Accident
Investigation Board
Norway

Issued November 2009

REPORT SL 2009/27

REPORT ON AIR ACCIDENT 21. NOVEMBER 2004 AT LAKE VÅGÅVANNET NORWAY INVOLVING EUROCOPTER SA 365 N1, LN-OPJ OPERATED BY NORSK LUFTAMBULANSE AS

Photos: AIBN and Trond Isaksen/OSL

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AIR ACCIDENT REPORT

Aircraft:	Eurocopter SA 365 N1 Dauphin 2
Nationality and registration:	Norwegian, LN-OPJ
Owner:	Helikopter Transportation Group AS, Norway
Operator:	Norsk Luftambulanse AS, Norway
Crew:	Commander, Doctor and Rescueman
Passengers:	None
Accident site:	Lake Vågåvannet approx. 250 m south of Vanglandet marina, Oppland, Norway (61°52'N 009°05'Ø)
Date/time of accident:	Sunday, 21 November 2004 at 1441

All times given in this report are in local time (UTC + 1) unless otherwise stated.

NOTIFICATION

On Sunday 21 November 2004 at 1523 the officer on duty at the Accident Investigation Board Norway (AIBN) received notification from the Joint Rescue Coordination Centre for South Norway (HRS-S) that a helicopter from Norsk Luftambulanse (Norwegian Air Ambulance Service) had crashed in lake Vågåvannet. Its crew of three, who were physically uninjured, were rescued, brought to the shore and taken care of by the local police. Two accident inspectors from the AIBN were called out and arrived at Vågåmo that same evening. Investigation work began on the morning of 22 November.

In accordance with ICAO Annex 13 "Aircraft Accident and Incident Investigation", the AIBN notified the accident to the accident investigation board in the country of manufacture (France). The French accident investigation board, Bureau d'Enquêtes et d'Analyses (BEA), appointed an accredited representative who assisted during the investigation together with advisers from the helicopter manufacturer, Eurocopter.

SUMMARY

The operator had specific requirements that crewmembers should perform training every 6 months on picking up people from the water using the helicopter. In connection with such training, LN-OPJ flew from its base at Dombås to lake Vågåvannet where ice had not yet formed for the winter. After arrival in Vågå, the first flight involved flying over the water with the Rescueman suspended below the helicopter on a rope 33 m in length. After that, the plan was that the Rescueman wearing a drysuit, would jump from the helicopter cabin into the water. When the Rescueman jumped, from an estimated height of 2 – 3 m, the crew heard a loud bang and the helicopter began rotating anticlockwise around the main rotor mast. The Commander realised that something had happened to the tail rotor and brought the helicopter down gently into the water approx. 250 m from the shore. The helicopter rolled over onto its left side and sank. None of the three on board were injured and the Rescueman was subsequently able to help the Commander and the Doctor up onto the helicopter which rested on the bottom and remained partially above the surface of the water. The Rescueman

stayed in the water for a short time until help arrived by boat. The water temperature was close to 0 °C with an air temperature of approx. -6 °C, consequently the situation could quickly have become critical for the two persons not wearing drysuits.

The AIBN believes that the accident was a result of the tail section inadvertently hitting the water, or came so close to the water, that water was sucked through the tail rotor and it became overloaded. The overload led to a fracture of the tail rotor drive shaft and subsequent loss of control over the helicopter. Contributory causes for the helicopter coming too low included a lack of good visual references for judging height. It also became clear that the operator did not have any procedures to prevent the helicopter coming too low in the critical phase of the operation.

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 The operator had a self-imposed requirement that crewmembers should as a minimum attend training every 6 months on picking up people from the water using a helicopter. Suitable lakes in the vicinity of the base at Dombås could be ice-covered up to May and so it was important for the autumn training to be carried out late in the year just before ice formed. The training sortie had been planned for the week before the accident, but snow and mist prevented it. However, the weather reports for Sunday 21 November were good, and it was decided that the training should go ahead.

1.1.2 The Commander started his working day at 0830 on Sunday morning. He inspected (Pre Flight Inspection) the helicopter indoors at the Dombås base and, with the Rescueman[1], prepared the equipment required for the day’s exercise. The training was then reviewed in detail together with the Doctor who was also to be involved.

1.1.3 The operator had previously carried out training on picking up people from lake Vågåvannet. Ice had not yet formed on the water and the weather was suitable for the mission. LN-OPJ took off from the base at Dombås at around 1400 and landed on the frozen beach near Vanglandet marina southwest of the centre of Vågåmo. (see Figure 1). This flight lasted around 10 minutes.

[1]Referred to as HEMS crew member in BSL JAR-OPS 3 context.

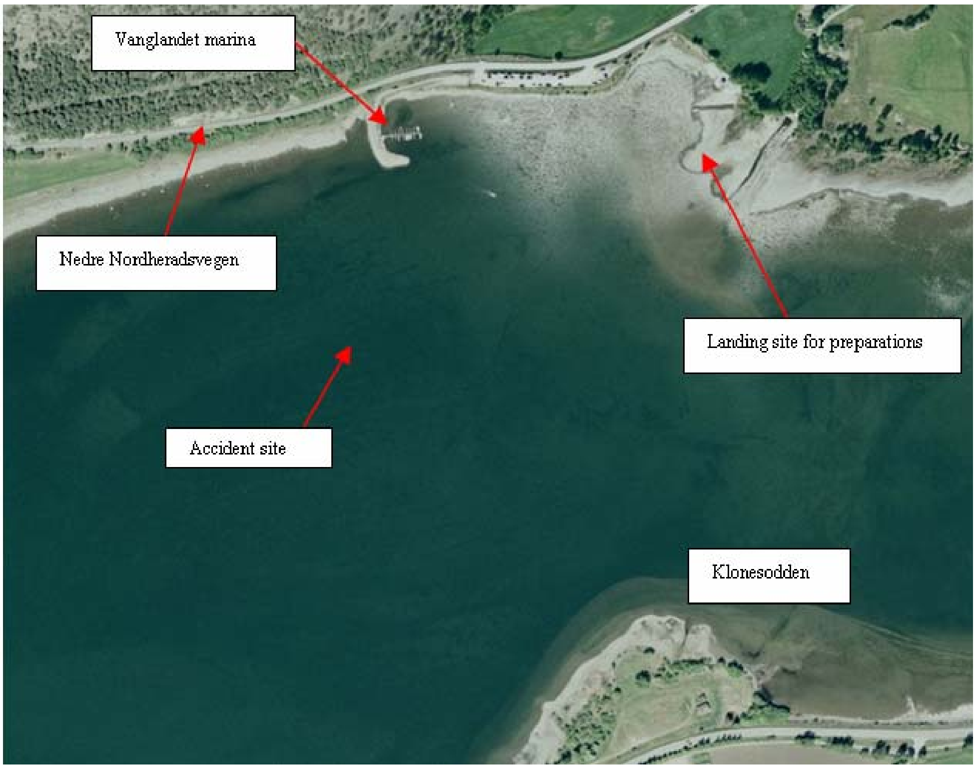


Figure 1: Overview of the east end of Vågåvannet.

1.1.4 The rotor and engines were stopped after landing on the beach and the procedures were reviewed once again. The first part involved practising flying with the Rescueman suspended below the helicopter on a rope 33 m in length. The Rescueman was wearing a drysuit and climbing harness (sit harness). A short flight was made during which the Rescueman was suspended approximately 15 m above the water. Then he was put down at an agreed point on the beach. The Doctor was sitting in the open door on the right hand side, giving directions to the pilot.

1.1.5 Once the helicopter had landed on the beach again, the Rescueman disconnected the rope, coiled it up and put it in the baggage compartment on the right side at the rear of the helicopter. The Rescueman was then to practise jumping out of the helicopter to rescue a person in the water. He brought an 11 m long rope with a rescue sling into the cabin and connected one end of it to the hook above the door on the right hand side of the helicopter. The other end holding the rescue sling was put into the cabin together with a 20 litre white plastic can. The plastic can, which was to be used as a marker, was marked with red tape to improve its visibility. In addition, an iron rod was attached to the can via a 2 m long rope to ensure that the can would not blow away due to the rotorwash. The Doctor sat at the back of the cabin on the right hand side and the Rescueman sat down in front of the Doctor by the open door.

1.1.6 The rotor was turning while this was going on. The helicopter took off and was then flown above the water at a height of approx. 50 ft. The area contained gently sloping shallows and the helicopter was flown approx. 300 m out towards the southwest to ensure that there was an adequate depth to allow the Rescueman to safely jump into the water. The Rescueman then threw out the marker and the helicopter flew a circuit including a subsequent approach towards the marker. The approach was carried out on a course of approx. 230° straight into the wind.

1.1.7 During the first approach, the marker was blown away by the rotorwash. The Commander therefore climbed and flew backwards until he had the marker approx 30 m ahead, before he began a new approach. The second approach was successful and the Commander had the marker in sight, ahead and to the right, when he brought the helicopter to a stationary low hover. The Rescueman dropped the rope-end out of the door. The rope, which was then attached to the helicopter and to the Rescueman, reached approx. 5 m below the helicopter. When the rope touched the water, it indicated the maximum height at which it was safe for the Rescueman to jump. According to the Commander, the radar altimeter was not accurate enough to indicate the jump height, nor was it justified to spend time watching the instruments in this phase where full attention is required outside the helicopter. When the Commander thought the time was right for the jump, he notified the Doctor who gave the sign to the Rescueman by tapping him on the shoulder. Based on visual contact with the marker, the helicopter was held in a stable position approximately 2 - 3 m above the water. The rotorwash whipped up the water and water vapour from the surface, with drops forming on the bottom of the windows. However, the Commander did not see the water freezing solid anywhere and described the flight as completely normal up to this point.

1.1.8 The Commander then heard a loud bang followed by something characterised as grinding noises before the helicopter began rotating to the left. He immediately realised that something had happened to the tail rotor and instinctively lowered the collective to put the helicopter down on the water. The helicopter rotated through approximately one revolution before it landed softly. To control the situation as far as possible, he held the collective up a little while he shut down the engines, switched off the fuel pumps, switched off the power and engaged the rotor brake. When the rotor was about to stop he rolled the helicopter over on its left side. He assumed that the two people onboard would be best able to escape from the right door which was then uppermost, while he also hoped that the Rescueman was in the water on the right hand side. The Commander had water up to his waist when he opened the door, held himself in the doorframe and released his seat belt. He got out without any problem and ascertained that the Doctor and the Rescueman were already swimming in the water.

1.1.9 The Doctor has stated to the police that the distance down to the water was approx. 2 m when the Rescueman jumped. The intention was that the Doctor would sit on the floor with his feet outside the helicopter, directing the Commander via the intercom. However he had not managed to get into position before he heard a loud bang just as the Rescueman jumped. The Doctor did not perceive any rotation in the helicopter, but rather a sideways movement. He thought immediately of getting himself free and released the rear right hand side door. He held it in place until the helicopter had settled on the water. He did not remember how he got out of the helicopter, but remembers that he waited until the rotor had stopped. The intercom cable to his helmet was difficult to disconnect and when he got into the water, he swam a certain distance away because he expected the helicopter to sink.

1.1.10 The Rescueman assumes that it was between 2 and 2.5 m down to the water from the cabin floor when he felt the tap on his shoulder and jumped. He then heard a bang. He could not say with any certainty whether the bang came when he had made the decision to jump, or if the bang sounded as he jumped. The sound was clearly audible above all other noise and was described by the Rescueman as sounding as if someone hit the hand hard with an empty plastic bottle. The Rescueman disappeared for a short time beneath the surface and when he resurfaced he saw that the helicopter was rotating around the rotor mast with its nose to the left. After a little more than one rotation the helicopter settled on the water, and the rotation stopped immediately. He was then located on the right hand side of the helicopter, a little behind the cabin.

