hrs, 18 minutes after the alarm, the rescue helicopter took off from Umeå with an estimated time of arrival to Älvsbyn 45 minutes later.

The private operated helicopter (SE-JDS), which was in contact via the air traffic control in Luleå/Kallax, picked up the ELT at 15:14 hrs. The helicopter was tasked with searching along the indicated power line (target route from the flight shown in figure 19)

At 15.19 hrs there information came from the company that owned the missing helicopter that its tracking device “tracker” had stopped sending. JRCC received then the last registered position from the company’s co-worker in Poland.

At 15:20 hrs, updated information was relayed from JRCC to SOS Alarm regarding the likely position of the helicopter.

The crash site was located by the rescue service and the patrol car at 15:29 hrs, after being guided to the site by SOS Alarm and by an employee from the company who was on site and could show the exact position of the crashed helicopter. The operator’s employee who had fuelled the helicopter had then already been at the site of the accident for 15–20 minutes. The exact crash site was communicated to JRCC.

The air rescue operation was concluded at 15:32 hrs. The air rescue coordinator at JRCC consulted with the municipal rescue coordinator in regard to which resources would be disengaged and which would continue the rescue operation.

1.15.3 Municipal rescue services

The municipal rescue services from Älvsbyn participated in the search for the helicopter, as instructed by JRCC, through a search on the ground in a forest area near a power line in the search area.

The site of the accident was located at 15:32 hrs when a rescue service vehicle and an ambulance arrived at the scene. The municipal rescue services organised the work on the ground. They cut open the helicopter so that the conscious pilot could be removed from the helicopter and continued the attempts to resuscitate the unconscious pilot that the company's co-worker had managed to pull out from the helicopter. They also requested assistance from an ambulance helicopter and moved hay bales in order to create a landing site for it.

There was a strong smell of fuel around the crashed helicopter which led the municipal rescue coordinator to make the decision to cover the area around the helicopter with foam. The municipal rescue operation ended at 16:15 hrs.

During the investigation, it emerged that the rescue services rarely carry out exercises concerning their participation in ground reconnaissance during searches (at the request of other agencies).

1.15.4 The operator's participation

The company normally maintains continuous monitoring of its aircraft, conducting line inspections via trackers in the helicopters which are linked to "Find my iPhone". The helicopters normally have an iPad on board.

The company quickly received information that the emergency transmitters on SE-JVI were activated in connection with them being contacted by JRCC. The contacted party disseminated the information within the company. The employee that refuelled SE-JVI in Älvsbyn was requested to return to the airport and attempt to make contact with the helicopter. This employee had amateur radio operator competence and pinpointed the emergency transmission at 121.5 MHz using a normal hand-held radio.

The company quickly put its action plans into motion. The information from the company's position monitoring of SE-JVI was shared with JRCC.

The employee who refuelled and one other employee from the company who was on-site met with the police and the rescue services on a number of occasions during the search operation.

The employee that fuelled SE-JVI was the one that located the emergency transmitter in the crashed helicopter using his hand-held radio. He dragged the unconscious pilot from the wreckage and began first aid, called for the help of his colleague who was nearby and contacted a colleague in Poland who in turn passed on the information to JRCC. The colleague had recently undergone CPR training.

1.15.5 Dissemination of information

JRCC provided continuous updates to SOS Alarm on the likely position of SE-JVI, which in turn provided this information to the municipal rescue services and the police. JRCC asked SOS Alarm which geographic reference system they preferred. The positions were given in both spherical coordinates (latitude and longitude) and in the common map reference system (x and y coordinates).

SOS Alarm asked for additional information on the missing aircraft. JRCC provided no information on the size or colour of the missing helicopter to the parties concerned.

No unified system was used to provide the available information to the units involved. There is a standard format for that to be used in form of a SITREP according to the IAMSAR[23]-manual.

The radio communication system RAKEL was used by the units affiliated with JRCC and SOS Alarm.

1.15.6 Positions and injuries of those on board and the use of belts

Both crew members used flying helmets and were strapped into their cockpit seats with a belt of the 4-point type.

The shock absorbing function consisted primarily of shock absorbers in the landing gear and fixed seating structures (boxes) which are intended to deform at different loads. The chairs consisted of a mesh fabric over a framework, with back support and seats where the seat bottom rests on four legs which connect with the fixed seating structure. The legs for both seats were bent or had come away, and both seat boxes were deformed from above. The back support showed no signs of damage. Both safety belt retractors worked and the belt mounting brackets were intact.

