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Swiss Transportation Safety Investigation Board STSB

Final Report No. 2320 by the Swiss Transportation Safety Investigation Board STSB

concerning the accident involving the Bell 206B helicopter HB-XSL

on 9th June 2016

400 m north-west of Heimenegg, municipality of Buchholterberg in the canton of Bern

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General information on this report

This report contains the Swiss Transportation Safety Investigation Board's (STSB) conclusions on the circumstances around and causes of the accident under investigation.

In accordance with article 3.1 of the 10th edition of annex 13, effective from 18th November 2010, on the Convention on International Civil Aviation of 7th December 1944 and article 24 of the Federal Aviation Act, the sole purpose of an investigation into an aircraft accident or serious incident is to prevent further accidents or serious incidents from occurring. Legal assessment of the circumstances and causes of aircraft accidents and serious incidents is expressly excluded from the aircraft accident investigation. It is therefore not the purpose of this report to establish blame or to determine liability.

Should this report be used for purposes other than those of accident prevention, this statement should be given due consideration.

The German version of this report constitutes the original and is therefore definitive.

Unless otherwise indicated, all information relates to the time of the accident.

Unless otherwise indicated, all of the times mentioned in this report are given in local time (LT). For the region of Switzerland, Central European Summer Time (CEST) was the local time at the time of the accident. The relationship between LT, CEST and coordinated universal time (UTC) is:
LT = CEST = UTC + 2 h

Final Report

Aircraft type	Bell 206B 'Jet Ranger II'	HB-XSL
Operator	Helitrans AG, Post Box, 4030 Basel	
Owner	Helitrans AG, Post Box, 4030 Basel	

Flight instructor acting as expert	Swiss citizen, born 1969			
Licence	European Aviation Safety Agency (EASA) commercial pilot licence helicopter (CPL(H)), issued by the Federal Office of Civil Aviation (FOCA)			
Flying hours	**Total**	7,613 h	**During the last 90 days**	146:17 h
	On the accident type	1,600 h	**During the last 90 days**	1:26 h

Pilot / examination candidate	Swiss citizen, born 1953			
Licence	EASA private pilot licence helicopter (PPL(H)), issued by FOCA			
Flying hours	**Total**	548 h	**During the last 90 days**	4 h
	On the accident type	477 h	**During the last 90 days**	4 h

Location	400 m north-west of Heimenegg, municipality of Buchholterberg in the canton of Bern		
Coordinates	620 188 / 185 201	**Altitude**	942 m AMSL[1]
Date and time	9th June 2016, 16:10		

Type of operation	Visual flight rules (VFR), private
Flight phase	Approach
Type of accident	Engine failure during an autorotation exercise

[1] AMSL: above mean sea level

Injuries to persons

Injuries	Crew members	Passengers	Total no. of occupants	Third parties
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	0	0	0	0
None	2	0	2	n/a
Total	2	0	2	0

Damage to aircraft Severely damaged engine, damaged left engine cowling, slight deformation of the landing skids

Third-party damage Slight damage to the ground

1 Factual information

1.1 Background and history of the flight

1.1.1 General

The following description of the background and history of the flight is based on the pilot's statements and statements from the expert appointed by the Federal Office of Civil Aviation (FOCA).

The flight was an annual proficiency check for the pilot with a view to extending his type rating on the helicopter type Bell 206B, with the expert acting as an examiner. To this end, dual controls had been fitted in the helicopter.

1.1.2 Background

The pilot arrived at the premises of the company Helitrans at Basel Mulhouse Airport (LFSB) at around 12:00 on 9th June 2016. Together with a flight instructor, he intended to fly the Bell 206B helicopter, registered as HB-XSL, to Bern Belp Airport (LSZB) in order to complete the proficiency check there. Together with the flight instructor, the pilot refuelled the helicopter and carried out pre-flight checks, during which nothing unusual was found. Subsequently, they completed preparations for the flight. This included obtaining weather information, consulting the notice to airmen (NOTAM) and the daily airspace bulletin for Switzerland (DABS) as well as calculating the mass and the centre of gravity.

At 14:12, the crew took off from Basel Airport in HB-XSL and flew in the direction of Bern, landing at Bern Belp Airport at 14:52.

On the ground, the expert welcomed the pilot and completed the flight preparations and the briefing for the planned proficiency check with him. Subsequently, the expert and the pilot proceeded to the helicopter and climbed aboard. The pilot sat down on the right-hand seat and the expert took the left-hand seat. Meanwhile, the flight instructor, who had carried out the flight from Basel with the pilot, was waiting on the airport site.