1.1.11 The Rescueman's first thought was to get as close to the rotor mast as possible in order to avoid being hit by the rotor blades. He pulled himself towards the door opening with the aid of the rope while also hearing the Commander call out that everyone should evacuate. The rotor speed dropped and the Rescueman tried to disconnect himself from the rope, but was surprised by how quickly the helicopter rolled over. The rope somehow got caught on the helicopter, and he was pulled under water for a short time. He released himself quickly however, and when he resurfaced the Doctor and the Commander were also in the water.

1.1.12 The Doctor tried to cling to the marker while the Commander had decided to swim ashore. However, the Rescueman discovered that the helicopter was lying motionless with parts of its belly and tail above the water. He was therefore of the opinion that it would be best if the Commander and Doctor climbed onto the helicopter. With the Rescueman's help, the Commander made his way up onto the slippery hull and climbed into the right hand wheel well. A short time after that the Doctor managed to get up into the same wheel well. At that time, the Doctor had stopped shivering and had become distinctly passive. The Commander and the Doctor were not dressed for staying outdoors in the cold. In order, if possible, to limit any further loss of heat, the Rescueman opened up the cargo compartment at the rear on the right hand side and, after some searching, found two wind sacks that he was able to pack around the other two. He himself chose to remain in the water, to be ready if anyone fell or if the helicopter were to turn over.

Figure 2: Picture taken facing northeast, the day after the accident. The plastic can which was used as a marker is shown on the left of the picture. The Commander and the Doctor sat in the wheel well closest to the camera.

1.1.13 There were several witnesses to the accident and the emergency number 113 was dialled immediately. A witness also made a direct call to the supervisor of the Red Cross's Search and Rescue Corps in Vågå. A short time later, the Red Cross's Search and Rescue Corps arrived by car with a boat on a trailer. The boat was launched, and the two sitting on the helicopter were first brought ashore. At time 1459, approx. 18 minutes after the accident, all three were safely ashore and being taken care of by staff from the Red Cross's Search and Rescue Corps (see also subparagraph 1.18.1).

1.2 Injuries to persons

Table 1: Injuries to persons

Injuries	Crew	Passengers	Other
Fatal			
Serious			
Minor/none	2	1[2]	

1.3 Damage to aircraft

The aircraft sustained considerable damage (see subparagraph 1.12.2 for details).

1.4 Other damage

There were no reports of oil pollution in conjunction with the accident and so it is not known that the accident caused any other damage.

1.5 Personnel information

1.5.1 Commander

1.5.1.1 Male, aged 41, trained as a helicopter pilot at North East Helicopters in the USA in the mid-1980s. He then flew for approx. 13 years in Norwegian helicopter companies in onshore/aerial work operations. He began flying for Norsk Luftambulanse in 1998 and has only been flying on the SA 365 N1 for the operator.

1.5.1.2 The Commander held a valid Air Transport Pilot Licence, Helicopter [ATPL(H)] issued on 18 September 2000. Type rating on SA 365 N1 was last extended with a Proficiency Check (PC) and Operational Proficiency Check (OPC) on 20 November 2004, the day before the accident. The Commander held a medical license with no restrictions valid until 2 May 2005.

1.5.1.3 The Commander had slept for 10 hours during the night before the accident took place. He felt rested and in good form when he started his working day at 0830.

Table 2: Flying experience – Commander

Flying experience	All types	On type
Last 24 hours	3	3
Last 3 days	4	4
Last 30 days	7	7
Last 90 days	25	25
Total	4,980	approx. 1,000

[2] In accordance with BSL JAR-OPS 3, the doctor is defined as a "medical passenger".

1.5.2 Rescueman

Male, aged 45. The Rescueman has been working as a Rescueman at Norsk Luftambulanse since 1987. He had completed the operator's initial and recurrent training programmes. He felt rested and in good form when he started his working day at approx. 0830. The Rescueman worked in a three-shift arrangement similar to the pilots'.

1.5.3 Doctor

Male, aged 40. In accordance with BSL JAR-OPS 3, a doctor is defined as a "medical passenger", but is nominated as "NLA Medical Crew Member" by the operator. The Doctor participated in a pool of doctors approved and trained by Norsk Luftambulanse and, to qualify had to participate in activities such as "Rescue Rope Operations training" every 6 months.

1.6 Aircraft information

1.6.1 General

SA 365 N1 is a twin-engine medium helicopter with seating for 8 people in the rear in the passenger version and two pilots or one pilot and a passenger in the front. LN-OPJ was entered in the Norwegian Civil Aircraft Register in October 1999 and was operated by Norsk Luftambulanse up until the time the accident occurred. The helicopter usually had one stretcher and three seats in the cabin in addition to medical equipment customised for the operator's operations. The helicopter's main rotor has a diameter of 11.94 m and it rotates clockwise when viewed from above. The tail rotor is discussed in more detail in subparagraph 1.6.4. LN-OPJ was not certified for flying in icing conditions.

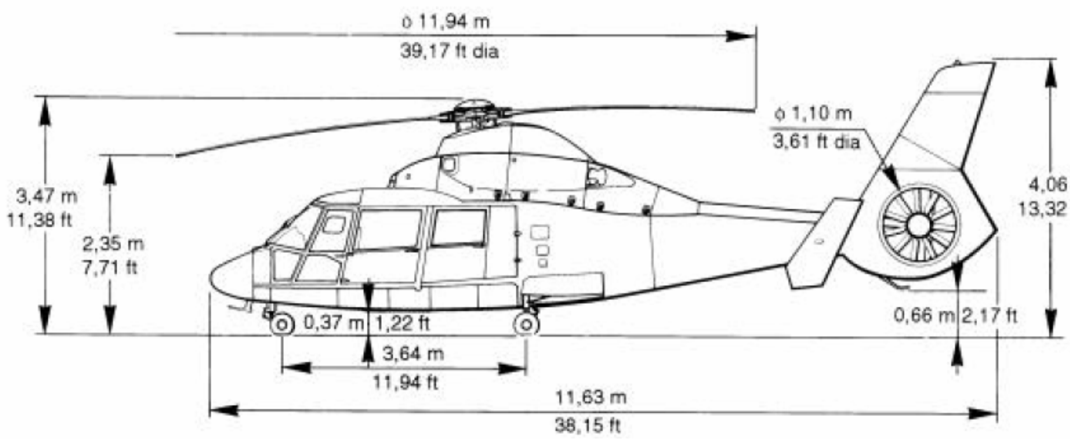


Figure 3: SA 365 N1.

1.6.2 Data

Manufacturer:	Eurocopter
Year of manufacture:	1989
Serial number:	6228
Airworthiness certificate valid until:	31 October 2005

Total number of flying hours:	4675:10
Engine type:	2 Turbomeca Arriel 1C1
Maximum permitted take-off weight:	4,100 kg
Type of fuel:	JET A-1

1.6.3 Mass and balance

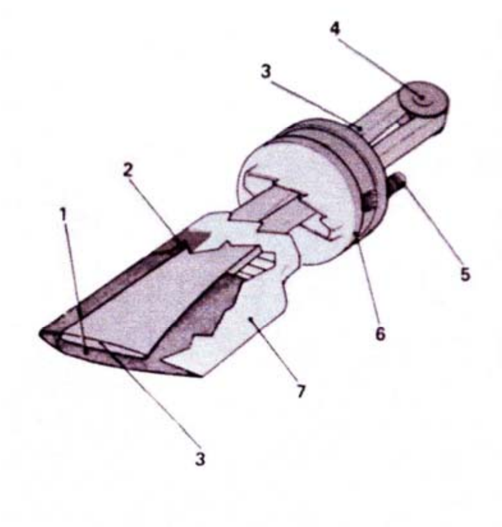
According to calculations carried out by the Commander, the helicopter's mass was 3,549 kg at the time of the accident. This was 551 kg below the maximum permitted take-off mass. The same calculations show that the location of the helicopter's centre of gravity was at 3,950 mm, which is well within the limits of 3,800 – 4,030 mm.

1.6.4 Tail rotor (Fenestron)

1.6.4.1 The tail rotor consists of 11 rotor blades connected to a hub. The rotor has a diameter of 1,100 mm and is mounted inside a tunnel in the helicopter's vertical fin (see Figure 6). Eurocopter's name for this type of tail rotor is the Fenestron. The tail rotor is operated at 3,665 revolutions per minute and is driven via a 90° gearbox that is located at the centre of the tail rotor and a horizontal shaft from the main gearbox. The blade pitch is controlled hydraulically by an actuator that is located adjacent to the gearbox. Maximum deflection is +25°/ - 20°. At normal rotational speed each blade is stretched with a force of 17,000 N. The distance between the tips of the blades and the tunnel wall should be no less than 3 mm when the rotor is stationary. This distance diminishes somewhat during rotation because the blades stretch by approx. 0.6 mm. The tail rotor and the 90° gearbox are held in place inside the tunnel by means of a vertical tube made of composite materials (see the red tube in Figure 11) and a horizontal aluminium tube on the outside of the tail rotor's drive shaft (see Figure 10).

1.6.4.2 Each tail rotor blade (type 365A 12 0020-04) is constructed around a composite spar of Kevlar (component 3 in Figure 4) as shown on the diagram below. The blade is fixed into an aluminium spool (component 4 in Figure 4) and changes in the blade pitch take place by turning the flexible main spar. The blade is centred by guiding the "blade root" (component 6 in Figure 4) in the rotor hub (see Figure 12). The blade pitch is regulated by means of the "pitch control crank pin" (component 5 in Figure 4). The blade itself, which consists of fibreglass and carbon fibre, is cast together with the main spar. Parts of the spar core consist of polyamide foam and the leading edge of the blade is protected by a titanium strip (component 2 in Figure 4). The blades are manufactured at Eurocopter's premises, using "pre-preg"[3] materials for fibreglass, carbon fibre and Kevlar.

[3]The glass, carbon or Kevlar cloth is supplied by the manufacturer ready impregnated with binder (matrix)



1. Foam slabs
2. Leading edge protective strip (titanium)
3. Spar (Kevlar)
4. Spool (aluminium)
5. Pitch control crank pin
6. Blade root (glass fibre and polyamide)
7. Skin (glass and carbon cloth)

Figure 4: Diagram of blade.

1.6.4.3 Tests carried out in conjunction with initial certification and later operational experience led to several improvements in design and production methods. The type of blade involved in the accident was the fourth version of the blade. During a visit to the factory in December 2004, the AIBN was given information about production control and production documentation. Each blade was subject to 81 control points and, during production, a total of 61 types of defects with a known cause had been discovered. In addition, the AIBN was given detailed documentation from the production of the 11 blades that were involved in the accident.

1.6.4.4 Operational experience had shown that the temperature of the blades could become considerably higher than the ambient air temperature. Accidents in Nigeria in January 2003, and in Angola in March 2003, (see subparagraph 1.6.8), which both involved fractures of the tail rotor blade, led to comprehensive testing at temperatures right up to 80ºC. It turned out that certain binders (resins) were affected badly by high temperatures in combination with high air humidity. It became clear that Kevlar is weakened by high air humidity (is hydrostatic), and that this, in combination with other weaknesses, triggered blade fracture. A blade with necessary improvements was type approved in July 2003 and approx. 3000 blades were replaced at the manufacturer’s expense. This type of improved blade was fitted on LN-OPJ.