1.16 Specific tests and examinations

1.16.1 Engine inspection by authorised maintenance organisation

Under SHK’s supervision, an extensive inspection of the helicopter’s engine has been carried out by an authorised aircraft engine workshop. The inspection revealed that the identified damage to the engine was

[23] IAMSAR MANUAL – International Aeronautical and Maritime Search And Rescue Manual – the ICAO och IMO joint accepted manual for air- and sea rescue.

caused upon collision with the ground. There were indications that the gas generator (N1) was in operation, though at idle speed and that the free turbine (N2) had a very low rpm and thereby did not provide any power to the rotor system. No other signs of malfunction were identified in the engine system, apart from the open connection to the fuel control unit (see figure 9).

The fuel control unit was mounted on a test stand in order to verify that the prescribed fuel flow was delivered when the reference pressure was removed. The flow proved to be correct and corresponded to just below idle for the gas generator.

The connection unit for the reference pressure sent by the compressor to the fuel control unit (Filter Assembly) differed somewhat from other connection units; for one, there were around two fewer rotations on the thread (see figure 19). In addition, according to the engineering drawing from the manufacturer of the fuel control unit, the article number should be engraved on the connection unit. This number was missing.

SHK has, however, obtained information from two authorised maintenance organisations with long experience that it is very uncommon for such connection units to actually have an engraved article number. Furthermore, these seldom need to be replaced during maintenance.

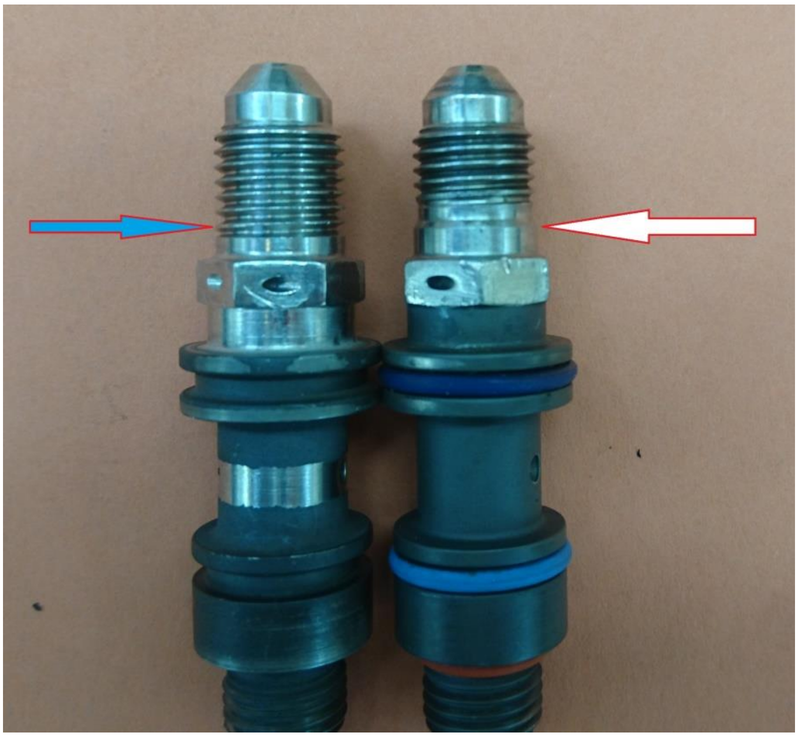


Figure 19. The inspected connection unit to the right and a reference connection unit to the left.

1.16.2 *Comparative inspection of the threads on the connection unit*

SHK has ordered an inspection of the thread geometry of the connection unit that was in place at the time of the crash and a comparison with the geometry of a reference connection unit.

As is clear from figures 20 and 21, the thread geometry is different.

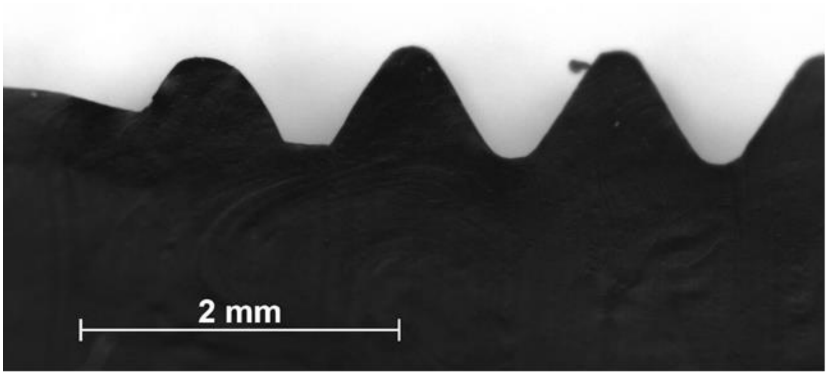


Figure 20. Cast of the mounted FA shown in figure 19. The white area represents the thread.

