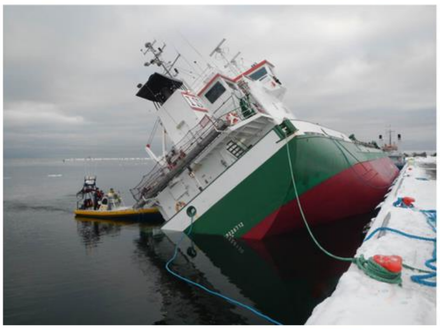
Statens haverikommission
Swedish Accident Investigation Authority



Final report RL 2014:02e

Accident at Aitik on 15 August 2011 involving helicopter SE-HVI of type Bell 206L-3, operated by Fiskflyg AB.

Ref no L-84/11

2014-02-17

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

The report is also available on SHK´s web site: www.havkom.se

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

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General observations

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

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

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

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

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

The investigation

SHK was informed on August 15, 2011 that an accident involving a helicopter with registration SE-HVI had occurred at the area of the Aitik mine, Norrbotten county, that same day at 18.54 hrs.

The accident has been investigated by SHK represented by Mr Göran Rosvall, Chairperson until 25 January 2012, thereafter Mr Jonas Bäckstrand; Mr Agne Widholm, Investigator in Charge until 19 August 2012, thereafter Mr Staffan Jönsson, also Technical Investigator (aviation) until 21 August 2013, and thereafter, Mr Agne Widholm was Investigator in Charge; Ms Ulrika Svensson, Operations Investigator until 16 March 2012 and Mr Urban Kjellberg, Investigator specialising in Fire and Rescue Services.

The investigation team of SHK was assisted by Mr Johan Lindvall, MTO Säkerhet AB, as an investigator specialising in behavioural sciences. Mr. Denis Rivard, and later Mr. John Britten, have participated as accredited representatives of the Transportation Safety Board of Canada.

The investigation was followed by Mr Sven Christiansson and, subsequently, Mr Mats Persson of the Swedish Transport Agency, Civil Aviation and Maritime Department.

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Aircraft:	
Registration and type	SE-HVI, Bell Helicopter Textron Canada Limited 206L-3
Class/Airworthiness	Normal, Certificate of Airworthiness and Valid Airworthiness Review Certificate (ARC)
Owner/Operator	Fiskflyg AB
Time of occurrence	2011-08-15, at 18.54 hours in daylight Note: all times are given in Swedish daylight saving time (UTC[1] + 2 hrs)
Place	Aitik mine, Norrbotten county, (position 67° 4.5'N 020° 54.0'E, 389 m above sea level)
Type of flight	Aerial work
Weather	According to SMHI's analysis: wind south-easterly 10-15 kts, visibility >10 km, no clouds under 3 000 feet, temperature/dewpoint 17/6 °C, QNH[2] 1021 hPa
Persons on board:	1
Crew members	1
Injuries to persons	Minor
Damage to aircraft	Substantially damaged
Other damage	None
Commander:	
Age, licence	53 years, CPL (H)[3]
Total flying hours	9,500 hours
Flying hours previous 90 days	250 hours
Number of landings previous 90 days:	430

[1] UTC (Coordinated Universal Time) is a reference for the exact time anywhere in the world.
[2] QNH indicates barometric pressure adjusted to mean sea level.
[3] CPL (Commercial Pilot License) (H) – Helicopter.

SUMMARY

The incident occurred during a flight commissioned for water bombing operations, using a helicopter equipped with “Heli buckets” (water containers) of the Bambi Bucket brand, with the purpose of binding the dust at the Aitik tailings dam. The pilot took off at lunchtime with the helicopter SE-HVI, and two other helicopters from the company also participated in the water bombing of the tailings dam. Towards the end of the day, the two other helicopters continued to retrieve water south of the dam while SE-HVI flew to a smaller tarn north of the dam. When the pilot had lowered the container into the water to fill it and subsequently commenced climb in order to lift the container up out of the water, the helicopter banked suddenly to the left with a pronounced nose rise. The pilot applied full cyclic stick to the right and simultaneously lowered the collective lever in order to correct the rolling movement to the left, but the helicopter still rotated to the left at a high roll speed and with the nose high. Shortly thereafter, the helicopter came down into the tarn. The pilot in one of the other helicopters that was engaged in water bombing noted the absence of SE-HVI. He flew towards the tarn and landed there about 10 minutes after the crash. It was found that the pilot only had minor injuries and was not in need of medical care.

The investigation has shown that when lifting in order to fill the Bambi Bucket, a cable was over the left landing gear skid and skid shoe. This increased the rolling moment markedly to the left, and the helicopter went into a “Dynamic rollover” with a high nose when the pilot raised the collective lever. Once the helicopter had gone into rotation with increasing mass forces at the same time as the laterally directed lift increased, the authority of the control system was not sufficient to correct the movement. The helicopter rotated at a high speed of rotation around the longitudinal and lateral axes before it came down into the tarn. The centre of gravity when lifting into the hover came to be far outside the limitations for which the helicopter was designed. The investigation reports the following causes of the accident:

- The position of the water container was not ascertained prior to lifting.
- The sun's position with sun reflections and shadows affected the pilot's ability to monitor the filling process in the rear-view mirror.
- The design of the landing gear, with its parts, made it possible for a cable to the water container to become caught over the skid.

SHK believes that one factor which contributed to the incident was that the chosen area of water had tall trees in the direction of approach and that the available area placed great demands on the pilot's flying when filling the Bambi Bucket.

Recommendations

The Swedish Transport Agency is recommended to ensure that:

- operators have established operational limitations, which take into consideration risks entailed by the helicopter's design during operations with a suspended load. (*RL 2014:02 R1).*

EASA is recommended to ensure that:

- EASA Member States in their supervision check that operators have established operational limitations, which take into consideration risks entailed by the helicopter's design during operations with a suspended load. (*RL 2014:02 R2*).

1. FACTUAL INFORMATION

1.1 History of the flight

1.1.1 The flight

During the morning of the day of the accident, the aviation company received a request from Aitikgruvan AB, which required help in binding the dust on the Aitik tailings dam. This was a task that the aviation company normally performed as dry spells and wind sometimes caused large quantities of tailings matter in the air. Water bombing from a helicopter equipped with water containers known as “Heli buckets” was intended to bind the dust and thereby reduce the spread of this from the tailings dam.

The pilot took off with helicopter SE-HVI from Ritsem at 12.41 hrs on a flight to Porjus in order to pick up the water container. Following a check of the opening mechanism, the pilot continued towards Aitik, where two other helicopters from the company were also engaged in bombing water on the tailings dam. All of the helicopters were performing the watering equipped with “Heli buckets”, in this case of the brand Bambi Bucket.

Initially, the south-easternmost part of the dam was being watered by all helicopters. They were then retrieving water from lakes just south of the mine's tailings dam. Towards the end of the day, when the north part of the tailings dam was to be watered, the two faster helicopters continued to retrieve water south of the dam, while SE-HVI flew to a smaller tarn north of the dam, see Figure 1, and thus gained a considerably shorter flight distance to the part of the dam that was to be doused with water.