1.6.4.5 Eurocopter had no similar documented knowledge or experience from operations in icing conditions or at low temperatures. Helicopters certified for flight in icing conditions, however, had only electrical heating of the tunnel because experience showed that ice did not accumulate on the rapidly rotating blades.

1.6.5 Radar altimeter

LN-OPJ was equipped with a radar altimeter (often also called radio altimeter) with an indicator on the lower right hand side of the instrument panel. The smallest subdivision on the scale was 10 ft and a 36° rotation of the indicator needle constituted 100 ft. Other radar altimeters adapted for helicopters have a smallest subdivision of 5 ft and a 90°

rotation of the indicator needle constitutes 100 ft. These can also be equipped with audio warning, but the accuracy is generally between 5 and 10 ft.

1.6.6 Maintenance

1.6.6.1 The tail rotor blades must be inspected for delamination every 25 flying hours. The prescribed method is "tapping"; in other words the blades are tapped lightly with a metal object to bring out differences in the sound depending on whether or not layers in the blade have become delaminated. According to the maintenance documentation, the "tapping test" on LN-OPJ was carried out in conjunction with a 25-hour inspection on 3 November 2004, at 4,662:55 flying hours. This was 12:15 flying hours before the accident. No delamination was found during this inspection. The tail rotor blades involved were produced during the period June 2003 to April 2004 and had had an operating life of 114:10 – 733:10 flying hours at the time the accident occurred.

1.6.6.2 The helicopter had undergone the following maintenance:

Pre flight check	21 November 2004	at 4674:40 flying hours
25/50-hour inspection	3 November 2004	at 4,662:55 flying hours
100- up to and including 1000-hour inspection	2 September 2004	at 4,661:25 flying hours

1.6.7 Operational experience

1.6.7.1 *General*

Described below are incidences of actual experience with several types of helicopter manufactured by Eurocopter. The common factor is the fact that they are equipped with Fenestron, consequently the properties in several areas are comparable. Except for that there are variations in the tail rotor's shape, dimensions and structural materials.

1.6.7.2 *Experience of icing with Eurocopter*

On 19 February 2007, Eurocopter issued a "Technical Note". The reason behind this was that an EC 135 had had ice in the Fenestron while airborne in weather conditions were ice was not expected. Ice had formed close to the blades on the low pressure side in the Fenestron tunnel. The document refers to tests carried out using an EC 135 during light and moderate icing conditions. The tests showed that up to 3 – 4 mm of ice could form in the Fenestron tunnel and on the stator blades during hovering, and that some minor icing could take place during other phases of flight. The icing caused only insignificant vibrations or reductions in performance. In addition, an EC 155 was tested under severe icing conditions in a low temperature chamber. During the test a layer up to 10 mm thick was observed near the rotor blades on the Fenestron tunnel's low pressure side. In the case of abrupt, powerful movements with the pedals, the rotor blades bent so much that they scraped into the ice edge. According to Eurocopter, this took place without the rotor blades becoming overloaded. Eurocopter concluded that flying with Fenestron under conditions of light icing did not threaten flight safety.

1.6.7.3 *Experience with Fenestron close to water*

In conjunction with this investigation, Eurocopter showed a film of an EC 120 with floats fitted. The helicopter landed on the water and, in that context, was hovering just above the water with the Fenestron less than one metre from the surface, without water being sucked into the tail rotor, nor did the Fenestron suck water even though it came very close to the surface during landing.

1.6.7.4 *Operational experience with SA 365N by the Icelandic Coast Guard*

The AIBN asked the Aircraft Accident Investigation Board – Iceland, to obtain information from the Icelandic Coast Guard regarding operational experience with SA 365N. The report came back that they had hoist installed on the helicopters and that hoisting operations consequently took place from a height of approx. 30 ft above the water/sea. During exercises involving picking people up from the water, the people often first jumped into the water from the helicopter. To reduce the drop, the helicopter then descended to a height of 10 ft. To quote from the letter of reply:

> *"At 10 feet there is little margin for errors, so the Coast Guard emphasises that during the hover the Monitoring Pilot monitors the Radar Altimeter and has his hand on the Collective and takes action if the helicopter sinks below 10 feet. During the hover the helicopter is in a 5 - 8° nose up attitude and therefore the crew has to be alert regarding the tail not striking the ocean. There is also a considerable danger for Vertigo due to the downburst from the blades making it difficult to judge the altitude over the water."*

1.6.7.5 *Operational experience from the Canadian defence forces*

The AIBN has been in touch with an accident inspector in the Canadian defence forces concerning experiences with icing on helicopters. To quote from the letter of reply:

> *"We do not have a great deal of experience with regards to ice accretion on helicopter tail rotors.*
>
> --------------------
>
> *Most of the hovering over cold water takes place over salt water which limits ice accretion."*

1.6.8 Previous accidents

The AIBN is familiar with the following accidents in which the type of tail rotor blades in question were involved or in which the tail rotor came into contact with water:

- An AS 365 N2 (5N-BBR) S/N 6446 crashed in Nigeria on 8 April 2002 due to fracture of a tail rotor blade. The accident investigation revealed incidences of delamination in the blade and static overloading of the main spar. Eurocopter believes that the blade fracture occurred because, over a period of time, the blade experienced delamination that exceeded the maximum permitted area. The relevant type of blade was removed from service in compliance with Eurocopter Service Letter no. 1558-64-02, dated 13 May 2002. In addition, the interval between each "tapping test" was reduced in compliance with Eurocopter Alert Telex T.F.S. No. 77, dated 10 July 2002.

- An AS 365 N2 (5N-BBS) S/N 6448 crashed in Nigeria on 03 January 2003. The helicopter was in the enroute phase when the emergency floats inflated unintentionally. The helicopter began to rotate around the rotor mast during the subsequent landing. Finding of fatigue fracture in tail rotor blade no. 35317. The blade fracture was not related directly to the problems with the emergency floats. Alert Service Bulletin No. 05.00.17 issued by Eurocopter on 16 April 2003 introduced operating time limits and more intensive maintenance. This was later followed up by DGAC Airworthiness Directive No. T2003-155 dated 30 April 2003.

- An AS 365 N2 S/N 6531 in Angola in March 2003. A tail rotor blade separated due to a fatigue fracture in the main spar.

- An SA 365 in Taiwan had engine problems while on a training mission to rescue people from the sea. The helicopter put its tail rotor in the sea for a short moment before climbing again and then started rotating to the left. After little more than one revolution, the helicopter dropped into the sea and rolled over on its right side. All tail rotor blades were broken off close to the hub during this accident.

1.7 Meteorological information

1.7.1 The Commander has stated that the wind was westerly and approx 2 kt, no cloud cover and –5 °C when the accident occurred.

1.7.2 The Norwegian Meteorological Institute had no weather observations for Vågå on the day in question. Weather observations from Kjøremsgrenda in Lesja and from Bråtå in Skjåk show that the temperatures were -4 °C and -5 °C respectively, relative air humidity 93% and 80%, and the wind 2 kt and 5 kt. In addition, it was stated that the cloud base was around 1,500 – 3,000 ft above the terrain.

1.7.3 There were no observations of frost mist over the water at the time of the accident.

1.8 Aids to navigation

Not relevant.

1.9 Communications

No communications were established with the air traffic services in conjunction with the training flight. However, the crew were in contact with the Emergency Communications Centre (AMK) at Gjøvik for “Flight following”.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

Not mandatory and not installed.

1.12 Wreckage and impact information

1.12.1 The accident site

The accident occurred in the eastern part of lake Vågåvannet approx. 250 m south of Vanglandet marina and approx. 1.5 km southwest of Vågåmo. The lake is located 362 metres above sea level, with the depth at the location being just under 3 m. Ice had begun to form in other parts of the lake at the time the accident occurred. The day after the accident ice had also formed in the marina. The temperature in the water was consequently close to 0°C.

1.12.2 The helicopter wreckage

1.12.2.1 The helicopter came to rest upside down in the water with the rotor head in contact with the lakebed. From the main wheels and aft, the helicopter was projecting out of the water so that the whole Fenestron was above the water level. The helicopter gradually sank into the lakebed, so that when the AIBN arrived at the site the next day, the water surface was on a level with the "tail rotor gearbox".

1.12.2.2 The temperature in the air had constantly been below zero from the time of the accident until the wreck was examined by the AIBN. Consequently, a strip of ice had frozen on the helicopter at the transition between air and water. In addition, frozen drops of water sat on those parts of the hull that had been above the water line. Otherwise, there was no sign of any ice formation on the tail rotor blades or on the tail rotor's tunnel.

1.12.2.3 The helicopter was turned round and lifted out of the water using another helicopter. In connection with that operation, the helicopter sustained minor damage on its front underside.

1.12.2.4 LN-OPJ was set down on its wheels and then loaded onto a truck and taken to the AIBN hangar at Lillestrøm for a more detailed examination. Apart from general damage caused by water, there was varying damage on all main rotor blades. The right rear door was missing and divers searched for it in vain. The 11 m long line with the rescue sling on the end was undamaged and was still attached to the helicopter. In addition, there was considerable damage to the Fenestron and associated power train up to the main gearbox. This damage is described in more detail in Chapter 1.16.

1.12.2.5 The tail rotor's control system was also examined, but no faults were detected that could explain the accident.

Figure 5: LN-OPJ after it was salvaged. The missing door, rescue line and the damage to the main rotor blades are shown.

Figure 6: The damage to the Fenestron.

1.13 Medical and pathological information

Routine blood samples were taken from the three people who were onboard. The samples showed no trace of alcohol or medication.

1.14 Fire

No fire arose in conjunction with this accident.

1.15 Survival aspects

1.15.1 Ice had begun to form on lake Vågåvannet when the accident occurred. The day after the accident, ice had also formed in the marina, north of the accident site. The temperature in the water was consequently close to 0°C when the accident occurred. The air temperature was approx. - 5°C in a 3 – 6 kts wind.

1.15.2 When the accident occurred, the Rescueman was wearing a drysuit and was therefore dressed to be able to stay in the cold water for a period of time. The Commander and the Doctor, however, were wearing the operator's standard flying suits and helmets and were not dressed for spending any time in the water or outdoors. The table below provides some indication of how long a person might be expected to survive in cold water.

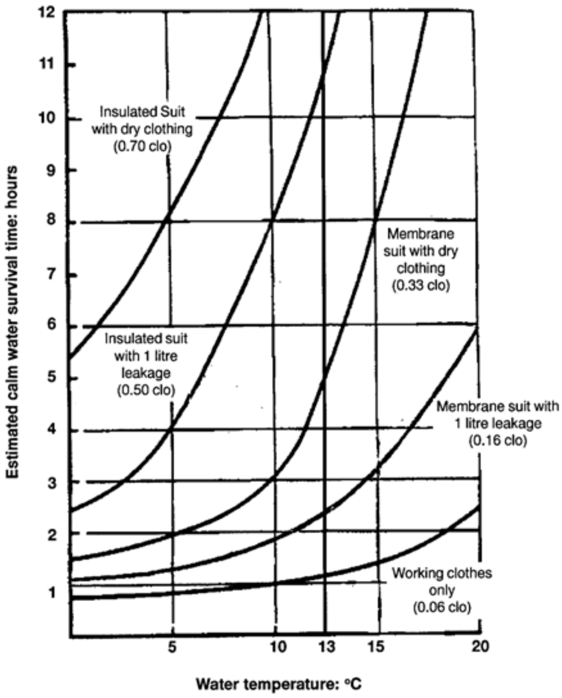


Figure 7: Assumed survival time relative to water temperature and clothing. Taken from a model drawn up by Wissler and modified by Hayes, 1987. In addition other data show that in very cold water, additional to hypothermia, there is a tendency to develop hyperventilation. In about 90% of cases this may quickly lead to drowning caused by inhalation of water, for the remainder it may lead to suffocation caused by blockage of the upper airways due to cramp.