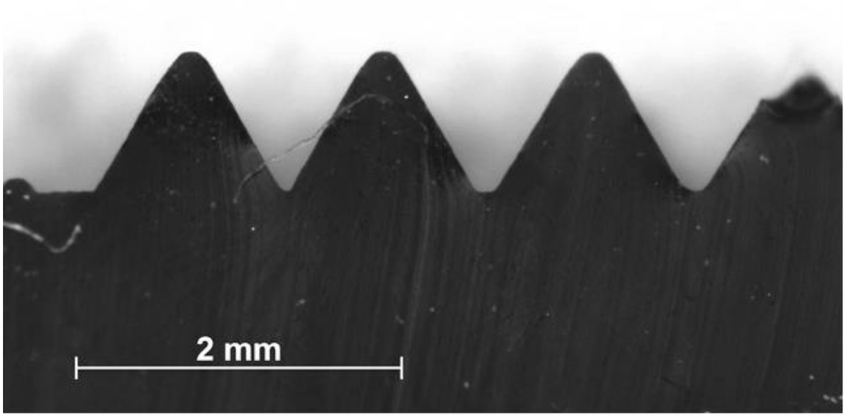


Figure 21. Cast of the reference FA shown in figure 19. The white area represents the thread.

1.16.3 *Fluid samples*

Engine oil and fuel from the ground tank installation in use, the auxiliary tank on board and the engine's fuel filter have been examined by an investigation laboratory. All tests were found to be according to specification.

1.16.4 *Torque testing of various combinations of Filter Assembly and pipe nuts*

SHK has conducted torque testing with various combinations of connection units (Filter Assembly) and pipe nuts (B-nuts). In each test, a clear difference was achieved compared with the other tests in terms of the torque required to dislodge the connection in question; either higher or lower. The tests also showed that the actual pipe nut did not reach the bottom of the thread despite there being fewer rotations on the thread of the connection unit in question. (See Appendix 1)

Colour markings on the connection units and pipe nuts (slip marks)

In torque tests of the connection unit with accompanying pipe nuts which was installed on the engine at the time of the accident, the colour marking of the pipe nut was consistent with that on the connection unit for the prescribed torque.

In accordance with the operator's checklist (see figure 22), and the engine's type certificate holder, *Rolls-Royce Corporation* (Operation and Maintenance manual 72-00-00 p. 602), the colour markings on all pipe nuts must be checked before every flight. No such inspection requirements were found in the documentation from the helicopter's type certificate holder (MD Helicopters Inc.).

The inspection can be carried out by the crew or by maintenance personnel. The pilots had received equipment and training for this, but no list of which pipe nuts were to be covered by the inspection.

Inspection of colour markings on pipe nuts.

PREFLIGHT CHECKS		
Perform these checks prior to subsequent flights of the same day		
Fluid levels	CHECK	SE-JVI SE-JVJ SE-JVM
Engine compartment - fluid leaks and bypass indicators	CHECK	
Air inlet screens/particle separator	CHECK	
Fuel cap, access doors and panels	CHECK	
Main rotor blades	CHECK	
Tailboom and empennage	CHECK	
Tail rotor rotor blades	CHECK	
Cargo and loose equipment	CHECK	
Crew and cabin doors	CHECK	
Inspection of VM		
Visually check for deformation, damage, loose fasteners and cracking of the Vision Module Mount, VMM (if installed)	CHECK	SE-JVI SE-JVJ SE-JVM
ENGINE ASSEMBLY		
Engine, general	CHECK	SE-JVI SE-JVJ SE-JVM
NOTE: Inspect the entire engine for loose bolts, broken or loose connections, security of mounting accessory, and broken or missing lockwire. Visually check for the presence and alignment of slippage marks (torque paint) on all B–nuts. Check accessible area for obvious damage and evidence of fuel or oil leakage		
LUBRICATION		
Check engine oil level	REPLENISH IF LOW	SE-JVI SE-JVJ SE-JVM

Figure 22. Part of the operator's checklist for pre-flight inspection.