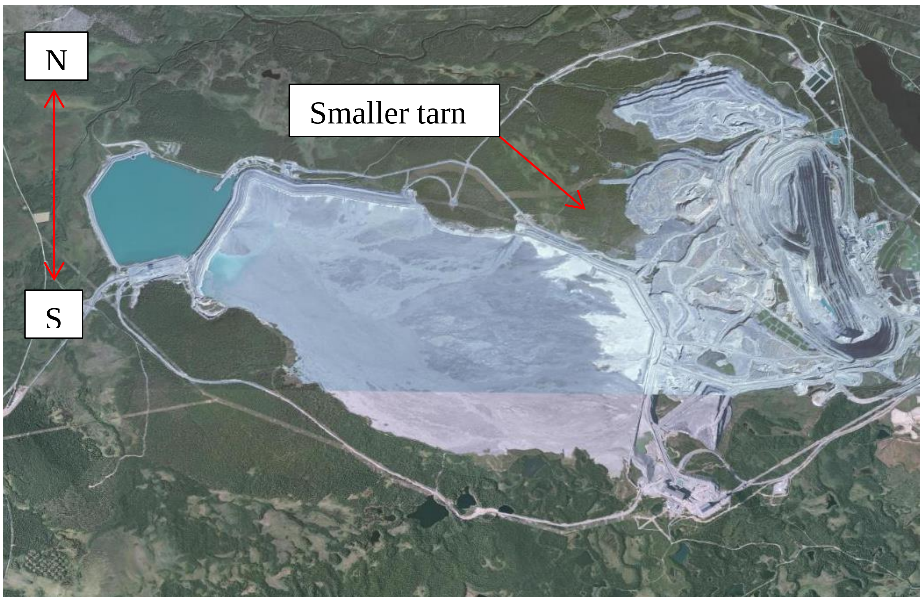

Figure 1. Overview image where the tarn is marked with a red arrow. Photo: Hitta.se, © Lantmäteriet Ref 2013/0375.

During the task, the pilot had been to the smaller tarn a great number of times when the crash occurred. When the pilot had lowered the container into the water to fill it and subsequently commenced climb in order to lift the container up out of the water, the helicopter banked suddenly to the left with a pronounced nose rise. The pilot applied full cyclic stick to the right and simultaneously lowered the collective lever in order to correct the rolling movement to the left. The pilot experienced something clatter above the cabin, upon which the helicopter rotated to the left at a high roll speed and with the nose high. Shortly thereafter, the helicopter came down into the partially buoyant, flowing and layered portion of the tarn. Just before impact, the pilot heard a heavy sound from the transmission. Figure 2 shows the helicopter in its final position after the incident and with its Bambi Bucket hanging over the skid.

The pilot in one of the other helicopters that was engaged in bombing water noted the absence of SE-HVI. He flew towards the tarn and landed there about 10 minutes after the crash.

Figure 2. Crash site.

The accident occurred at pos. 67° 4.5'N 020° 54.0'E, 389 m above sea level.

1.1.2 *Interview with the pilot and his work colleagues*

The pilot set off by car from his home in Gällivare and travelled to the operator's base in Porjus. The journey was less than one hour. The working day started at 07.40 hrs with the pilot purchasing supplies to take to Ritsem. Thereafter, he continued with his car to the aviation company's summer base at Ritsem. He arrived at around 10.30 hrs.

The various details provided about the flights below have been obtained from the log in the GPS that was mounted in the helicopter. A couple of hours after the pilot's arrival at Ritsem, a request was received relating to Aitik mine's tailings dam needing to be doused with water due to dust problems. The pilot took off from Ritsem with SE-HVI at 12.41 hrs and flew directly to Porjus to connect a Bambi Bucket as a suspended load. He tested filling it, verified that the emptying process worked and re-filled the water bucket with water as ballast and then flew to Aitik mine. The water bombing began on the south side of the dam in order to avoid flying with the helicopters in the dust from the tailings dam.

On site at the mine, the pilot flew 48 runs between a small lake south-east of the dam where water was retrieved and the area to be watered. The pilot then flew to Gällivare Airport for refuelling.

After refuelling, the pilot returned to Aitik mine, but after a few runs with the container as a suspended load, the pilot stopped and returned to a helicopter base near Gällivare to eat. The time was then 16.54 hrs.

The pilot has stated that sun reflections and shadows sometimes arose in the mirror that made it difficult to perceive where the cables to the Bambi Bucket were in all situations. Furthermore, he stated that when lifting, the cables were hanging straight down as they normally do. When filling with the Bambi Bucket in a small tarn, with limited room for manoeuvre, it is not possible to have any forward speed. This means that the Bambi Bucket is lowered vertically and initially floats. The cables thus slacken when the container reaches the surface of the water, before it sinks.

At 17.43 hrs, the pilot took off for the journey back towards Aitik, where a further 35 runs were flown, this time between the tailings dam and a somewhat smaller tarn north of the tailings dam. At 18.54 hrs, the helicopter crashed.

The pilot's total duty time, calculated from 07.40 hrs to the time of the crash, was 11 hours and 14 minutes. During this time, the pilot drove a car for a couple of hours and attained flying hours totalling 5 hours and 11 minutes “airborne”[4].

The total number of “loops” that the pilot had got done at Aitik mine was around 83. The first group of flights consisted of 48 runs with an average time of 166 seconds, and after the food break, 35 runs were made with an average time of 108 seconds. The time for the later flights was shorter due to the pilot retrieving water in a lake/tarn that was closer to the part of the tailings dam to be watered. Furthermore, the pilot made a few more runs between refuelling and the food break.

The pilot states that a transport loop with Bambi Bucket is normally flown at a speed of around 50 knots. When filling, the helicopter is completely still, or moved with very little forward speed, and after lifting the pilot accelerates to 50 knots. When emptying the water, the

[4] Airborne time – Time from when the helicopter's collective lever is raised above a position corresponding to flight position until the lever is lowered below this position.

speed is reduced to half and the altitude to the minimum safe altitude, i.e., 100 to 200 feet.

The pilots at the aviation company have stated that they experience water bombing operations at Aitik as worthwhile jobs and not especially taxing. This is because the pilots themselves have great influence over the shift durations.

1.2 Injuries to persons

	Crew members	Passengers	Total	Others
Fatal	-	-	0	-
Serious	-	-	0	-
Minor	1	-	1	N/A
None	-	-	0	N/A
Total	1	0	1	-

1.3 Damage to aircraft

Substantially damaged.

1.4 Other damage and environmental impact

None.

1.5 Personnel information

1.5.1 Commander

Commander, 53, had CPL (H) with valid flight operational and medical eligibility.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	0	0	250	9,500
This type	0	0	100	3,500

Number of landings this type previous 90 days: 430.
Type rating concluded 1989.
Last PC[5] conducted on 26 april 2011 on Bell 206B.

1.5.2 The pilot's duty schedule

The pilot’s duty time was within permitted limits according to the company's OM. Prior to these duties, the pilot had had two weeks' holiday.