1.15.3 The Commander was attached by a four-point seatbelt when the helicopter crashed. The Doctor was sitting in the door opening and was secured to an anchor point in the floor via a line. Otherwise he was not secured.

1.15.4 The Commander stated to the AIBN that, in conjunction with the helicopter rolled over, he remembered useful details from the “Dunker” training course held at Falck Nutec. Particularly pertinent was the importance of not becoming disoriented as to where the door was when the helicopter overturned.

1.15.5 The helicopter was fully equipped for potential ambulance missions when the accident occurred. In other words, among the onboard equipment were items to reduce heat loss in patients.

1.15.6 There were no raft or life vests onboard. The helicopter had no flotation gear fitted.

1.15.7 The helicopter was equipped with an emergency beacon, but this was not triggered during the accident. If it had been triggered there is high probability that it would not have transmitted signals because the antenna was lying under the water.

1.15.8 There were several witnesses to the accident and this contributed to the rapid notification to the emergency number and directly to Vågå Red Cross’s Search and Rescue Corps.

1.15.9 Because ice had begun to form on lake Vågåvannet, there were few leisure crafts in the marina and few boats along the lake in general. In summer, Vågå Red Cross’s Search and

Rescue Corps normally had a rescue boat ready loaded on a trailer in its garage in Vågåmo. In winter, the boat was driven to a remote storage location and replaced by a snow scooter. When the accident occurred, the Search and Rescue Corps still had the boat standing in its garage. It was therefore only a short time before the boat reached the accident site.

1.16 Tests and research

1.16.1 Fenestron

1.16.1.1 The Fenestron had sustained major damage (see Figure 8 and Figure 9). All 11 blades were damaged to varying degrees. The tunnel in which the tail rotor was located was damaged along its entire circumference and fragments of the blades lay inside the hollow structure of the tail. The “forward attachment coupling tube” on the tail rotor gearbox had split at its rear attachment point (see Figure 10) and the “aft attachment tube” was snapped at the back edge of the gearbox (see Figure 11).

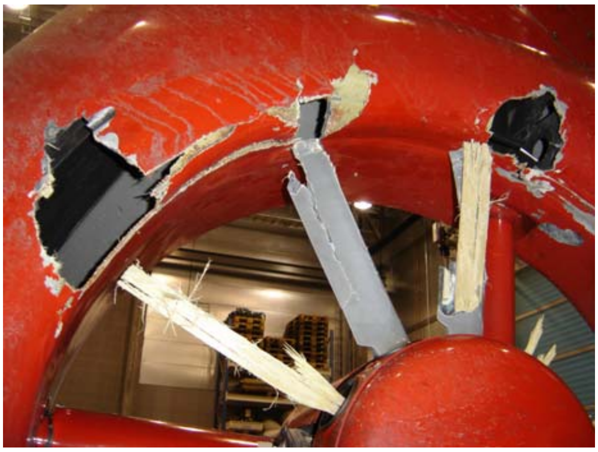


Figure 8: Damage to blades and the tunnel.

Figure 9: The arrow is pointing at part of a rotor blade that is located in one of the holes in the tunnel.

Figure 10: The picture, taken from the left side obliquely towards the back, shows the fracture in the "forward attachment coupling tube".

Figure 11: Picture taken from the left hand side obliquely towards the front. The arrow is pointing at the snapping point on the "aft attachment tube".

Figure 12: The centre of the tail rotor holds the rotor blades in position by means of bushings. The arrow marks a bushing which has partially disappeared.

1.16.1.2 The blades were disassembled and the blade roots from blades 3, 6 and 7 were extracted from the hollow in the structure of the tail. Figure 12 shows all that was found of the 11 blades.

Figure 13: The 11 blades laid out in numbered order. Blade no. 1 to the left.

1.16.1.3 The tail rotor including the blades and the rotor hub was sent to Eurocopter in Marignane for a more detailed examination. The work was led by the AIBN. Also involved were representatives of the French accident investigation board (BEA), the helicopter manufacturer Eurocopter and the operator Norsk Luftambulanse. In short, the examination findings can be listed as follows:

Blade no. 1: Only part of the spar and the spool remain.

Blade no. 2: Only part of the spar and the spool remain.

Blade no. 3: Part of the spar, full length. Remnants of the fibreglass on the top of the spar. The blade root and parts of the skin were found separately.

Blade no. 4: Rips along the length of the blade skin on the upper side which coincide with width of the spar. Impact damage at the front edge of the blade tip. Intact blade root.

Blade no. 5: The blade skin is missing on the upper side and large parts of the blade skin are missing on lower side. Multiple damage to the leading edge of the blade. Intact blade root.

Blade no. 6: The blade skin is missing entirely. Part of the spar and the spool remain. The blade root with impact damage found separately.

Blade no. 7: Part of the skin from the upper side of the blade found separately, along with blade root. Otherwise, only parts of the spar and the spool remain.

Blade no. 8: Several minor rips in the blade skin. Minor damage on the leading edge, the spar and blade root.

Blade no. 9: Scraping at the blade tip, otherwise undamaged.

Blade no. 10: Rips along the length of the blade skin close to the leading edge on the upper and lower sides. Otherwise undamaged.

Blade no. 11: The blade cut approximately in the middle. Only parts of the spar remain at full length. Minor damage on the leading edge of the titanium strip at the fracture point was investigated in more detail (see subparagraph 1.16.1.5). Otherwise undamaged.

1.16.1.4 After a detailed and thorough examination, no faults were found in the glued joints (adhesive failure) or any signs of delamination, nor was any sign found indicating that any fracture had occurred in glass or Kevlar threads in the blade spars prior to the accident. The pictures below are from the investigation laboratory at Eurocopter.

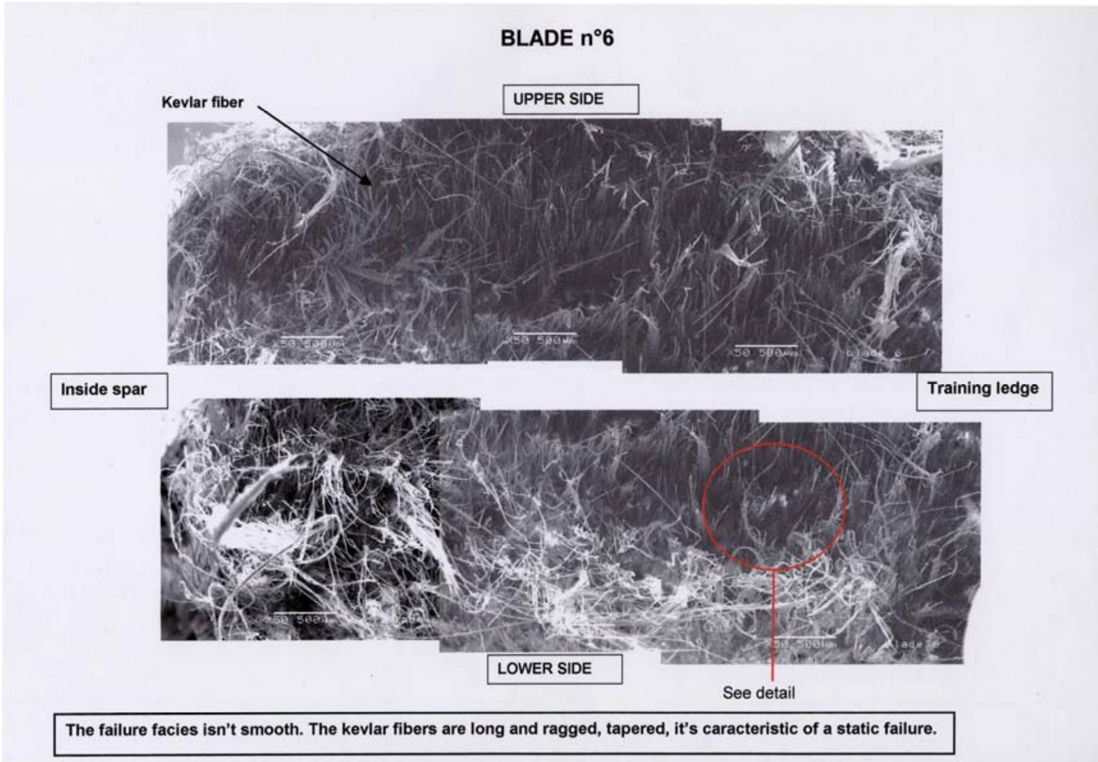


Figure 14: Detail of a typical overload fracture in the blade spar. The fibres are long, ragged and taper off towards the end.

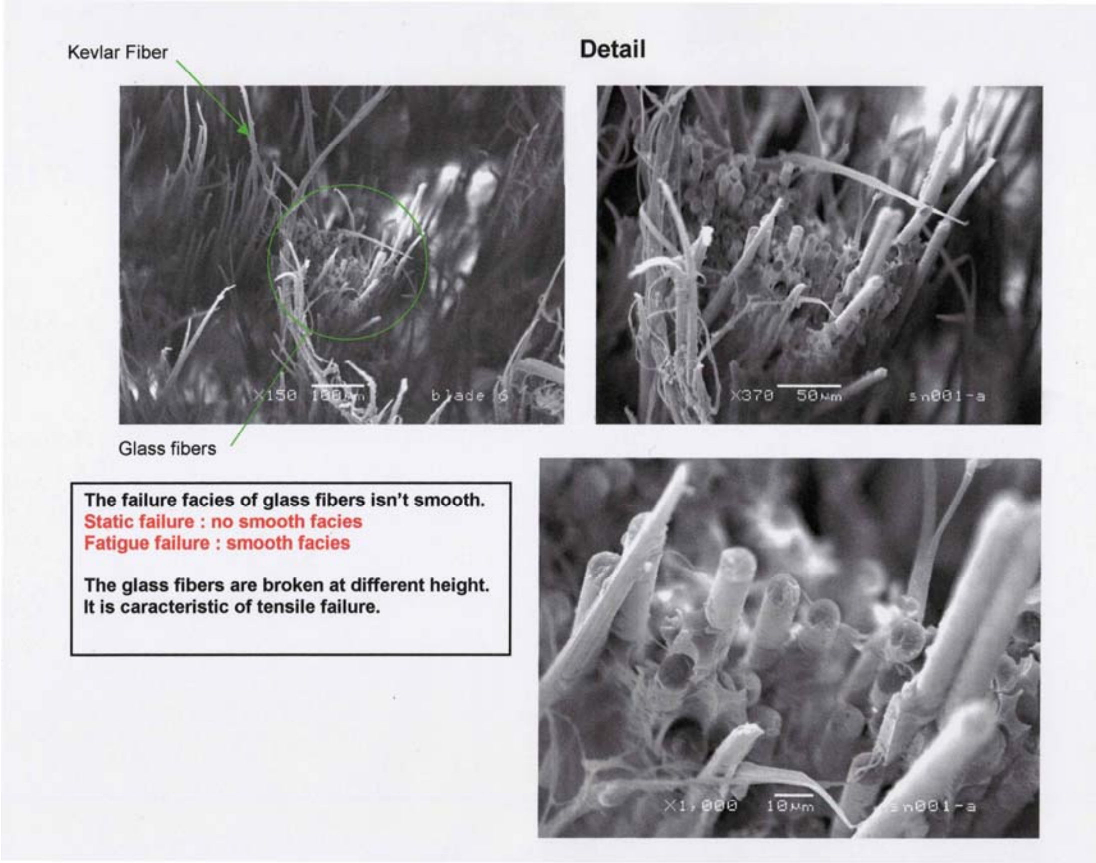


Figure 15: Details from the pictures in Figure 14.