1.17 Concerned actors' organisation and management

1.17.1 The operator

The flight operator FEAC, First European Aviation Company, is a flight operator based in Poland and has a permit for aerial work/SPO. At the time of the accident, FEAC was operating three helicopters of type MD 500 for power grid companies, within Europe, with the Visimind measurement system installed. The pilots were contracted to conduct flights for the operator and they had undergone type rating on the helicopter type and company specific training which included using and flying with the Visimind system.

1.17.2 Requirement for documentation of maintenance

Commission Regulation (EU) No. 1321/2014, Annex II, 145.A.55 states that "*The organisation shall record all details of maintenance work carried out. As a minimum, the organisation shall retain records necessary to prove that all requirements have been met for the issue of* *the certificate of release to service, including subcontractor's release documents*". The purpose of these requirements is i.a. to ensure that it is possible to check that all elements of the work which are crucial to safety have been correctly performed.

SHK has reviewed the maintenance documentation which had been kept from the last known maintenance work on the reference pipes that were loose on the engine. The work – replacement of the free turbine regulator including implementation of AD 2004-0009R3 – was carried out by the operator during the period 18 July–1 August 2017.

It is clear from the maintenance documentation presented to SHK that AD 2004-0009R3 has been implemented for the engine in question. The documentation does not, however, provide details; i.e., as confirmation that all maintenance actions in the AD have been performed.

1.18 Additional information

1.18.1 Experiences of similar accidents with engine type RR 250

Tampere, Finland 10 January 2013[24]

A similar fault caused an accident involving a helicopter of the same type in Finland in 2013. The connection came loose at the other end of the piping system which runs between the PC filter and the fuel control unit (FCU). The loss of power resulted in the destruction of the aircraft. In all material aspects, the engine's type certificate holder Rolls-Royce Corporation was of the opinion that inadequate maintenance led to the pipe nut coming loose, causing engine failure.

Zurich Schweiz, 9 August 2003[25]

An accident involving an Agusta Bell AB206B Jet Ranger III helicopter occurred when a pilot experienced engine disruptions and performed an autorotation landing. The investigation revealed that a pipe nut had begun to come loose at the fuel control unit as it had not been correctly tightened. Air had therefore begun leaking from the connection, which affected engine power.

1.18.2 Autorotation

During autorotation, the flightpath – all things being equal – is dependent on the rotor rpm, wind speed and how heavy the helicopter is in relation to its maximum permitted flight mass (weight).

An autorotation landing is the method which facilitates an emergency landing if the engine is no longer providing power. The method means that the pilot has one attempt to manage the landing under favourable conditions.

[24] Finnish Safety Investigation Authority – Investigation report L2013-01.
[25] Swiss Confederation – Final Report No. 1920 by the Aircraft Accident Investigation Bureau.

Flight in autorotation entails that the main rotor is driven by the air flowing up through the main rotor from below, instead of being driven by the engine. This status entails that the air drives the rotor whilst at the same time the rotor generates a certain amount of lift and steering capacity during descent with a high vertical speed. This makes it possible to steer towards an emergency landing site but the flight path is steep and the rpm during autorotation is normally somewhat higher than during engine-driven flight. The situation requires the pilot not to utilise the power in the form of the living mass of the main rotor caused by the rotation – the "rotational energy" – until the last moment above the ground, when the angle of attack on the rotor blades increases in order to generate more lift at the expense of the rotation energy in the rotor and thereby slow the descent before touchdown. When this is done, the rpm decreases quickly, the rotor gains an increased coning angle (the rotor blades bend upwards) and the lift decreases with the diminishing rotor rpm.

The procedure is based on the assumption that the aircraft is outside of the marked area in the Height Velocity diagram "dead man's curve" (see figure 21) when the fault occurs and that the pilot quickly becomes aware that the engine has stopped providing power. If an engine failure occurs, it is important to lower the collective lever within the space of around a second in order to maintain and, where possible, regain the rpm which will otherwise rapidly decrease.

The urgency to lower the collective lever, and thereby the decrease in lift, is dependent on the speed and altitude of the helicopter at the time the fault occurs. In order for an autorotation landing to be possible, the rpm must firstly not drop below a critical level and secondly have enough time to build up again, whilst at the same time an appropriate speed is stabilised, prior to the final phase with the necessary speed reduction. An indicated speed of 60–80 knots during autorotation is recommended for this helicopter model.