[5] PC (Proficiency check).

1.6 Aircraft

1.6.1 Helicopter

TC-holder	Bell Helicopter Textron Canada Limited
Type	206L-3
Serial number	51407
Year of manufacture	1990
Gross mass, kg	Max authorised start/landing mass suspended load 1928, current 1750
Centre of gravity	Within permitted area.
Total flying time, hrs	4794
Flying time since latest inspection.	63.2
Number of cycles	9,376
Type of fuel loaded before event	Jet A-1
Outstanding remarks	
MEL	None
HIL	None

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

1.6.2 Description of parts or systems related to the accident: Heli buckets

A Bambi Bucket is a container of rubberised canvas, open at the top, that is attached with cables in the cargo hook under the helicopter. The container is lowered into the water, overturns and quickly fills with water. The helicopter flies to the area to be watered, and the water is emptied by means of a valve in the bottom of the container being opened electrically. The content of the container flows out as a more or less heavy rain depending on the speed and height over the target. The entire container can be dropped by the pilot in an emergency by means of opening the cargo hook electrically or mechanically.

The manufacturer, SEI Industries Ltd., is a Canadian corporation, and Bambi Bucket is a protected trademark associated with the company. Most Bambi Buckets available on the market today have the same Operations Manual, which can be downloaded from the manufacturer's website. At the time of the accident, version F of the manual was applicable. On page 11 of the manual there is an operational warning, see Figure 3.

The warning concerns the risk of the suspension lines getting caught in the rear part of the helicopter's skid landing gear or equivalent. According to the warning, there is a particularly high risk of this if an abrupt 90-degree turn is performed while the container is being filled with water.

Warning

When filling the Bambi bucket, do not execute an abrupt 90 degree pedal turn with the helicopter close to the water while towing the bucket. While filling, there is a danger that the Bambi bucket suspension lines (as with any other external load) could get caught on a rear skid resulting in a dynamic rollover on liftout. This could cause personal injury and helicopter damage. Check the load and suspension cables with your mirrors before liftout.

Figure 3 – Warning text in the Bambi Bucket user manual.

1.7 Meteorological information

According to SMHI's analysis: Wind south-easterly 10-15 kts, visibility >10 km, no clouds under 3 000 feet, temperature/dewpoint 17/6 °C, QNH 1021 hPa

1.8 Aids to navigation

Not applicable.

1.9 Communications

The three helicopters communicated internally on the frequency 123.5 MHz and were monitoring Gällivare Information frequency 123.1 MHz.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

None.

1.12 Accident site and aircraft wreckage

1.12.1 Site of occurrence

The tarn where the helicopter crashed was situated north-east of the tailings dam and was relatively small. The greatest length in the direction of flight was about 30 metres. The filling of the container took place flying against the wind on a heading of around 100 degrees over a curtain of forest just before filling.

The trees closest to the tarn in the direction of approach were about 6 to 8 metres high. Surrounding the open water was a flowing and partially buoyant layer of ground around the entire tarn. In the direction of climb out, the obstacle clearance was greater. The height of the trees in the direction of climb out was lower than at approach, and the flight path gradient had a considerably more level slope compared with the approach.

Figure 4. Overview picture of the tarn from the south. Within the part of the tarn marked in red, the water depth was more than one metre. The black arrow indicates a distance of around 20 metres.

Figure 4 shows how the tarn looked from the south. It should be noted that the area with a water depth greater than one metre constituted less than half the tarn's free water surface.

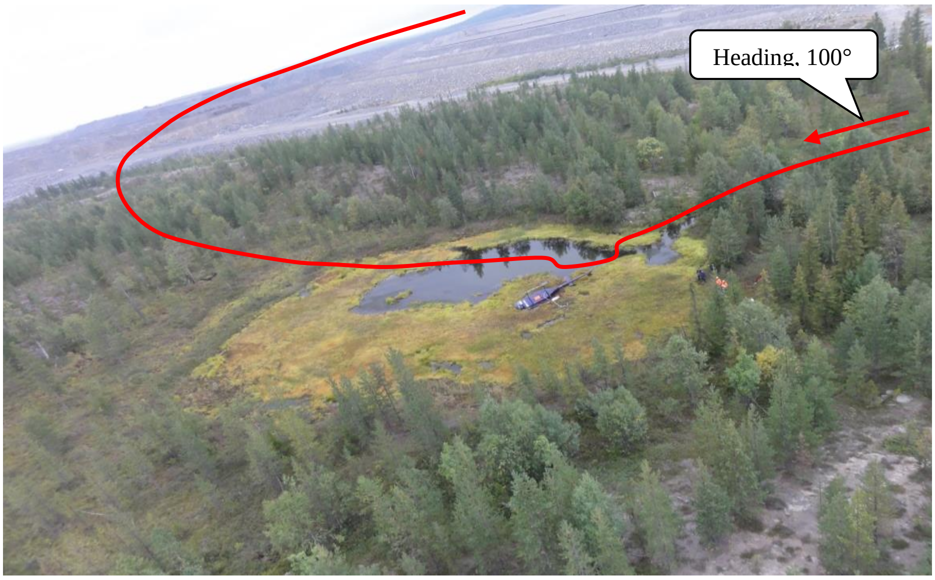

Figure 5. Overview picture of the tarn from the north. Approach and climb out when filling Bambi Bucket at the tarn.

The tarn leg of the flight has been exemplified in Figure 5. The heights of the tree curtains are shown as well as a ridge between the tarn and the forest edge (to the top of the picture). The tailings dam can be spotted at the top edge of the image.

1.12.2 Aircraft wreckage

The helicopter came to rest on its right side in the tarn. The entire main rotor and mast situated above the main rotor gearbox separated from the helicopter. The parts found on the ground and in the surface of the tarn were lying in a semicircle to the right of the place at which the helicopter came to rest after the crash, see Figure 4. The main rotor hub with the inner sections of the blades was found later just in front of the helicopter beneath the upper layer of the tarn's quagmire.

The tail boom was cracked 0.3 m behind the parting line between fuselage and boom. The right fin of the stabiliser was broken off. Most evident was that the entire main rotor with the mast and one of the blade pitch links had separated from the helicopter. Both front windows and the lower right nose window were damaged or missing. Following salvage and a closer examination of the helicopter's fuselage structure, damage was discovered to the rivet joints on the upper side of the rear fuselage and a depression in the roof above the pilot. When the interior fittings had been dismantled, it was revealed that the engine mounts in the roof had been pushed downwards. The main rotor had also been in contact with the upper side of the engine gearbox and engine exhaust outlet before the rotor package left the helicopter.

The rear mount of the left skid shoe had been overloaded and was twisted about 30 degrees clockwise as seen from behind. The cable as well as the skid and skid shoe exhibited wear damage which upon comparison was found to be matching, see Figures 6, 7 and 8.

The permanent deformation of the skid shoe, as well as the position and deformation of one of the cables, indicates that the cable had been in contact with the skid shoe under load, see Figure 8.