1.1.3 History of the flight

At 15:50, the crew took off from Bern Belp Airport in the Bell 206B 'Jet Ranger II' helicopter, registered as HB-XSL, and flew in the direction of Konolfingen via reporting point Hotel Echo (HE). On the instructions of the expert, the pilot then carried out various flight manoeuvres and performed an off-airport landing and several slope landings in the Homberg-Buchen region. Following this, an autorotation exercise to a large piece of meadowland in the Heimenschwand region was planned (see illustration 1), where the pilot first carried out reconnaissance of the landing site. Afterwards, he commenced the autorotation at an altitude of around 4,500 ft AMSL, i.e. approximately 1,500 ft above ground, and continued on to the power recovery procedure, from which the helicopter would normally be set down on the ground. As the flare and the subsequent hover were carried out slightly higher than the desired altitude, the expert requested that the autorotation exercise be repeated. The pilot climbed to the starting altitude of 4,500 ft AMSL in HB-XSL once again and commenced the second autorotation to the same landing site. A few metres above the ground, the pilot increased the pitch of the helicopter by pulling back on the cyclic blade control whilst raising the collective blade control slightly in order to reduce the vertical and horizontal speed. During this phase and even before the expert increased the power once more using the twist-grip throttle, the crew suddenly perceived a loud noise. At virtually the same time, the ENG OUT (engine out) warning light illuminated and the associated acoustic warning sound rang out. At this time, the helicopter was still a few metres above the ground. The expert assumed control of the helicopter without hesitation, restored it to a horizontal flight attitude and landed HB-XSL in the meadowland's long grass.

Immediately after the landing, the crew noted an increase in the turbine outlet temperature (TOT) on the corresponding indicator instrument. The crew immediately switched off the automatic emergency location transmitter (ELT) activated by the impact of the helicopter. Subsequently, they actuated the circuit breakers (CBs) for the two fuel boost pumps as well as the caution lights and switched off the battery master switch. Then the expert opened the left-hand cabin door and, with a look towards the rear of the aircraft, made sure that the helicopter had not caught fire. Apart from a small amount of smoke emanating from the engine area, nothing could be identified. Once the main rotor had come to a standstill, the crew left the helicopter having not sustained any injuries. The expert shut off the fuel valve, disconnected the plug for the electrical system from the battery and then opened the engine cowling, where he ascertained damage to the engine.

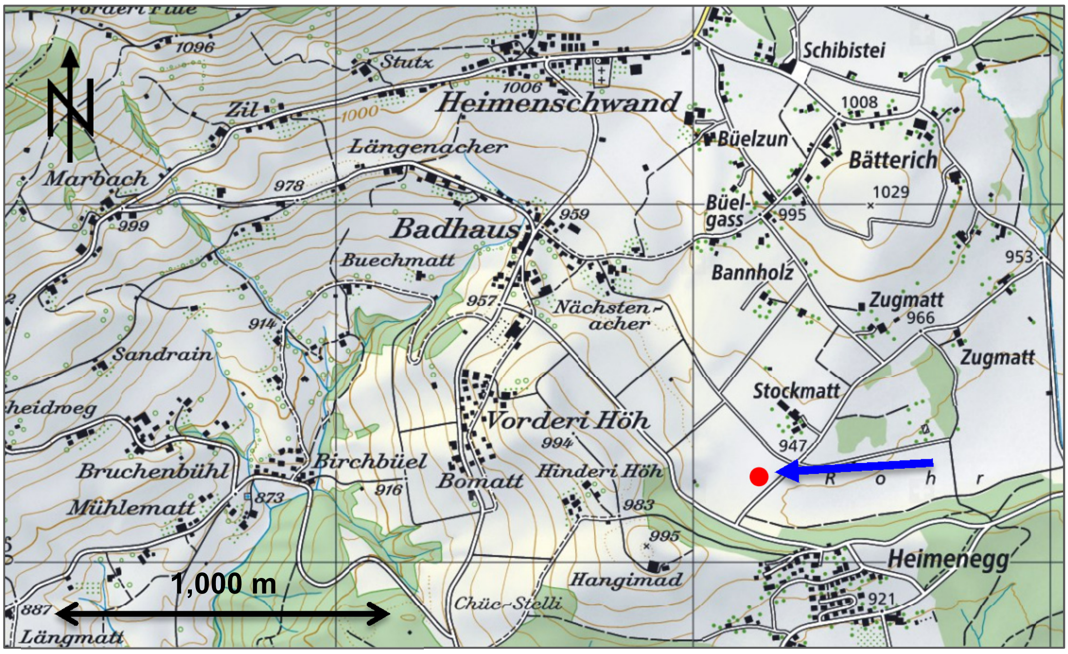

Illustration 1: Touchdown point of the helicopter HB-XSL north-west of Heimenegg in the canton of Bern following the engine failure (red dot). The blue arrow indicates the approximate direction of the final approach during the autorotation exercise. Source of base map: Federal Office of Topography.