A heavily loaded helicopter means a higher rate of descent and thereby a shorter glide distance than for a helicopter of the same type with a light load. A more heavily loaded helicopter also entails a higher air-flow which drives the main rotor, thus affording a better opportunity to regulate the rotor rpm. The combinations of altitudes and speeds whereby the type certificate-holder states that there are conditions for performing a safe autorotation landing are illustrated by the different areas in figure 23. It is not prohibited to fly within the two marked areas, but this should be avoided where possible.

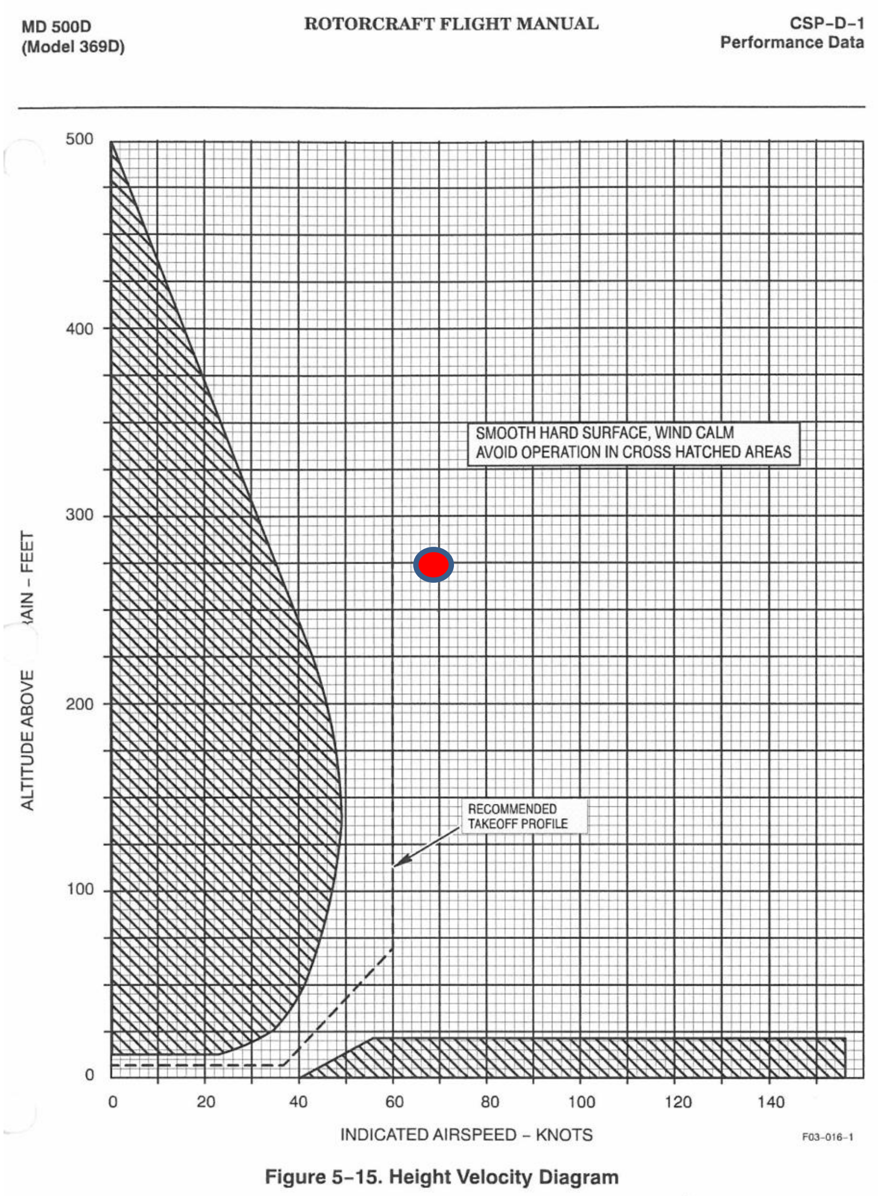


Figure 23. Height Velocity Diagram. The red dot marks the approximate speed and altitude at which the engine fault occurred. The marked areas represent speed and altitude combinations at which a successful autorotation landing is difficult to perform.

1.18.3 *Action taken*

The operator has stated that, following the accident, it has implemented or intends to implement the following measures, among others:

Follow-up measures taken within SOP-HR

- A new emergency response plan has been issued and practised, and first aid training shall be offered annually.