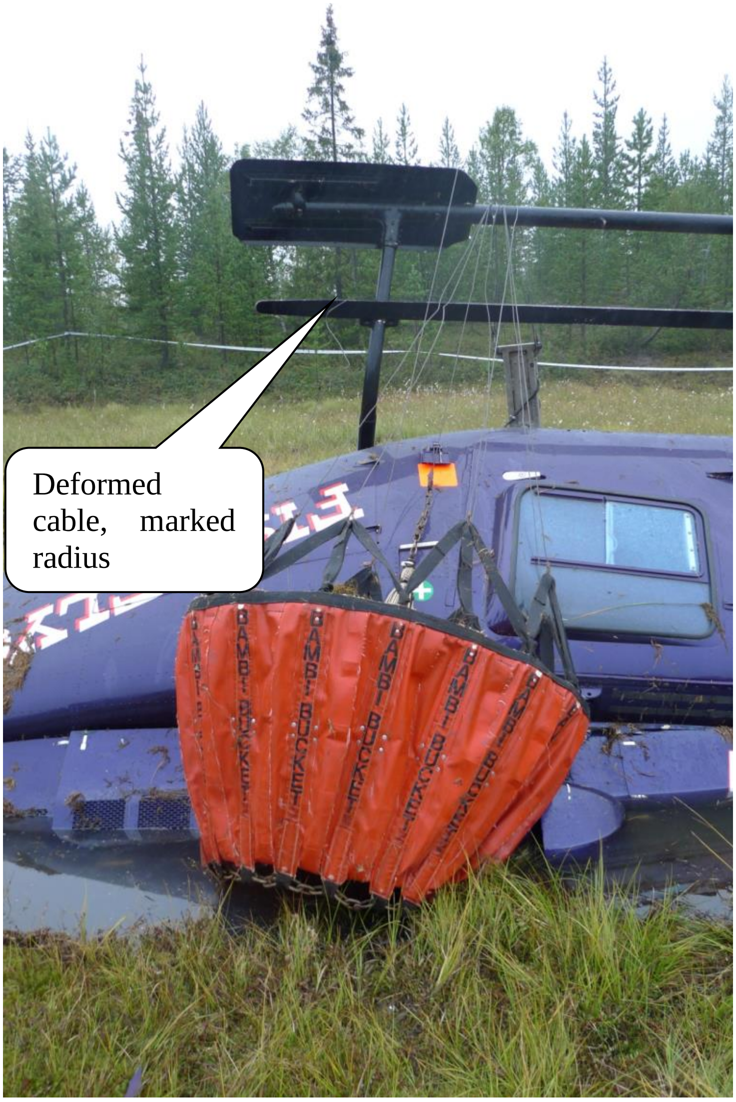

Figure 6. Bambi Bucket, left skid and skid shoe, note the radius of the marked cable.

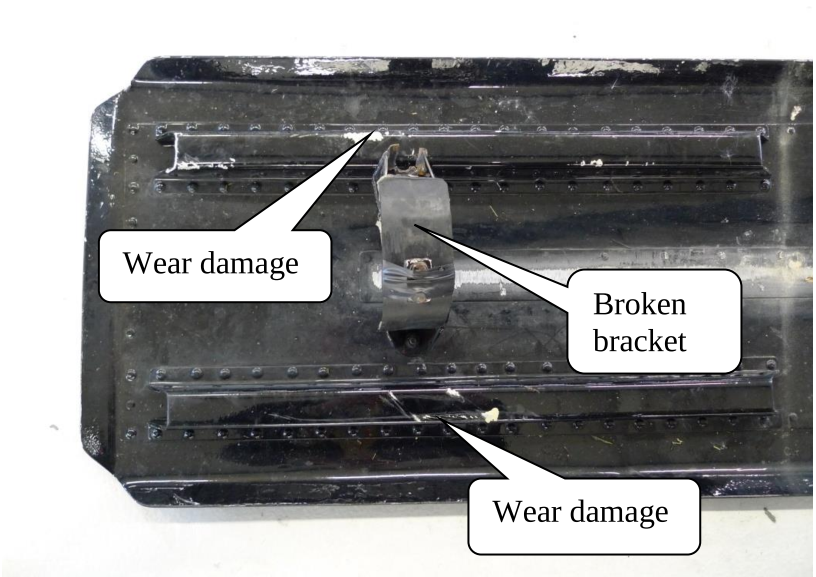

Figure 7. Left skid shoe, note wear damage from the cable and broken bracket.

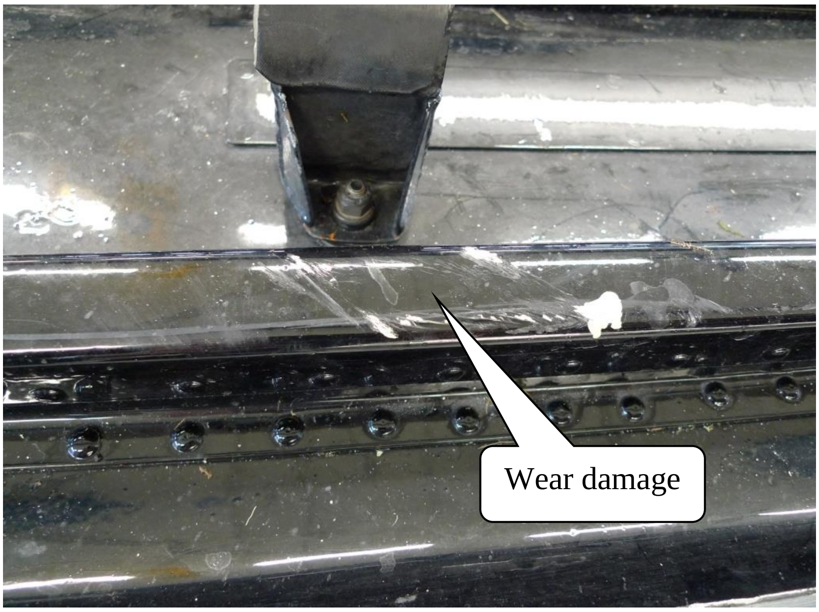

Figure 8. Close-up image of the left skid shoe, note wear damage from the cable.

1.13 Medical information

Nothing indicates that the general condition of the pilot was impaired before or during the flight.

1.14 Fire

There was no fire.

1.15 Survival aspects

1.15.1 Rescue operation

Provisions on rescue services are found primarily in the Civil Protection Act (2003:778, Swedish abbrev. LSO) and the Civil Protection Ordinance (2003:789, Swedish abbrev. FSO).

According to Chapter 1, Section 2, first paragraph of LSO, the term “rescue services” denotes the rescue operations for which central government or municipalities shall be responsible in the event of accidents and imminent danger of accidents in order to prevent and limit injury to persons and damage to property and the environment. Central government is responsible for mountain rescue services, air rescue services, sea rescue services, environmental rescue services at sea, and rescue services in case of the emission of radioactive substances and for searching for missing persons in certain cases. In other cases, the municipality concerned is responsible for the rescue services (Chapter 3, Section 7, LSO).