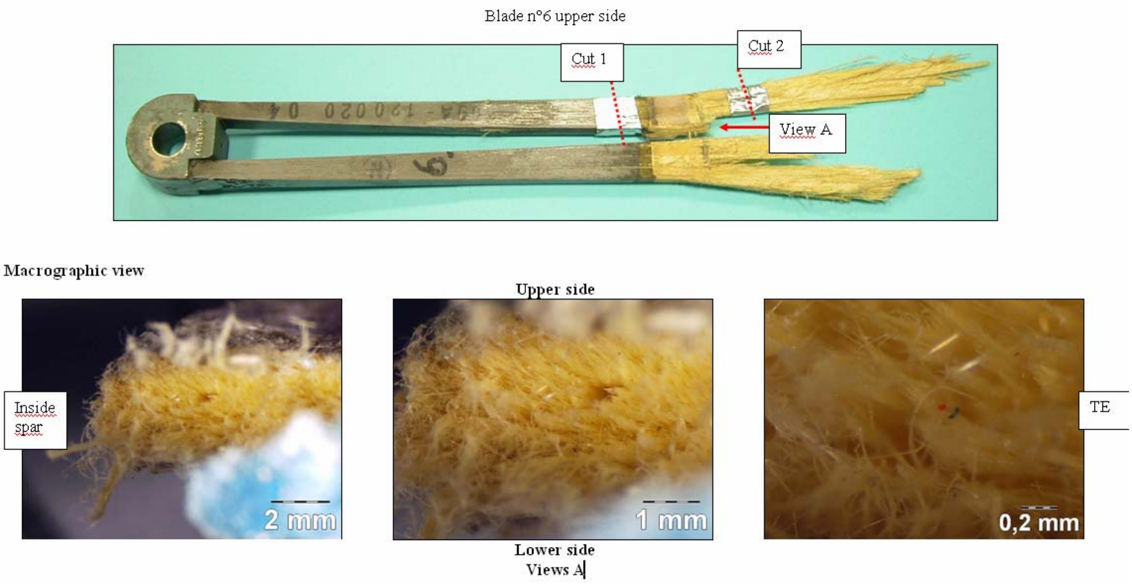


Figure 16: Examples of overload fractures in which the fibres are long, ragged and tapered towards the end.

Figure 17: The two pictures above show examples of surface texture in the joint between the Kevlar spar and the blade skin on blade no. 3. The adhesive joint has not failed (cohesive separation). On the other hand, the material itself has been torn up (uneven and ragged surface).

Figure 18; Equivalent example of the joint between two materials having failed (adhesive failure). The Kevlar has a smooth surface with visible indications of fabric. The example is taken from a blade that failed at 957 flying hours.

1.16.1.5 The blades were investigated for foreign object damage. An incidence of damage at the fracture on the leading edge of the titanium strip on blade no. 11 was examined in more detail. Marks of tungsten and cobalt were found at the location and this was assessed by Eurocopter as coming from the "pitch control crank pin" (see Part 5 of Figure 4).

1.16.2 The tail rotor gearbox driveshaft

1.16.2.1 The tail rotor gearbox drive shaft had fractured just behind the output from the main rotor gearbox (see Figure 19).

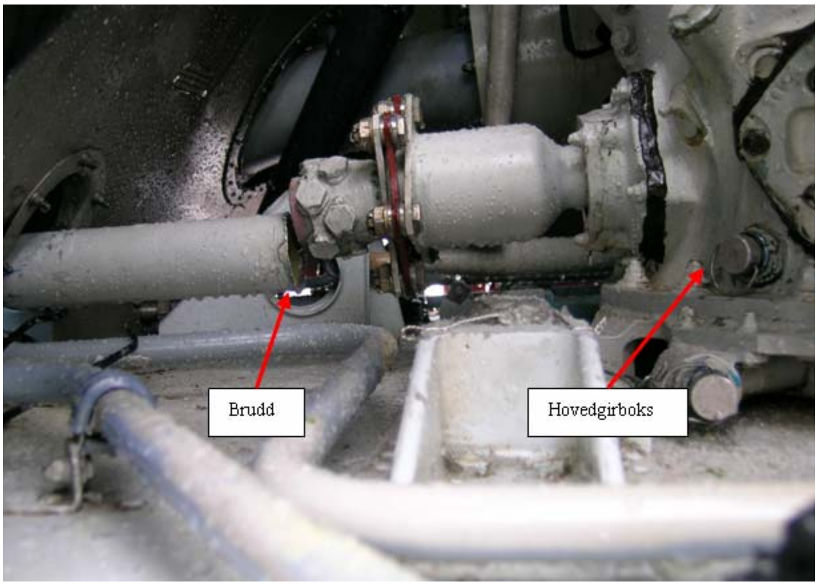


Figure 19: Fracture in the tail rotor drive shaft.

Finding the fracture mechanism in the shaft was desirable, and the parts were sent to the Norwegian Armed Forces' analytical laboratory at Kjeller for more detailed examination. The following is the conclusion quoted from the laboratory's report no 041213.05:

> *"Based on the investigation it is concluded that both the tail rotor driveshaft and the tail gearbox support tube failed due to overload. The driveshaft failed due to overload in torsion."*

1.16.2.2 A fracture was also discovered in the "forward attachment coupling tube" (see Figure 10). Combined with structural damage in the "aft attachment tube" (see Figure 11) this made it possible for the entire tail rotor gearbox to be pushed backwards. With a displacement of approx. 20 mm, the teeth in the coupling between the tail rotor gearbox and the drive shaft could come out of mesh. Some damage was observed on the splines on the tail rotor gearbox as shown in Figure 20 below.

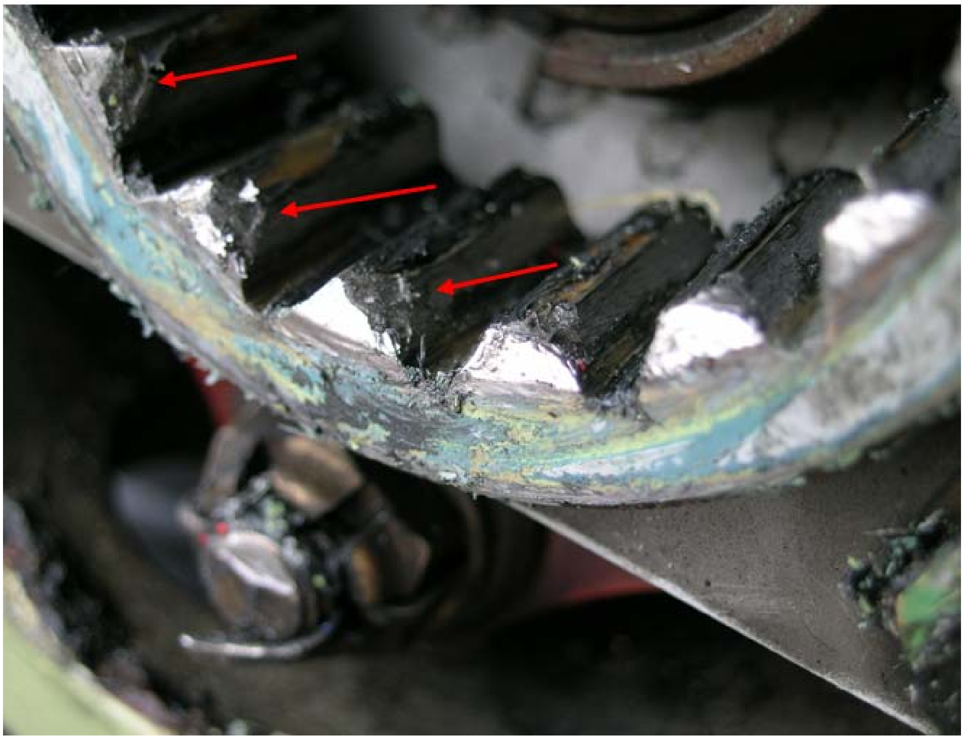


Figure 20: The arrows clearly show damage to the splines in the tail rotor gearbox.

1.17 Organizational and management information

1.17.1 <u>Norsk Luftambulanse AS (NLA)</u>

1.17.1.1 Norsk Luftambulanse was established in 1977. The operator is wholly-owned by Stiftelsen Norsk Luftambulanse. At the time of the accident the operator had approx. 50 employees involved in the operations, and was operating 9 helicopters. These were four helicopters of the type BO 105, three of the type SA 365 N1 and two of the type EC 135. At the time of the accident, the operator had new helicopters on order and was in the process of establishing a uniform fleet comprising the types EC 135 and EC 145. The operator has its head office in Drøbak, engineering headquarters at Langhus, in Ski municipality and seven operating bases distributed across the country. The accident helicopter that was operating out of the base at Dombås, in Dovre municipality.

1.17.1.2 At the time of the accident, the operator had a licence covering commercial air transport with passengers, mail and cargo using aircraft of less than 10 tonnes (MTOM) and with a seating capacity of less than 20 passenger. The licence was based on an Air Operator Certificate (AOC) issued in accordance with BSL JAR-OPS 3. In addition, the operator had operating permits for carrying out photographic and advertisement flights VFR and IFR using helicopters.

1.17.2 <u>The operator's procedures</u>

1.17.2.1 *Procedures for Rescue Rope Operations (RRO)*

NLA has described Rescue Rope Operations (RRO) in its Operations Manual (OM), part A, section 13.8. The last time the procedure was revised was on 15 October 2004. In subparagraph 13.8.3, the following limitations are set for RRO over both land and water:

- *"Maximum rope length is 50 meters. For land rescue a direct communication between the pilot and the Rescueman it is recommended.*
- *Flight tests have shown that the danger of developing rotation increases with short rope length. For operation with rescue bag or stretcher is therefore highly recommended to use a rope length of 30 meters or more.*
- *RRO shall not take place during hours of complete darkness.*
- *RRO shall not take place unless there are sufficient references to assure steady hover condition. Factors to be considered may be snow/reduced visibility, distance to land, and terrain in view and wind direction.*
- *All crewmembers must be trained and qualified according to NLA regulations*
- *RRO shall not take place if the local wind condition does not allow a steady hover. Wind velocity of 30 KTS or more, or a gust spread of more than 10 KTS will in many cases prohibit a safe Rescue Rope Operation.*
- *Speed limitation is 60 KTS IAS. Recommended speed is 40 KTS IAS".*

OM-A, subparagraph 13.8.8, contains the operator's procedure for "Rescue Rope Operations over water":

"NLA A/S helicopter may be used for certain rescue operations over water. The operation must be of a simple nature, and shall take place in the vicinity of land, island or ship only with good references to these and NEVER more than 10 minutes flying from land.

Any hovering in open sea without these references is prohibited. This also includes drop of smoke, flare or rescue-dingy from a hover. Any drop of such objects without mentioned references must be performed at speed above V_{toss}. Only company approved ropes may be used for RRO over water.

The primary procedure consist of the Rescueman attached to the rope and wearing company approved equipment, exiting the helicopter from a low hover, into the water, for the purpose of picking up one person, utilizing a pick-up sling. This is followed by a flight out in a careful slow manner to the predetermined landing area.

Proceed as follows:

Reconnaissance
Both pick-up site and the landing site

Planning
Finish planning taking into consideration knowledge learned from the reconnaissance.