Follow-up measures in the operator's maintenance organisation

- The operator's other helicopter discontinued ongoing activities in order to undergo preventive maintenance and to perform an inspection of the engine components in focus in SHK's investigation of the crashed helicopter.
- Refresher training in accordance with the training programme run within the Maintenance Organisation Exposition (MOE) with special focus on the subject of human factors in maintenance and updates in part 145 requirements.
- Use selected reports from similar accidents involving MD 500 to keep the technical staff informed.

Follow-up measures taken within the operator's CAMO

- Refresher training for pilots authorised to perform inspections before and after flying.

1.19 Special methods of investigation

Not applicable.

2. ANALYSIS

2.1 Scope of the investigation

Shortly after the take-off from Älvsbyn/Högheden Airport, at a height of about 80 metres above the forrest and a speed of 68 knots, the aircraft began to rapidly lose both altitude and speed. Twelve seconds later, the helicopter collided with the ground at the side of a grass field behind a building and near the edge of a forest with tall trees.

The examination of the accident site revealed that the helicopter had struck the ground with a nose-up attitude, tail boom first. It had a descent angle of approximately 70 degrees, close to zero forward speed and very low rpm in the main rotor and tail rotor, combined with an exceptionally large coning angle of the rotor disk at some point during the sequence. All findings indicate that the engine stopped supplying power during the flight, and a key question of the investigation has been why this happened.

Another key question is why the emergency landing attempt was unsuccessful.

A third question is why it took 1 hour and 40 minutes before the crashed helicopter was located by the rescue services and medical resources arrived at the scene, despite the helicopter's ELT starting to transmit at the time of the accident.

2.2 Why did the engine stop supplying power?

In the examination of the helicopter, SHK discovered that the pipe that supplies reference pressure from the engine compressor to the free turbine regulator and the FCU had come loose from its fitting. The threads of both the pipe nut and the fitting were intact, which indicates that the pipe had loosened prior to impact.

The loss of the reference pressure meant that the gas generator's rpm fell below the normal idle rpm. At this low rpm from N1, there was no power to drive the rotor system. Landing via autorotation was therefore the pilot's only choice in the situation at hand. SHK returns to this issue in section 2.3.

In SHK's opinion, there are two possible causes which individually or in combination may have entailed the pipe loosening from the assembly. One is that the threads on the connection unit (Filter Assembly) were not consistent with the fuel control unit manufacturer's specifications, and the second is that the pipe nut was not mounted correctly.

With regard to the way in which the connection unit in question deviated from the specifications, SHK's tests and checks have shown differences in the force required to loosen a pipe nut which has been tightened to the correct torque. As a result of the differences, the material stress in the unit may have been too low even if the correct tightening torque was applied. This would mean that the unit would have a lower resistance to loosening in the event of alternating stresses such as vibrations. SHK has been unable to trace the origin of the connection unit. However it was fitted to the fuel control unit on 29 September 2015 by one of the type certificate holder's approved workshops for aircraft engines.

If the pipe nut had not been tightened to the correct torque during the last maintenance, this is of course a factor which can lead to it coming loose. In SHK's test-torqueing's of the loosened pipe nut, however, the colour marking between the pipe nut and the connection unit have been consistent, which suggests that it was tightened to the correct torque. At the same time, the maintenance records from the operator does not provide satisfactory evidence that all elements of the prescribed maintenance were carried out; such as air tightness tests of pneumatic pipes in the fuel system (Operations and Maintenance Manual), and that all parts of AD 2004-0009R3 were performed correctly in connection with replacing the free turbine regulator.

During the engine investigation, it was established that another pipe nut in the same piping system had an inadequate tightening torque. This pipe nut was mounted on a connection which was consistent with the type certificate holder's specifications. The fact that the pipe nut was loose thus indicates that the right torque was not applied when it was mounted. It should be noted that the colour marking on this connection was faded and difficult to identify.

In accordance with instructions from the engine's type certificate holder, the operator had chosen to include a check of the colour marking during the inspection performed before each flight. There was however no list of which pipe nuts should be covered by the check.

Such checks are, in theory, a means of ensuring the pipe nuts are correctly tightened and thereby not at risk of coming loose during the flight. In reality, however, it is not realistic to believe that such checks can be performed to a satisfactory standard before every flight. The inspection requirement covers 31 pipe nuts and the inspection takes place in a space which is not easily accessible, often with high temperatures and poor visual conditions. The colour markings can also, as noted above, be difficult to make out.