A pilot in a helicopter that was engaged in the work of water bombing Aitik mine's tailings dam called air rescue at JRCC at 19.11 hrs. The conversation disclosed that a colleague had crashed in connection with the filling of a water container that was a suspended load beneath the helicopter.

From JRCC, contact was made with the SOS centre in Luleå, which alerted the rescue services in Gällivare, an ambulance and the police authorities.

A unit from the rescue services arrived at the crash site at 19.47 hrs and the ambulance a minute later. It was found that the pilot only had minor injuries and was not in need of medical care. The helicopter pilot himself chose to leave the site in another of the company's helicopters.

Personnel from the rescue services disconnected the battery in the helicopter and assessed that there was no risk of environmental damage.

The ELT[6] manufactured by Airtex, model 406ME, was activated during the accident and deactivated by the rescue services.

1.15.2 Crew injuries

Chapter 4, Section 8 of the Swedish Civil Aviation Authority[7]'s Regulations and General Advice (LFS 2007:49) on commercial aerial work by helicopter states the following.

"For forms of activity in which the altitude is primarily below 250 feet or when the helicopter is primarily within the critical speed range given in the autorotation diagram, the flight crew and accompanying persons (category A in accordance with Appendix 2)

1. *must be secured with safety belts with a strap over each shoulder and must*
2. *wear a flying helmet."*

The company's *"OM 13.3.1.8 Firefighting – helicopter"* states that a flying helmet is to be worn during the extinguishing work. There is no mention of exceptions to the regulation. The pilot was not wearing a helmet during the flight. In the crash, he hit his head on the interior fittings but remained conscious. He also sustained light wounds to one arm.

Parts of the helicopter cabin were filled with water. With some difficulty, the pilot was able to pull himself loose and climb wet out of the helicopter via the broken left front window.

[6] ELT (Emergency Locator Transmitter).
[7] Now the Swedish Transport Agency.

1.16 Tests and research

1.16.1 Materials examination on the mast

In order to determine whether the mast broke as a result of the crash and to gain an assessment of the helicopter mast's mode of failure, the fracture surfaces were examined by an independent materials laboratory with well-documented expertise in steel alloys.

The examination established that the mast's primary mode of failure was overloading through torsion (twisting). The cracks sloping at 45° on the mast's periphery indicate the mode of failure, see Figure 9. The material of the mast is ductile[8] and the superposed bending force deformed the mast (bent the mast) when the rotor disc came in contact with the tarn's water surface.

The mast wall thickness in the fracture surface was checked. It varied from 8 to 12 millimetres (in the section subjected to wrenching). Nominally, the mast material's thickness is 10.5 millimetres.

The mast's chemical composition is consistent both with AMS 6414 and AISI 4340. The hardness was determined on a cleaned, polished surface at five measurement points according to Vickers[9] (HV10), and the average value was 408.

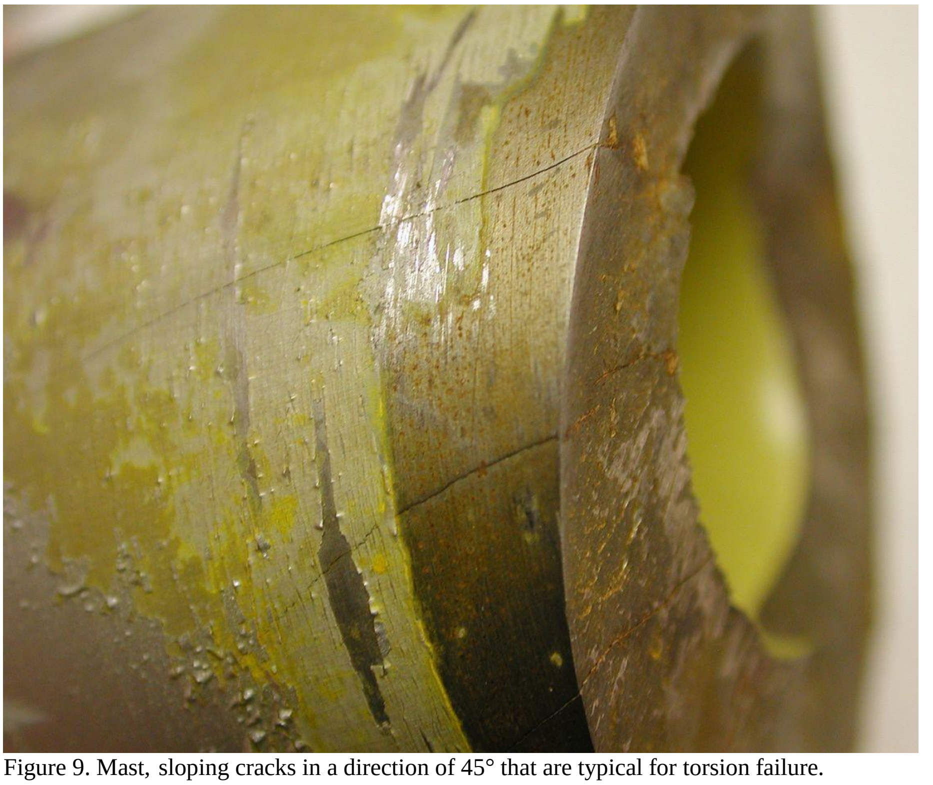

Figure 9. Mast, sloping cracks in a direction of 45° that are typical for torsion failure.

[8] Ductile - State after heat treatment which allows the alloy to plasticise without crack formation prior to failure.

[9] Vickers – Hardness measured according to the Vickers method.

1.16.2 Examination of Bambi Bucket

SHK, in consultation with an expert on the product, conducted a separate examination and evaluation of the Bambi Bucket used during the flight.

The container was relatively old and worn, but the wear may be considered moderate with reference to the age of the equipment. The opinion of the expert who participated in the examination was that the characteristics of the equipment in use had not been affected by age and wear. However, it should be noted that the Bambi Bucket that was used during the crash was an early variant that had battens reinforced with fibreglass to stiffen the bucket rim. In terms of design, these are a reinforcement around the periphery at the very top of the edge in order for the container to retain its form when it is not filled with water. Later designs have a star-like aluminium frame in the corresponding position that is stiffer and also retains the container's round form at a higher speed.

1.16.3 The Bambi Bucket's position in relation to the skid landing gear

To illustrate the position that is necessary for the cable to become caught in the skid, the Bambi Bucket involved in the crash was placed under a helicopter.

For the sake of simplicity, the measurement assumed a detachable skid landing gear of the same design as on the helicopter involved in the accident. The landing gear is said to be high, but has the same width as the normal variety (the distance from the helicopter's centre line to centre of the skid is 1092 mm).

Lining up the cargo hook's position (in the horizontal plane) and laying out the lines to the sack showed that the angle from the helicopter's centre line to the rearmost point of the skid was about 40°, see Figure 10. The container's angle (double cone angle) between the cables when it is filled with water is around 20°. If the sack is not filled with water, the cone angle is slightly less, and the sack must in this case swing out > 30° to touch against the skid. If the angles are considered in a vertical plane across the cargo hook and the direction of flight, the result is of approximately the same magnitude as in the first case.