Preparations at landing site
- *Prepare for flight according to preparation*
- *Cabin-door, open.*
- *NLA Medical Crew Member secured*
- *Rescueman attached to the pick-up rope*

Execution
- *Departure with all crewmembers on board.*

- *A shallow approach shall be established to the pick-up site, in order to arrive at a steady state hover above the person in the water.*
- *On final, the pilot tells the NLA Medical Crew Member to give the Resuceman a cleared to jump signal.*
- *After this clearance the Rescueman feeds the rope and jumps on own discretion.*
- *As the Rescueman jump, the NLA Medical Crew Member moves to the position in the door.*
- *The NLA Medical Crew Member shall keep the pilot continuously informed about the situation, and the pilot shall keep the NLA Medical Crew Member continuously informed about his intentions.*
- *When the Rescueman signals ready and secures, the helicopter shall be lifted slowly until the Rescueman and the patient are well clear of water.*
- *Establish a slow vertical climb to at least 10 feet above the water.*
- *Proceed with a positive climb-out.*
- *A shallow approach shall be established to the landing site, in order to arrive in a high hover with the Rescueman approximately 20 feet above the landing site."*

1.17.2.2 *Precautions when flying in icing conditions*

The following quotation is taken from OM part A, subparagraph 8.3.8 "Adverse and potentially hazardous atmospheric conditions":

> *"Icing condition*
>
> *IFR flights into forcasted or known icing conditions shall not be planned or conducted.*
>
> *During flight, the formation of ice on an aircraft results from the freezing of water droplets, which are intercepted by the leading edges and exposed surfaces. There are only two fundamental requirements for ice formation; First, the aircraft must be flying through visible water in the form of rain or cloud and second, the temperature of the liquid droplets must be 0°C or below."*

The chapter is primarily aimed at icing due to atmospheric conditions and does not contain any warnings or descriptions of icing at low heights above the sea or water.

1.17.2.3 *Procedure in the event of Tail Rotor Failure*

The following checklist is contained in OM-B "Emergency Checklist" page 26, and as a separate checklist onboard the helicopter:

> ***"TAIL ROTOR FAILURE***
>
> ***Indications:***
>
> *Yawing motion to the LEFT. The rate of turn depends on power and speed at the time of failure. Possible noise and vibration from tail area.*
>
> ***ACTIONS***
>
> *IN HOVER OR LOW AIRSPEED*

1. Collective	*LOWER TO LAND*
2. Yaw control	*USE WHEEL BRAKE*

3. Engines……………………………………….…………………..SHUT DOWN

4. Rotors stopped………………………………….EVACUATE PASSENGERS"

This checklist is generally in agreement with the equivalent emergency procedure in the Eurocopter Flight Manual SA 365 N1. The same manual does not contain any procedure for emergency landings on water. However, a checklist of this type is contained in the operator's OM-B under the heading "ditching". This checklist is formulated for operations involving two crewmembers in the cockpit and lists action points that are to be carried out prior to the actual landing on the water. The checklist is of no relevance here because, in this case, there was no time for the action points before the helicopter hit the water. One of the action points is the release of flotation gear, which was not installed on LN-OPJ.

1.17.2.4 *Technical Rescue Operations Manual*

In addition to the operator's operational procedures described in OM-A and OM-B, the operator has drawn up a Technical Rescue Operations Manual containing procedures with particular emphasis on the duties of the Rescueman and the Doctor and the use of various items of rescue equipment. For Rescue Rope Operations[4] the manual describes in detail the preparations and equipment that are to be used, signals and communications, and details such as the fastening of ropes etc. To assist the reader, the manual is richly illustrated. The following quotation is taken from Chapter 3 of the manual:

"6.6.1 Preparation

When preparing for rescue rope operations, the entire crew shall have a thorough review of the procedures and the sequence of the operation.

Approach and direction takes place in accordance with the procedure, ref. OM Part A 8.9 Standard operating Procedures, SOP. Normal and Special operations. Note that the red safety sling must be double. Be aware of the water depth at the location where a jump is to be carried out. Whether fastening is to be done at the base or on/at the accident site will be decided by the Commander.

6.6.2 Approach

On the Commander's ready signal the Rescueman moves out onto the skid and throws the pick-up rope. The Rescueman checks that the pick-up rope is on the inside of the skid, in front of the crosstube, so that the rope does not interfere with the jumping. This applies to BO 105. On the EC 135 the pick-up rope should be located on the outside of the skid. The pick-up rope must touch the water before jumping in, and the Rescueman now decides when he wishes to leave the helicopter."

1.17.2.5 *Training requirements*

Training on rescue rope operations must be carried out minimum every 6 months. This is described in NLA OM-D subparagraph 2.2.10 for the Commander, subparagraph 2.5.10

[4]A collective term in the operator's Technical Rescue Operations Manual, which describes various operations carried out using a rope suspended beneath the helicopter.

for the Rescueman and subparagraph 2.7.1.1 and 2.7.1.2.1 for the Doctor. For the Doctor there is also a requirement for briefing/training on the content of OM-A subparagraph 13.8 prior to participating in operations of this type.

The training was carried out according to these operating procedures.

1.17.3 Training carried out on the SA 365

The operator has carried out a number of Rescue Rope Operations on the SA 365 after that helicopter type came into operation in December 2001. The first training was on 22 October 2002 at the helicopter base in Ål. In total, 31 landings have been carried out in winter/autumn in conjunction with this type of training up to the time of the accident. Training took place in lake Vågåvannet on 22 October 2003 and 5 November 2004. The crew had experienced no problems with icing during the training.

1.17.4 Revision of procedures

After the accident, the operator introduced several limitations on Rescue Rope Operations. According to OM-A, revised 1 June 2005, no jumps are to be made from helicopters if the temperature of the water is less than + 4 °C. Further restrictions where laid down during a revision 15 December 2005 where jumping from the helicopter was prohibited. In addition, Skid Rescue over open water was prohibited, wearing a life-vest during Rescue Rope Operations over open water became mandatory and minimum hover height over water became 5 meters.

1.18 Additional information

1.18.1 Witnesses

1.18.1.1 There were several witnesses to the accident. One witness stated to the police that he was on his way to the marina, driving westwards along Nedre Nordheradsvegen (see Figure 1). In company with his wife, he became aware of the helicopter. He himself had a background in the Red Cross's Search and Rescue Corps and had participated in exercises in which the Air Ambulance had been involved. He saw the helicopter take off and fly out over the lake. Then it remained stationary while something was thrown down. When the witness came to the marina he decided to observe the helicopter operation and used his binoculars which he had with him. He observed something he perceived as the head of a person in the water and assumed that this person was to be picked up. In addition, he saw a rope with a sling on the end which was suspended from the helicopter. The right side door of the helicopter was open and a ladder was hanging out of the door. The helicopter made a few trips back and forth from east to west while the rope was hanging outside the helicopter before the helicopter reversed a little eastward and gained a little height. It then came calmly towards the location where an object or a person was located in the water.

1.18.1.2 The witness reacted to the fact that the helicopter came very close to the surface of the water. When it had almost reached the location where the object was in the water, the rear end of the helicopter came down into the water. Through the binoculars, the witness saw that the housing around the tail rotor hit the water and that a spray of water rose up. He did not notice any abnormal sounds prior to this, nor did he hear anything in particular when the tail rotor hit the water. After the tail rotor hit the water, it looked as if the aircraft jumped forward a little and its undercarriage came down into the water. At the same time he saw that the helicopter turned sideways a little. It righted itself again with its front facing west. When the helicopter had its undercarriage in the water, the witness thought he heard an increase in revolutions before it quieted down. The helicopter first tilted to the left so that the rotor blades hit the water with a loud bang before it turned right round and tipped over. The witness had his mobile phone with him and called 113 and the supervisor at Vågå Red Cross's Search and Rescue Corps. He then ran along the shore to find a boat.

1.18.1.3 One witness stated to the police that she was a passenger in a car that her partner was driving westwards along trunk road 15 at Klonesodden (see Figure 1). She saw the helicopter flying slowly over the water. Suddenly it looked as if it were going to land. This was perceived to happen in an apparently controlled and normal manner. She could not see any persons in the vicinity or in the water. The helicopter was then over the middle of the lake facing the other side. She saw that water was spraying from the tail rotor and that the helicopter tipped over backwards. It seemed as if the helicopter righted itself. However, the helicopter was out of balance and tilted over onto its side. She was able to see that the main rotor whipped into the water once before it came to a stop. Then a short time passed before the helicopter lay over on its side and sank. The witness said that the belly and a little of the tail protruded above the surface. The witness and her partner stopped the car at a bus stop. Since neither of them had a mobile phone, they stopped a car and made sure that the accident was reported. After some searching the witness's partner found a boat and rowed out to the helicopter.

1.18.1.4 One witness stated to the police that he was standing outside his home around 2.5 km from the accident site. He heard the noise of the helicopter and was able to see a red helicopter taking off from Vanglandet beside the marina. When he took out his binoculars, he saw a dark object which he thought was a person lying in the water. The helicopter was facing west and was hovering over the water before it reversed a little and flew forward again. He saw the main rotor hit the water on the left hand side before the machine turned over to the left. He is not certain whether the helicopter rotated before it overturned. The witness immediately ran in to his house and called 112.

1.18.2 <u>Demonstration at Mønevann in Lørenskog.</u>

To gain a better understanding of the training that took place at lake Vågåvannet a demonstration was held at lake Mønevann in Lørenskog on 14 June 2005. At the time, Norsk Luftambulanse had stopped operating the type SA 365 and the demonstration was consequently carried out using LN-OOA, a Eurocopter EC 135. The conditions during the demonstration were different in some respects to those prevailing at Vågåvannet. However, on the basis of the demonstration, for example, it can be assumed that the last flight lasted between 90 and 150 seconds. For only a fraction of this time, the helicopter was lower than approx one rotor diameter (10.2 m). It was only below this height that a significant amount of droplets and moisture was whirled up from the water. It also became evident that the nose position of the helicopter varied by approx. 5° in relation to the horizon (pitch) while manoeuvring to hold the helicopter steady over an object in the water.

1.19 Useful or effective investigation techniques

No methods have been used during this investigation that warrants particular mention.

2. ANALYSIS

2.1 Introduction

In conversations with the crew, it became clear that the tail rotor (Fenestron) had rapidly lost its function after they first heard a noise. The rotation which then occurred could not be controlled, and the Commander put the helicopter in the water as rapidly and gently as possible. On the basis of this information it became clear that the direct cause of the accident was linked to the tail rotor. The further investigation work was focused on the following potential problems:

- Failure in the drive system or control system for the tail rotor
- Technical failure in the tail rotor
- The tail rotor being damaged by foreign objects
- The tail rotor becoming damaged as a result of icing
- The tail rotor entered the water unintentionally

These alternatives are analysed below.

2.2 Failure in the drive system or control system for the tail rotor

2.2.1 The investigation has shown that the fracture of the tail rotor shaft right behind the main gearbox was caused by an overload through torsion. It can therefore be established that the fracture did not occur as a result of normal operating loads. One probable explanation is that the shaft fracture arose as a result of the damage to the tail rotor. The overload in the ”aft attachment tube” (see Figure 11) and the fracture in the ”forward attachment coupling tube” (see Figure 10) can both be explained by a large backward force on the tail rotor gearbox. A force of this type is consistent with a major imbalance in the tail rotor, probably caused by damage to the rotor blades when they were rotating at normal operating speed. Consequently, the ”aft attachment tube” and ”forward attachment coupling tube” may have become damaged by whole rotor blades or parts of them falling off. If the tail rotor gearbox moved backward by a minimum of 20 mm, the spline coupling at the front of the tail rotor gearbox could come out of mesh with the drive shaft at the same time as the undamaged tail rotor blades would be able to impact with the tunnel wall, slowing the rotor's speed. If a split second later, the gearbox were to be pressed forward because of a dynamic imbalance in the rotor system, the spline coupling might once again go into mesh and lead to a rapid acceleration of the tail rotor. This sudden acceleration could have subjected the drive shaft to abnormally high torque. This scenario most probably led to the damage found at the front of the external splines of the tail gearbox (see Figure 20) and the overload fracture in the drive shaft immediately behind the main gearbox (see Figure 19).