In practice, this means a shift of responsibility for the engine being in satisfactory technical condition from the maintenance organisation to the crew. In SHK's view, this is unsatisfactory from a flight safety perspective.

There are ways of improving the locking of pipe nuts, e.g., with lock wires. Considering the recurrent problems with this engine model and the accidents which have occurred, the European and US aviation safety authorities EASA and FAA should consider imposing new requirements regarding improved locking. Otherwise, the risk remains that a similar accident may occur in the future.

2.3 Why was the emergency landing unsuccessful?

The pilot has been unable to describe how the fault manifested itself. During tests, the identified fault has proven to involve the engine losing all propulsion as the rpm drops to just below idle. The vertical speed and the damages which indicate a very low rpm suggest that the helicopter lost all engine power and that the pilot was forced to reduce the power output to a position where the main rotor transitions to be driven by what is known as autorotation.

In the event of a fault which entails the engine no longer providing power, it is vital that the pilot immediately – within the space of 1–2 seconds – take action to retain the rpm on the main rotor by reducing the collective lever and attempting to assume an appropriate speed. The conditions are better the greater the altitude and speed at the time the fault occurs. When the fault occurred, the crew was flying at around 80 metres above the forrest at a weak climb and a speed of 68 kts with close to the maximum permitted flight mass. According to the Pilot's flight manual, this means that it is possible to perform a successful emergency landing, if the landing site permits this. The margins are however small. The relatively low speed and altitude mean that the probability of regaining the original rpm and stabilising the recommended speed for autorotation was low in practice.

The diagrams produced by the type certificate holder and presented as combinations of speeds and altitudes that should be avoided are based on tests carried out by highly qualified pilots who are prepared for the situation. Even if the diagrams include a safety factor, it is important to see them as a recommendation or a guide and not an absolute limit for which flight situations can or cannot be handled in the event of an engine failure.

Given the relatively little flying experience of the pilot, it is understandable that a pilot would look for suitable emergency landing terrain in the direction of the best visibility, and that they are used to pivoting towards this when an emergency situation arises. In this case, there was land able field terrain to both the left and right side in the direction of flight. The fields to the right side were closer but they were partially obscured by the system operator's screen and featured buildings and a small power line. Despite the relatively low speed and altitude, combined with the heavy load of the helicopter, the pilot was able to overcome the obstacles present, but at the cost of the rotor rpm. The rotor rpm was therefore too low for a safe landing and the collision with the ground was forceful, despite the damage to the rotor head indicating that the maximum possible lift was drawn from the rotor at a low rpm.

2.4 Why was the damage so extensive?

The high vertical speed of some 2000–2400 feet per minute (10–12 m/s) and low or zero forward speed at the time of the collision means that the helicopter was subjected to forces which exceeded what it was designed to manage without the crew being severely injured or killed.

2.5 Why did it take so long to locate the helicopter?

Once JRCC received the first report that the emergency transmitter on SE-JVI had been activated, which was followed by a report 13 minutes later which gave the position, 30 minutes passed before JRCC gave the event an alert status. Another 19 minutes passed before the event was classed as an emergency situation. Two minutes later, around 50 minutes after the first report had been received by JRCC, the first airborne rescue units (the police – other airborne rescue units and the base in Umeå – airborne SAR unit) were alerted.

One explanation as to why the event was not immediately classed as an emergency situation was that in an uncertainty phase, JRCC performs "internal factual collection" as per normal procedure when a COSPAS-SARSAT report has been received, in order to obtain more information and rule out "false alarms", which normally constitute around 90 % of all ELT alarms received by JRCC.

When it was not possible to make contact with anyone who could confirm that the helicopter was parked on the ground in Älvsbyn, the event was given alert phase status and it was decided to send out units to confirm the status of the helicopter. When an alert status arises, the Air Rescue Coordination Centre shall immediately inform the appropriate rescue units. This did not happen. The first contact with the airborne rescue units was made once the event was upgraded to emergency status. No explanation, has been given for this during the course of the investigation.

The initial search for the helicopter was performed by units which were not trained in searching for and locating aircraft in emergency situations or homing in on emergency transmitters. The event, where two private aircraft attempted to locate the helicopter, shows that this is not a simple task.

Four of the reports from COSPAS-SARSAT revealed one and the same position, which was some 600 metres from the site of the accident. The precision requirement for COSPAS-SARSAT is that 95 % of the positions given in the reports are within a 5 km radius of the activated emergency transmitter; a requirement which was thus fulfilled in this case. The crashed helicopter was found close to a large barn with a sheet metal roof, which may have affected the distress signals received by the COSPAS-SARSAT system.