Figure 10. Bambi Bucket angled about 30° to the left behind the helicopter.

1.16.4 The helicopter's landing gear skid

The helicopter's landing gear is also used as an attachment point for all kinds of equipment. The necessary equipment is mounted on skids and foot plates in order to perform a large number of mission profiles. If this equipment is mounted when flying with a suspended load, it is reasonable to examine the conditions for its function together with the equipment hanging from the cargo hook.

Skid shoes should be correspondingly checked in order to eliminate the risk of objects getting caught.

1.16.5 Dynamic rollover

When lifting into hover, the helicopter can become locked or the skids or wheels can become stuck asymmetrically in the surface, the result of which usually concludes with a quick rolling movement which cannot be corrected. This situation is known as ”Dynamic rollover”[10].

If one of the Bambi Bucket's suspension lines gets caught around the rear part of a skid, this causes the helicopter to end up in a “Dynamic rollover” with an accelerating roll. In addition to this, there is also a

[10] Dynamic rollover - If a helicopter is subjected to a rolling moment above a certain critical level of roll, for example around a skid, the thrust from the main rotor will reinforce the rolling moment. Reference: Principles of Helicopter Flight, Wagtendonk.

severe nose rise because the centre of gravity along the longitudinal axis is far behind the permitted position, see Figure 11.

To avoid this phenomenon, regardless of cause, the aircraft flight manual's recommendation is to lower the collective lever. Applying increased cyclic stick only worsens the situation because increasing total rotor lift results in a greater horizontal lift thrust component. This component increases the moment around the point that is locked (in the ground, or where the helicopter's resulting external forces attack during flight with a sling). Experience shows that in the avoidance of dynamic rollover, carefully countering the bank is more effective than raising the collective lever. If the main rotor is rotating anticlockwise (as on the Bell 206L-3), the tail rotor generates force to the right, i.e. the nose of the helicopter will yaw to the left, and this movement is counteracted by pedal displacement to the right. If the pilot does not compensate for this yaw, the sequence is accelerated and very quickly becomes uncontrollable.

1.16.6 The helicopter's centre of gravity

The helicopter's centre of gravity in flight before the accident was within permitted limits. The helicopter's take-off mass prior to the final flight was 1320 kg and, with a full container, 1750 kg. This is under the maximal take-off mass that, with a suspended load, is 1928 kg. In order to show according to scale how far outside the permitted centre of gravity area the resulting force takes effect when a cable is caught over the skid, the following calculations are presented.

<u>Longitudinal centre of gravity:</u>

At a mass of 1750 kg, the longitudinal[11] permitted centre of gravity is 3020 to 3230 mm. The centre of the rotor hub in this coordinate system is at 3084 mm, and the cargo hook's suspension point is at 3112 mm. Note that the calculated centre of gravity 3130 is behind the positions of both the main rotor hub and cargo hook.

Table 1. Longitudinal basic centre of gravity with Bambi Bucket suspended beneath the helicopter by the cargo hook (normal position).

BHT Canada Limited 206L-3 SE-HVI			
Description	Mass (Kg)	Arm (mm)	Mass mom. (kgmm)
Empty mass	1106	3283	3 630 138
Pilot	95	1651	156,845
Fuel (243 lb)	110	2939	323,290
Helicopter	**1311**	**3136**	**4 110 273**
Bambi B 9011	439	3112	1 365 949
Helicopter + BB	**1750**	**3130**	**5 476 221**

[11] Longitudinal – Coordinate system lengthwise; the zero position is 25 mm in front of the helicopter nose.

In Tables 2 and 3, the centre of gravity is calculated, and Figure 11 shows to scale how this changes if a cable to the Bambi Bucket gets caught in the left skid, rearmost at the skid shoe.

Table 2. Longitudinal centre of gravity with Bambi Bucket suspended on a cable around the skid.

BHT Canada Limited 206L-3 SE-HVI			
Description	Mass (Kg)	Arm (mm)	Mass mom. (kgmm)
Empty mass	1106	3283	3 630 138
Pilot	95	1651	156,845
Fuel (243 lb)	110	2939	323,290
Helicopter	**1311**	**3136**	**4 110 273**
Bambi B 9011	439	3112+1350	1 958 818
Helicopter + BB	**1750**	**3468**	**6 069 091**

Initially, the sack is completely filled with water before the helicopter begins to lift, but when the cable tightens, the water will run out of the sack (the sack is lifted by only one cable), and the mass decreases, but in this case a “dynamic rollover” has already been initiated (see Section 1.16.5), and the rotation speed in both tip and roll is very high. For an illustration of the centre of gravity, see Figure 11.

<u>Lateral centre of gravity:</u>

The helicopter's weighing protocol does not present mass data in the lateral plane[12]. The flight manual gives information that the centre of gravity is 2 mm (to the right of the fuselage centre line).

Table 3. Lateral centre of gravity with Bambi Bucket suspended on a cable rearmost on the left skid.

BHT Canada Limited 206L-3 SE-HVI			
Description	Mass (Kg)	Arm (mm)	Mass mom. (kgmm)
Empty mass	1106	2	2,212
Pilot	95	356	33 820
Fuel (243 lb)	110	0	0
Bambi B 9011	439	-1125	-493 875
Helicopter + BB	**1750**	**-262**	**-457,843**

[12] Lateral – Coordinate system across the helicopter; the zero position is in the fuselage's line of symmetry, positive to the right with reference to the direction of flight.

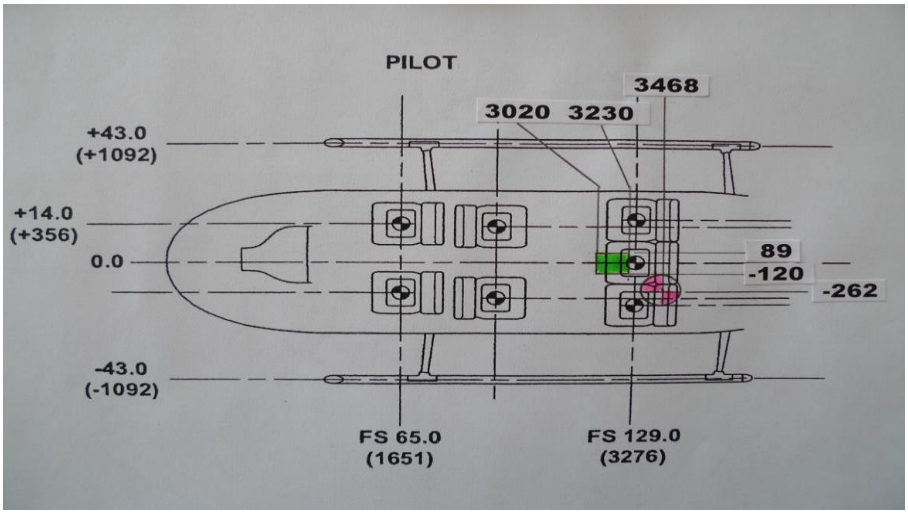

Figure 11. Schematic presentation to scale of the longitudinal and lateral centres of gravity when the cable is around the left landing gear skid, Bambi Bucket completely filled with water. The green area marks the permitted centre of gravity, and the pink-white symbol shows the actual centre of gravity.