2.2.2 Except from this, the investigation has not detected any other failures in the power train from the engine to the tail rotor or any failures in the control system for the tail rotor. Based on this, AIBN finds it reasonable to exclude that the control problems experienced by the Commander could initially have been caused by a failure in the tail rotor's drive train or control systems. However, it is probable that the fracture of the tail rotor's drive shaft arose early in the sequence of events and that the tail rotor stopped completely because of that before the helicopter made the emergency landing in the water.

2.3 Technical failure in the tail rotor

2.3.1 The aircraft industry has amassed more than 80 years of experience in analysing damage and failure mechanisms in metallic structures. For example, based on metallurgical investigations, it can be determined in most cases whether or not a fracture was initiated through fatigue. This contrasts with the damage investigations in components constructed from composite materials. For components like that, establishing failure mechanisms and the sequence in which damage occurred can be demanding. Eurocopter has experienced a number of problems with the type of tail rotor blade fitted in the SA 365. Consequently the helicopter manufacturer has acquired information about several failures that can occur in the blades, and what this damage looks like in practice. For that reason the AIBN decided to carry out its examination of the tail rotor blades at Eurocopter's premises.

2.3.2 The damage found on the tail rotor blades all point to their being destroyed due to overloading. No failures have been found in glued joints, nor are there any signs of delamination. In addition, no signs have been found to indicate that any fracture has occurred in the Kevlar fibres prior to the accident. It is the opinion of the AIBN that such failures, if present, would most probably have been detected in the material that was examined. Alternatively, the first failure may have arisen in some of the material that was not recovered after the accident. This is something which the AIBN considers fairly improbable. For example, a fracture in a blade could lead to major imbalance, but it is unlikely that such a shortened blade would be further damaged because is can no longer reach into the tunnel wall. That would indicate that at least part of an original fractured surface would remain on the hub.

2.3.3 As far as the AIBN has uncovered, LN-OPJ has undergone its prescribed maintenance. This includes the ”tapping test” of the tail rotor blades 12:15 flying hours before the accident. In addition, the tail rotor was examined at the ”Pre Flight Inspection” prior to departure from the base at Dombås. During these inspections, no findings were made that would indicate that any failure was developing in the tail rotor. Altogether, therefore, the AIBN considers it fairly improbable that the accident arose due to a technical failure in the tail rotor.

2.4 The tail rotor being damaged by foreign objects

2.4.1 The tail rotor rotates at such high speed that even the smallest foreign object can damage the rotor blades. Grains of sand and similar items that are sucked into the tail rotor will normally just lead to wear on the titanium strip on the leading edge, but all larger objects such as paper, plastic bags, ice, etc. can cause considerable damage. The examination of the tail rotor blades detected no trace of any such foreign objects. Based on the crew's explanation and findings at the accident site, the AIBN has made the following assessments:

- The crew did not see or notice anything to indicate that the helicopter had any foreign objects in the tail rotor during the flight to Vågå. The AIBN considers it fairly improbable that anything like that could happen without it being detected.

- The crew did not see or notice anything to indicate that the helicopter had any foreign objects in the tail rotor during its stay on the beach at Vågåvannet. The crew had full control of the equipment that was used (rope etc.) in connection with the training mission. The Rescueman could confirm that the baggage compartment in the rear was closed after the helicopter ended up in the lake. In addition, no one noticed any plastic bags or other debris that could have been sucked into the tail rotor. The AIBN therefore considers it fairly improbable that any foreign objects hit the tail rotor during the first part of the training mission.

- The crew was aware of the hazard of loose objects in the cabin that might be blown out when the helicopter was flying with doors open. Consequently everything was secured before the door was opened. The crew did not notice anything disappearing out through the door in connection with the Rescueman jumping into the water. Some light objects were left floating on the water after the accident, but none of these showed any signs of having been in contact with the tail rotor. In addition, no objects were missing from the cabin after the helicopter was brought ashore. There was no record of any missing hatches, covers or other external objects on the helicopter, which might have fallen off and gone into the tail rotor. Last but not least, the rope that the Rescueman used was still attached to the helicopter when it was recovered, and the rope showed no signs of damage from having been in contact with the tail rotor. The AIBN therefore considers it fairly improbable that the tail rotor was hit by any foreign object that had come from the helicopter, cabin or the crew.

- The crew did not notice any floating objects in the water that might have been sucked into the tail rotor when the helicopter was hovering low over the water. In this case, these would have had to be very light objects to be able to be sucked out of the water and pulled into the rotor. The AIBN has found no trace of any such objects and considers it unlikely that anything of this nature could have been the cause of the accident.

- The bang that the crew heard occurred in the same period that the Rescueman jumped into the water. On impact, a certain amount of water would spray up. This water spray could, if it hit the tail rotor, possibly be enough to cause damage. This theory is unlikely, however, because the distance from the door from which the Rescueman jumped, back to the tail rotor is approx. 7 m. If the bang sounded after the Rescueman hit the water, it is also fairly improbable that he would have heard it, particularly if he was under the water at the time. This is also supported by what the Rescueman said, when he thought he had heard the bang before he hit the water.

- The damage found on the front of the titanium strip (see subparagraph 1.16.1.5) was assessed by Eurocopter as having been caused by contact with a ”pitch control crank pin”. This seems logical since several parts of blades were ripped free while the rotor was rotating. Some form of collision between blade components would consequently be probable.

2.5 The tail rotor becoming damaged as a result of icing

2.5.1 The air temperature was estimated at -4 °C to -5 °C and air humidity was between 80 % and 93 % in the area at the time of the accident. Since visibility was good, and there was no precipitation in the area, the probability of icing ought to be low. The low temperature should result in low air humidity, but this can vary considerably depending on the distance to the water and the water temperature. It is known that frost mist arises easily in areas where cold air is close to open water. This phenomenon will be particularly apparent when there is a large difference in temperature between the water and the cold air. In this case, ice was in the process of forming on the lake and the temperature of the water was consequently close to 0 °C. Thus, the difference in temperature vas just 5 °C which agrees with that no frost mist was observed over the water. Consequently, the AIBN considers it to be fairly improbable that ice formed on the helicopter during that part of the flight that took place at a good distance from the water. When flying in the immediate vicinity of the water, i.e. 10 m or less, droplets and moisture whipped up by the rotor would hit the helicopter. According to the Commander this did not freeze on the windows. This could indicate that the heat inside the helicopter heated up the windscreens somewhat.

2.5.2 It is not possible to state anything with certainty about icing in other locations on the helicopter. Information from Eurocopter indicates that ice can form in the tail rotor tunnel in the immediate vicinity of the blade tips on the EC 135. The tail rotor on the SA 365 is in principle very similar, and the AIBN bases this analyses on the assumptions that conditions concerning icing are comparable. Eurocopter has also found that the tail rotor blades become warmer than the surrounding air. Combined with the high rotation speed, there are therefore reasons to believe that there would have to be severe icing conditions before ice would form on the tail rotor blades. In the opinion of the AIBN, three cases of icing may lead to damage to the tail rotor blades:

- Icing in the tail rotor tunnel.
  According to Eurocopter, this type of icing is not considered a problem in moderate amounts. The most probable way ice in the tunnel could damage the tail rotor is if pieces of ice breaks loose and are sucked through the rotor. This is conditional either on a lot of ice forming or on the ice melting and working loose for one reason or another. The AIBN is of the opinion that it is improbable that ice could form on the tunnel in large amounts in the short space of time the helicopter was close to the water. If ice did form in the tunnel, it would be difficult in that case to find any explanation for why the ice would begin to melt a moment later. Eurocopter has experienced rotor blades touching ice in the tunnel in the case of rapid, strong pedal movements. This is also found by the AIBN to be improbable because rapid and strong movement of the pedals is incompatible with keeping the helicopter stationary in conjunction with the Rescueman's jump. If ice did form in the tunnel, it is not impossible that some of this ice could have remained, even after the accident. No trace of such ice was observed on the day after the accident.

- Icing on the tail rotor blades
  For ice on the actual tail rotor to cause damage there would first have to be considerable amounts of ice forming on the blades. Then the ice would have to break off and damage the blades, or the ice would have to break off in such a way that it caused a major imbalance and subsequent contact between the blades and the tunnel wall. The AIBN doubts that large volumes of ice would form on the tail rotor blades in the short time the helicopter was close to the water. It should also be expected that this would lead to vibrations, which would have given prior warning that something was about to happen. No such prior warning in the form of increasing vibrations was noticed by the crew.

- Icing on the helicopter's hull or main rotor.
  For ice to damage the tail rotor, it would potentially have had to fall off in considerable amounts and then be sucked into the tail rotor. The AIBN sees no reason for considerable amounts of ice to form on the hull, only to melt and fall off during the short period in which the helicopter was close to the water. A potential accretion of ice on the main rotor could be one alternative, but it is assumed that the ice would have created vibrations before the amount forming would have been sufficient to constitute any danger.

2.5.3 Based on available information, the AIBN cannot totally exclude the possibility that the accident was due to an accretion of ice on the hull or rotors. However, the investigation has to a very limited extent detected any conditions that indicate icing as the triggering causative factor, nor has icing been a problem in previous training flights over water. After an overall assessment, therefore, the AIBN finds it fairly improbable that the accident was due to icing.

2.6 The tail rotor entered the water unintentionally

2.6.1 <u>Visual references and assessment of altitude</u>

2.6.1.1 The operator had drawn up a practical procedure to prevent the Rescueman jumping out of the helicopter from too great a height. Because, in general, it may be difficult to judge heights above water, it seems sensible to use a rope of a known length as an indicator in order to determine a maximum height. Assessing the height down to the water will become more difficult the smaller the size of any waves on the surface. In addition, the assessment of height depends on the value of existing visual references. During the operator's training flights for lifting people out of the water, the crew had only visual aids to assist in assessing height above the water surface. The operator had also not indicated any minimum heights. The Commander consequently had to personally judge minimum height, based on visual references. The AIBN considers this to be very challenging. Highlighted below are some circumstances which contributed to making the task more difficult.

- The training took place approx 250 m from the shore, and the surrounding terrain could not provide visual references when the eyes were aimed at the area directly beneath the helicopter.

- According to the Commander, the installed radar altimeter was not sufficiently accurate to allow correct assessment of a jump height for the Rescueman. It would also be difficult for the Commander to avert his eyes from the external references to look into the cockpit and check the radar altimeter.

- The visual references down towards the water were surrounded by a ring consisting of droplets and moisture stirred up by the helicopter's main rotor. As a consequence, the Commander's visual references were generally limited to a dark water surface with a white plastic can, surrounded by an area of poor visibility.

- The windows in the cockpit did not permit a view immediately underneath the helicopter. In order for the plastic can to act as a good visual reference while not being blown away by the rotor downwash, the helicopter would have to be kept close to the can. The Commander consequently had to see the plastic can obliquely through windows that were partially obscured by water droplets. These were not the best conditions for maintaining good visual references.

- A stable position above the plastic can required a continuous focus on the actual can. Consequently, the options for the Commander were limited as regards removing his eyes from the plastic can to check the position in relation to the surrounding land and what was happening underneath the helicopter or in the cabin.