The municipal rescue services performed their function well, according to SHK's investigation, once they arrived at the site of the accident. On the other hand, the rescue services seldom undergo training exercises in assisting in ground reconnaissance during searches (at the request of other authorities), which may affect their ability to assist in search tasks.

3. REPORT

3.1 Findings

a) The pilots were qualified to perform the flight.
b) The helicopter had Certificate of Airworthiness and a valid Airworthiness Rewiev Certificate.
c) The engine lost power during flight.
d) A connection to the gas generator's fuel control unit had come loose.
e) The fuel control unit's connection unit (Filter Assembly) had no article number and deviated from the manufacturer's specifications.
f) It is unusual for connection units to be marked with an article number.
g) Loosened connections of the same type have previously caused accidents.
h) The pilot had limited experience of autorotation in the present configuration.
i) It took 50 minutes from the helicopter's emergency transmitter being activated until the airborne rescue units were alerted to respond.

3.2 Causes

The accident was caused by an engine failure in flight where the possibilities for a safe emergency landing were limited by the low speed and altitude in combination with a heavily loaded helicopter.

The cause of the engine failure was that the pipe nut backed off and the pipe came loose resulting in a loss of engine power. The nut could back off due to the methods of securing the engine fittings with prescribed torque and the visual slippage inspections before flight was flawed.

4. SAFETY RECOMMENDATIONS

The FAA is recommended to:

- Evaluate whether the construction of the Rolls-Royce engine RR 250-C20 and other models using the same type of B-nut, without any other safety measures than the tightening torque and the prescribed nut checks, provides a sufficiently safe protection against engine failure in single-engine configurations. *(RL 2018:08 R1)*

- Investigate whether there is a need to inform concerned sections of the industry that there may be deviating fittings (Filter Assembly) in circulation in international flight operations. *(RL 2018:08 R2)*

EASA is recommended to:

- Evaluate whether the construction of the Rolls-Royce engine RR 250-C20 and other models using the same type of B-nut, without any other safety measures than the tightening torque and the prescribed nut checks in accordance with EASA AD 2004-0009R3, provides a sufficiently safe protection against engine failure in single-engine configurations. *(RL 2018:08 R3)*

The Swedish Maritime Administration is recommended to:

- Review their procedures for how classification of emergency broadcasts on international emergency frequencies is applied. *(RL 2018:08 R4)*

- Evaluate and, if needed, develop their procedures to ensure a sufficiently quick dispatch of flying rescue units that are equipped, trained and have practised for search missions, including homing of emergency locator transmitters. *(RL 2018:08 R5)*

The Swedish Accident Investigation Authority respectfully requests to receive, by **19 November 2018** at the latest, information regarding measures taken in response to the safety recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Mikael Karanikas Stefan Carneros

APPENDIC: APPENDIX 1 TORQUE TESTING

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At the contracted laboratory				
	Torque in, Newtonmeter	Break away torque		Average Break away torque
Actual filter assemby and B-nut	11,06	10,31	93%	
	11,06	8,46	76%	
	11,15	8,38	75%	
	11,07	8,61	78%	
	11,03	8,51	77%	
Actual filter assemby and alternate B-nut	11,04	8,21	74%	
	11,08	8,23	74%	78%
Actual filter assembly and new B-nut without pipe	11,02	9,08	82%	
Reference filter assembly and actual nut	11,14	6,26	56%	
	11,08	6,56	59%	
	11,04	6,77	61%	
Reference filter assembly and actual nut	11,08	6,96	63%	
	11,18	7,57	68%	
Reference filter assembly and alternate B-nut	11,04	6,48	59%	61%
Alternate fitting and alternate B-nut	11,03	7,58	69%	
	11,18	7,64	68%	
Alternate fitting and actual B-nut	11,08	7,62	69%	
	11,25	9,23	82%	
	11,15	8,28	74%	72%
At Engine MRO, Malta				
	Torque in, Inchpound	Break away torque	%	Average Break away in %
Actual filter assembly and actual B-nut	100	70	70	
	100	30	30	
	100	60	60	
				53
Down stream Pc-filter		ca 5		just a little more that finger tight
Upstream T-fitting PTG		65		
	100	80	80	
	120	90	75	78
Down stream T-fitting PTG		90		