For an illustration of the centre of gravity, see Figure 11. The calculations above show the centre of gravity when the load is lifted and the cable has hooked into the left landing gear skid and is over the skid shoe.

1.16.7 *Flight test with Bambi Bucket 9011 hanging over the left skid*

On its own initiative, the operator conducted a flight test with the container used at the time of the incident, mounted on a Bell 206B. The container was, as in the crash, ballasted with about 15 kg of chain in the front edge to fill with water faster. An empty container weighs just under 40 kg. The container was suspended by the cargo hook according to instructions from SEI Industries, and one of its suspension lines was hung over the left skid in keeping with the situation in the crash. The pilot found that countering of bank was required and a little down elevator to maintain the correct attitude when hovering.

1.16.8 *The pilot's work environment*

Human and Organisational Factors is a concept in behavioural science that adopts a holistic approach to the causes of accidents and incidents. This means that the causes of accidents and incidents can often be found in the interplay between human, technology and organisation and not simply in these individual parts alone. Accidents are often a result of a number of circumstances that can be traced to the individual operator or technology, as well as to organisational factors. Here, humans can be seen to be influenced by both internal and external factors. Internal factors include stress, fatigue, personality and lack of attention or knowledge. Organisational factors include level of training, work procedures, safety culture and leadership.

Factors in the work environment may contribute to an increased risk of undesired events. One such factor which is particularly evident in helicopters is noise. Noise may not only cause physical hearing impairments, but can also have a number of physiological effects such as high blood pressure, headaches and fatigue.

To reduce this effect, the company has gradually introduced the use of ANR headsets. ANR (Active Noise Reduction) is a technology that, in short, means sound cancels sound by inverting the phase of the unwanted noise. ANR has proved to be very effective against low-frequency noise, which is dominant in the sound pattern on helicopters. The interviews have revealed that the employees experience that they can get tired after a working day, but that this eased considerably when headsets with ANR are used. At the time of the accident, there was no ANR headset available in the crashed helicopter.

Human performance capacity can also be affected by a series of internal factors. The ability to concentrate and focus diminishes with the increase in complexity of the mission and the length of the mission.

1.17 The operator's organisation and management

The operator has long experience of flying in the mountains and held a permit issued by the Swedish Transport Agency's Civil Aviation Department for helicopter operations, according to the rules for commercial aerial work and commercial air transport. The event that SHK is investigating was conducted under the regulatory framework for commercial aerial work by helicopter. The company only flies under VFR[13] and has a seasonal variation in the utilisation of flight capacity.

The company's working methods have been reviewed and a number of interviews conducted. Interviews have thus been held with the pilot, but also with two colleagues who participated in the operation, as well as with representatives from the company's management.

The company has a documented procedure to follow in the event of incidents and accidents. This is described in the operations manual (OM). The application follows the operations manual and it has emerged that both management and the employees felt that this procedure worked well. The pilot felt that he received the support he needed after the accident, both from management and from colleagues. Other employees also consider themselves to have received the support they needed after the incident that occurred.

[13] VFR - Visual Flight Rules.

1.18 Additional information

1.18.1 Training and risk factors in general

The company has an operations manual (OM) and access to a user manual for Bambi Bucket. With regard to flying with the Bambi Bucket, it is described that refresher training shall be conducted every year (OM D 2.1.1). From the interviews, it has emerged that practical refresher training is conducted at the beginning of each season and that the equipment is tested before missions with the Bambi Bucket are to commence. Risks associated with flying with the Bambi Bucket are described in the operations manual (OM A 13.3.1.8.4), see Section 1.18.2. Both the employees and the management believe that there is a good balance between requirements and training, and that the employees receive the training that is necessary.

A good safety culture has been shown to help minimise the risk of accidents. Characteristic of a good safety culture is, among other things, that there is a climate of openness in the organisation. This means that there is an open dialogue between employees and management, that there is a culture which recognises that people sometimes make mistakes and that it is necessary to learn from these in order to avoid serious incidents in the future. This can be achieved through an effective reporting system and an accepting attitude towards operational deviations.

The company has a system for experience feedback, consisting partly of an officially documented system and partly of a tradition of openly discussing incidents and experiences. These discussions often raise risks associated with operations in general. Furthermore, the company has a procedure described in the operations manual for “operational control” (OM A 2.4). This operational control means that the management team has regular meetings to identify risks associated with the operational activities. Before the accident, no special risks associated with flying with Bambi Bucket had been identified at these meetings.

1.18.2 Risk factors during flight with Bambi Bucket as a suspended load

The SEI Industries Bambi Bucket Operations Manual 2011 version F does not state how great an area or length is recommended for being able to fill the container in an accepted manner, only that the water depth is to exceed one metre. The operator's description of flying with the Bambi Bucket during firefighting only mentions that an area of 8-10 m^2 is required at a water depth of one metre or more.

The operator's manual OM part A13.3.1 *“Operations with a suspended load are generally considered to be operations of a high level of risk, but with demands for greater control and management.”*

There is no explicit description of how operations with the Bambi Bucket for watering dust are to be carried out; parts of A13.3.1.8

Firefighting – helicopter are instead applied. There are not really any differences between these two types of mission. There is no further detail as to how the flight is to be performed, and there is no reference to the SEI Industries OM in the operator's manual.

The operator enumerates a number of risk factors in OM A13.3.1.8.4 for flying with the Bambi Bucket, the following being applicable in this case:

- *“Attention to other helicopters”.*
- *“Attention to fuel consumption. There is a risk that the ambition to extinguish quickly entails overly long sessions between refuelling and breaks.”*

OM part A13.3.1.8.2 *“After emptying, normal cruising speed may be maintained. The container follows without any tendency to swing, even when slowing and descending to refill”.*

The container used in this flight did not meet the above description in all respects, but had a tendency to swing. This was probably due to the design, which meant that there was a stiffener reinforced with fibreglass in the container rim. Later designs are different, see Section 1.16.2.

The Bambi Bucket user manual and the company's operations manual describe how the lifting speed can be used as a technique to influence filling. A high lifting speed (the pilot pulls the collective lever) results in maximum filling, and a low speed results in the achievement of a minimum degree of filling. The risks with this technique are not discussed further in terms of narrower time margins in which to detect if something had become caught in the helicopter. Furthermore, the user manual for the Bambi Bucket states that when filling with water, there is a risk that the cables slacken and can become caught in such things as skids and skid shoes, see Section 1.6.2.

The pilots who were interviewed pointed out that the Bambi Bucket can be filled to the maximum even with a temporally slower sequence and that several other factors affect the filling process in addition to how quickly the pilot raises the collective lever. From a safety point of view, it was pointed out that in most cases a slower filling gives better control of the water container's filling process.

1.18.3 Bambi Bucket used in the incident

The Bambi Bucket used in bombing water from the helicopter was of the model 9011 with serial number 200. Total mass including sack and water was 439 kg. The model is intended for helicopter model 206B, but can also be used by model 206L-3. The load from the rubber sack is taken up by eight cables. One of the cables had a marked radius, see Figure 6.