- Longitudinal movements of the helicopter would mean changes in the position of the nose (pitch). Raising the nose by 5° is equivalent to a 90 cm lowering of the tail rotor in relation to the cockpit's height over the water. Depending on the helicopter's pitch attitude, the height of the tail above the water could consequently vary considerably in relation to the height perceived from the cockpit.

- According to the crew's own assessments, the distance down to the water was between 2 and 3 m when the Rescueman jumped. Consequently, if the helicopter's floor plates are used as a starting point, the distance from the helicopter's wheels down to the water was between 1.40 m and 2.40 m. Without adopting a specific figure, this appears to give small margins for error, particularly considering the chance that the tail rotor might at times have been lower.

2.6.2 Witness statements

2.6.2.1 Statements provided by various witnesses can vary considerably even if they have been observing the same incident (see subparagraph 1.18.1). Witnesses can be affected by information they receive from other sources, such as from other witnesses or the media, and it can be difficult to differentiate between personal experience and information added afterwards. In addition it can be more difficult for a witness to remember the sequence of events than it is to remember the incident itself. In this case, two of the witnesses have independently stated that the tail hit the water causing water to be sprayed from it. The AIBN believes these are observations that ought to be taken seriously. An observation of this type can either be because the tail rotor rotated when it hit the water, or that the tail hit the water while the helicopter was rotating about its vertical axis at considerable speed.

2.6.2.2 According to the crew, the helicopter rotated through approximately one revolution before it landed softly. This conforms well with the helicopter coming to rest with its tail pointing east. Correspondingly, none of the witnesses can provide an unambiguous statement about the helicopter rotating about the vertical axis before it crashed. There is therefore no reason to believe that the helicopter rotated rapidly or through several revolutions. Consequently, the AIBN believes that the spray of water observed by the two witnesses came from water being sucked thought the tail rotor.

2.6.2.3 The technical examination has shown that the fracture of the tail rotor drive shaft was consequential damage and not a cause. In addition, there is reason to believe that the helicopter started to rotate around its vertical axis because the tail rotor ceased rotating. The tail rotor has relatively small mass and it is highly probable that the rotation speed would decrease rapidly after the shaft fracture, after it came into contact with the tunnel wall. It is therefore highly probable that the tail rotor was at a standstill when the helicopter landed in the water. A logical conclusion from the two witness statements would therefore be that the tail rotor was rotating at full power when it came close to the surface of the water and began to suck water. The accident was therefore probably triggered by the tail rotor inadvertently hitting, or being too close to, the water.

2.7 Probable sequence of events

2.7.1 The AIBN believes that, at one point when the Rescueman was about to jump, the helicopter's tail rotor came too close to the surface of the water. It is difficult to determine the tail rotors exact distance from the water when it was damaged without doing extensive tests or research. There are, however, strong indications suggesting the tail need to be in direct contact with the water before the tail rotor can suck sufficient water to be overloaded. During the accident one or more blades broke off and the subsequent imbalance led to a fracture of the “forward attachment coupling tube” and a bending of the “aft attachment tube”. The tail rotor with the gearbox, was then free to move in the helicopter's longitudinal direction inside the tunnel. As a consequence of this, the tail rotor's rotation centre was displaced and the tips of the blades came in contact with the tunnel wall. This caused damage to many tail rotor blades and damage to the tunnel wall. The bang, described by the Rescueman as if someone was hitting the hand with an empty plastic bottle, probably came from the tips of the blades striking the tunnel wall. It is probable that, at some time, the tail rotor gearbox moved backwards more than 20 mm and that the spline coupling in front of the tail rotor gearbox came out of mesh. The speed of the tail rotor then decreased. Because of dynamic imbalance in the tail rotor, the gearbox was pushed forward a short time later and a sudden overload arose as the teeth once more came into mesh. This overloading led to the fracture of the tail rotor drive shaft immediately behind the gearbox. The AIBN believes that this damage arose in the course of a very short time. It is highly probable that the crew perceived this as a loud bang. The grinding noises that the Commander heard may have come from the loose drive shaft or the damaged tail rotor, which continued to rotate for a short period after the bang.

2.7.2 A course of events, such as described here, would have led to total failure in the tail rotor and an incipient rotation to the left. The Commander was given a clear warning that something was wrong when a loud bang was heard in the helicopter and he immediately noticed that the problem was linked to the tail rotor. The AIBN believes that the Commander acted correctly when he rapidly put the helicopter in the water, in that way reducing rotation to a minimum. There is further reason to believe that the tail rotor had stopped completely when the helicopter hit the water, and that a considerable amount of water then sprayed up when the main rotor blades hit the water.

2.8 The operator’s procedures

2.8.1 The operator's procedures concerning rescue rope operations appear to be detailed, and covering many aspects (see subparagraph 1.17.2). The procedures bear the characteristics of being built on experience and are very detailed at times. The AIBN has not tried to undertake a complete evaluation of the operator's procedures regarding RRO, but notes that no minimum hover height above water was discussed. The AIBN believes that this accident confirms that judging hover height above water can be problematic. The operator had procedures preventing the Rescueman jumping out from too great a height, to avoid injury when hitting the water. There was, however, no description of a method to prevent the helicopter getting too close to the water.

2.8.2 A radar altimeter can be of assistance in assessing heights provided that it has sufficient accuracy/resolution and on the indicator being positioned to avoid it significantly influencing the pilot's focus on external references. One alternative could be to use radar altimeters with an audio warning. Following the accident, the operator established a 5 meters minimum hover height limit over water. This gives better safety margins and reduces the possibility of misjudgements of heights. The operator ought to evaluate whether radar altimeters can be used to assist in estimating heights above water or terrain with marginal visual references. Additionally, the operator has prohibited the Rescueman from jumping into the water. Therefore, the AIBN is of the opinion that the operator as a sum has taken measures that should prevent similar accidents.

2.9 Survival aspects

2.9.1 Plainly, remaining in water at temperatures of around 0 ºC is a potentially fatal. Depending on the clothing worn and physical condition it will only take a few minutes for the body temperature to drop so much that the body becomes rigid. The chances of surviving an emergency landing 250 m from shore wearing only general flying clothing depends only on coincidence. In this case, three factors were crucial to the outcome:

- The helicopter remained lying upside down on the lakebed so that its belly protruded out of the water. If the helicopter had turned over onto its side or crashed in deeper water, the situation would have been far more critical for the Commander and the Doctor. Then they would have had to stay in the water until help arrived or would have had to try to get to the shore. The bottom was gently sloping shallows in towards the shore, but they would have had to swim for some distance before they could have waded ashore.

- The Rescueman was wearing a drysuit and was, at the outset, dressed to spend time in the water. He was therefore able to help the other two, by getting them up onto the helicopter among other things. In addition, the Rescueman was able to fetch two wind sacks, thus reducing the heat loss for the two people sitting on the helicopter. In other words, the Rescueman was an aid resource for the two others who were poorly dressed for the conditions.

- There were several witnesses to the accident. Consequently, help would arrive within a short time. The crew also knew this and, in the opinion of the AIBN, this definitely contributed to their behaving rationally while waiting.

2.9.2 The life of the Rescueman was at risk when the helicopter began to rotate and later made its emergency landing on the water. The fact that the Rescueman was not injured is due to luck and to rational assessments. Previous experience has shown that, in accidents, the rotor is least dangerous to those located close to the centre of the main rotor. In this case, the Rescueman acted rationally when he tried to get in close to the helicopter hull. There would, however, have been a major risk of being hit by rotor blades with huge amounts of kinetic energy if the helicopter had turned over to the right, towards the Rescueman.

2.9.3 The helicopter was not equipped to carry out an emergency landing on water and did not have emergency equipment onboard which was appropriate for operations over water. Because the helicopter was operating so close to land, there is no requirement for this in current regulations. The AIBN, however, believes that the operator's rescue rope operations contain several high-risk elements. As a consequence, an assessment ought to be made considering if the crew should be wearing watertight suits and the helicopter equipped with emergency equipment beyond what is currently required by regulations, when such operations take place over water. Further, the use of safety boat should be evaluated. Following the accident, the operator made the use of survival suits mandatory for similar flights below a certain water temperature.

3. CONCLUSIONS

3.1 Findings

a) The crew possessed the necessary licenses and ratings to serve onboard.

b) The crew had many years of relevant experience with the operator and had previously carried out similar training.

c) The helicopter was registered in accordance with regulations and had valid environmental and airworthiness certification.

d) The aircraft's mass and the position of its centre of gravity were within limits.

e) A radar altimeter had been installed, but it was not considered as being a suitable aid for maintaining the correct height during the operation in question.

f) The weather was of no significance to the accident occurring.

g) The training was carried out according to the operator's procedures.

h) The crew heard a loud bang at about the same time as the Rescueman jumped into the water. Then the helicopter began to rotate to the left (anticlockwise) around the main rotor mast. This was due to the tail rotor failing.

i) The AIBN believes that the Commander acted correctly when he quickly put the helicopter in the water. He thus reduced rotation to a minimum and contributed to ensuring that the Rescueman, who was in the water, was not injured.

j) After landing in the water, the Commander kept the helicopter stable until the rotor speed dropped. Then he rolled the helicopter over onto its left side. This contributed to no one being injured and to the two persons onboard being able to evacuate rapidly via doors on the helicopter's right hand side.

k) The helicopter remained lying upside down on the lakebed so that parts of the helicopter protruded out of the water. In addition, the Rescueman was wearing a drysuit and was dressed for spending time in cold water. These were crucial factors in their chances for survival.

l) There were several witnesses to the accident and assistance arrived on site quickly.

m) The investigation has not revealed any technical failures on the tail rotor or any failures in the transmission and control systems for the tail rotor that might have led to the accident occurring.

n) The AIBN has not made any findings indicating that the tail rotor was damaged by foreign objects or ice.

o) The AIBN believes that the accident was a result of the tail section inadvertently hitting the water, or came so close to the water, that the tail rotor managed to suck water and thus became overloaded.

3.2 Significant findings

a) The operator had no procedures to prevent the helicopter coming too close to the surface of the water in Rescue Rope Operations. Consequently, the Commander's assessment of height under difficult visibility conditions became absolutely crucial in preventing the tail rotor from inadvertently coming too close to the water.

b) The helicopter was not equipped for an emergency landing on water. Nor did the Commander and the Doctor have lifevests or other clothing designed for that purpose, and were consequently poorly prepared for a potential emergency landing on water. The cold water and the low air temperature might, as a result, have been life threatening for those two.

4. SAFETY RECOMMENDATIONS

Following the accident, the operator has revised its operational procedures in several aspects. The training has been altered accordingly. The AIBN is of the opinion that these measures have taken care of the weaknesses revealed by this investigation. Therefore, no safety recommendations will be issued.

Accident Investigation Board Norway

Lillestrøm, Norway, 30. November 2009

APPENDIX

Appendix A

AIBN	Accident Investigation Board Norway
AOC	Air Operator Certificate – approval documentation for aviation operators
BEA	Bureau d'Enquêtes et d'Analyses – the French accident investigation board
BSL	Bestemmelser for sivil luftfart (Norwegian civil aviation regulations)
E	East
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JAR-OPS	Joint Aviation Requirements – Operations
KTS	Nautical Mile(s) (1,852 m) per hour
MTOM	Maximum Take Off Mass
N	North
N	Newton
NLA	Norsk Luftambulanse (Norwegian Air Ambulance Service)
OM	Operations Manual - in compliance with JAR
OPC	Operator Proficiency Check
PC	Proficiency Check
RRO	Rescue Rope Operations
S/N	Serial number
UTC	Universal Time Coordinated
VFR	Visual Flight Rules