1.19 Useful or effective investigation techniques

Not applicable.

2. ANALYSIS

2.1 Technical analysis

In light of the damage visible on the rear mount of the left skid shoe, the cable, the landing gear skid and the left skid shoe, SHK feels it is clear that during the final lift of the Bambi Bucket, a cable was hanging over the left landing gear skid and skid shoe.

SHK has found that the mast's dominant mode of failure was overloading through torsion (twisting). The cracks sloping at 45° on the mast's periphery indicate the mode of failure. The bent part arose when the rotor disc came in contact with the tarn's water surface. The failure of the mast did not initiate the crash. Other damage to the helicopter also arose as a result of the accident.

2.2 The flight

During the approach over the forest edge, the forward speed was reduced at the same time as the altitude was decreased. The distance from the forest edge to the point where the container was to be filled with water was no more than 15 metres. A minor error in this part of the flight may have created a need to correct the flight path and a risk of the container thus beginning to swing.

During the vertical descent prior to filling, which involved no forward speed, the Bambi Bucket may have been swinging somewhat due to the downwash from the main rotor prior to being filled with water. It is therefore likely that the cables to the helicopter's Bambi Bucket slackened slightly when the container was still floating. In this position, a cable probably went around the rear part of the left landing gear skid and skid shoe.

The available water area with a depth of more than one metre was small, but fulfilled the requirements of 8-10m² in accordance with OM. The pilot's attention was presumably focused on the positioning of the helicopter during the filling of the container with water. It is probable that the ability to clearly see the position of the Bambi Bucket was further reduced due to the sun's position with sun reflections and shadows. The cable hanging over the skid was thus difficult to detect.

When lifting into the hover after filling, the quantity of water in the container increases if the lift takes place quickly due to the container flexing outwards somewhat in the rim. The risk of getting into an uncontrollable situation increases with this means of maximising the load. This may have also contributed to the pilot missing the fact that a cable had become hooked over the skid.

With a cable from the container hanging around the left rear landing gear skid and skid shoe, the rolling moment increased markedly to the left, and the helicopter went into a “Dynamic rollover” with a high nose when the pilot raised the collective lever. Once the helicopter had gone into rotation with increasing mass forces at the same time as the laterally directed lift increased, the authority of the control system was not sufficient to correct the movement. The helicopter rotated at a high speed of rotation around the longitudinal and lateral axes before it came down into the tarn. The centre of gravity when lifting into the hover came to be far outside the limitations for which the helicopter was designed.

The operator's technical control flight with Bambi Bucket suspended on one of the lines gave a clear feedback to the pilot in terms of attitude and roll information that the water container was not hanging by the cargo hook as was normal during flying. This circumstance suggests that the cable was not hanging around the landing gear skid and skid shoe prior to the final filling of the Bambi Bucket.

2.3 The helicopter's landing gear design

The helicopter was equipped with landing gear of a higher model with skid shoes of standard design. The rear part of the landing gear was straight, which made it possible for lines and cables to become caught. The mounted skid shoe had unsuitably designed mounting elements and bending radii.

2.4 The pilot's work environment and working day

The ability to concentrate diminishes with the increase in complexity of the mission and the length of the mission. The fact that a mission is lengthy and repetitive may result in a lack of focus.

The investigation has shown that the pilot had had a pause with a food break about an hour before the accident. Both the pilot's duty time and the distribution of pauses and breaks for food remained within the limits of the company's operations manual. Moreover, the pilots who have been interviewed reported that they experience water bombing operations as worthwhile jobs that are not especially taxing. It is therefore SHK's assessment that the circumstance of the pilot flying many short runs to perform the task had not had any significant effect on the sequence of events. The margins for error can be considered to have been small.

2.5 The company's safety culture

The interviews have revealed that there is open and clear communication between employees and management and between the employees themselves. The employees feel that the management is open to discussing safety, that it takes safety seriously and that it takes appropriate measures when there is potential for improvement. There is mutual trust between management and employees.

Furthermore, the employees feel the management is concerned about their health and that speaking up is always accepted and expected when something that may have an adverse effect on safety is discovered. This is the case even if the employees for some reason feel that they are not in a position to perform a planned flight safely. Both management and employees believe that they are all well trained for their positions with respect to the operations they carry out and that there is a mutual responsibility for safety. In summary, SHK's assessment is that there is a good safety culture within the company.

The company has a system for experience feedback, which functions well, consisting partly of an officially documented system and partly of a tradition of openly discussing incidents and experiences. These discussions often raise risks associated with operations in general. Furthermore, the company has a procedure described in its OM for "Operational control", which means that the management team identifies risks associated with the operational activities. Before the incident, no special risks associated with flying with Bambi Bucket had been identified at these meetings.

After the incident, the company's internal investigation drew attention to risks of flying with Bambi Bucket, and from 15 November 2011 this is described in the documented "Operational control" (OM A2.4). The existing operational instructions and procedures are assessed to function, but they will be supplemented by a clarification of the risks related to the use of water containers, and greater focus will also be placed on this in connection with the training of pilots.

2.6 The rescue operation

SHK has found that the operation by the rescue services functioned according to the areas of responsibility and procedures applicable for this operation.

3. CONCLUSIONS

3.1 Findings

a) The pilot was qualified to perform the flight.
b) The helicopter had a Certificate of Airworthiness and valid ARC
c) The technical investigation shows that the rotor mast was overloaded when the rotor disc came in contact with the water in the tarn.
d) The pilot followed the operator's applicable provisions, apart from the requirement to wear a helmet.
e) The water container was not stabilised in relation to the helicopter at all stages of the filling process.
f) The design and parts of the landing gear were unsuitable for this type of suspended load.
g) A cable from the water container became caught over the left rear landing gear skid.

h) The centre of gravity with the cable over the skid initiated a "Dynamic rollover" in the helicopter.
i) The pilot sustained minor injuries and was able to exit the wreckage unassisted.

3.2 Causes

The accident was caused by:

- the position of the water container not being ascertained prior to lifting.
- the sun's position with sun reflections and shadows affecting the pilot's ability to monitor the filling process in the rear-view mirror.
- the design of the landing gear, with its parts, making it possible for a cable to the water container to become caught over the skid during filling.

SHK believes that one factor which contributed to the incident was that the chosen area of water had tall trees in the direction of approach and that the available area placed great demands on the pilot's flying when filling the Bambi Bucket.

4. RECOMMENDATIONS

The Swedish Transport Agency is recommended to ensure that:

- operators have established operational limitations, which take into consideration risks entailed by the helicopter's design during operations with a suspended load. *(RL 2014:02 R1).*

EASA is recommended to ensure that:

- EASA Member States in their supervision check that operators have established operational limitations, which take into consideration risks entailed by the helicopter's design during operations with a suspended load. (*RL 2014:02 R2*).

The Swedish Accident Investigation Authority respectfully requests to receive, by 17 maj 2014 at the latest, information regarding measures taken in response to the recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Jonas Bäckstrand Agne Widholm