1.2 Meteorological information

1.2.1 General weather conditions

Switzerland was situated between an area of high pressure over the British Isles and an area of low pressure over Corsica and Italy.

1.2.2 Weather at the time and location of the accident

The weather was dry. Visibility was more than 10 km. The cloud from the north-west was breaking up. A light north-easterly wind was blowing in the Swiss Central Plateau. The local wind close to the ground was light and was primarily blowing from the south.

Weather/clouds	3/8-4/8 at 5,300 ft AMSL
Visibility	10 km or more
Wind on the ground	Variable, 2 kt

Temperature / dew point	16°C / 10°C
Atmospheric pressure (QNH)	1,017 hPa
Hazards	None

1.2.3 Astronomical information

Light conditions	Daytime	
Position of the sun	Azimuth 248 degrees	Elevation 50 degrees

1.3 Information on landing site and damage to the helicopter

1.3.1 Landing site

The touchdown point for the helicopter HB-XSL was next to a road in a large piece of meadowland (see illustration 1 and illustration 2). The terrain in this area is relatively flat and was covered with long grass at the time of the accident. There was a wood around 150 m away from the touchdown point in the direction of the flight.

Illustration 2: The helicopter HB-XSL having landed in the long grass; the people behind the helicopter in the photo were on the road.

The marks in the grass indicated that the helicopter had touched down without any forward speed. The tail skid did not touch the ground.

1.3.2 Damage to the helicopter

Several punctures were evident in the left engine cowling of HB-XSL level with the turbine, which were the result of turbine components being ejected. The underside of one of the main rotor blades had also been damaged by turbine components which had been catapulted out. The landing skids were deformed slightly. No other damage to the outer airframe of the helicopter was evident.

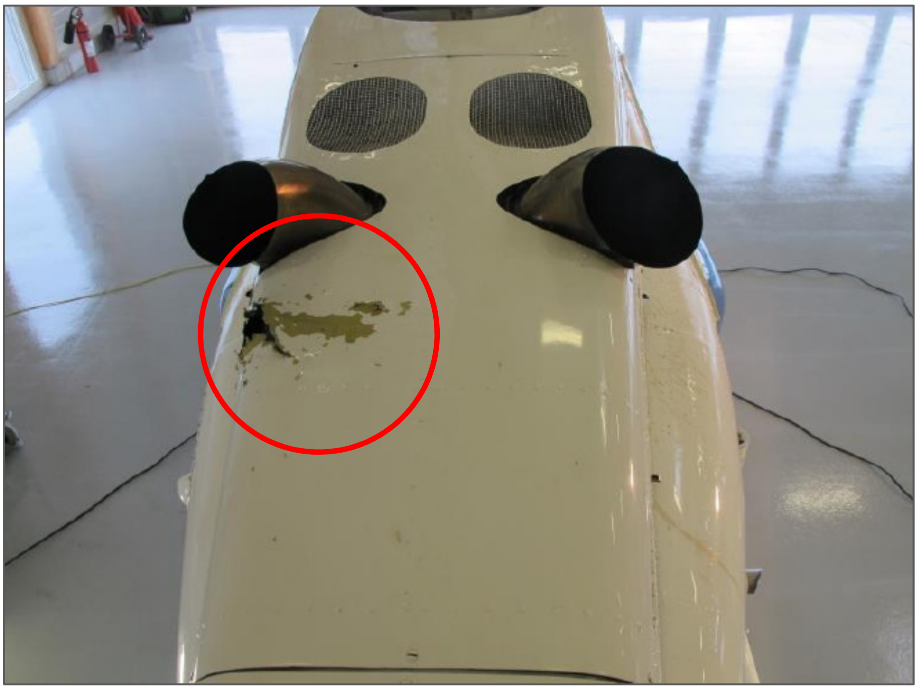

Illustration 3: View of the airframe of HB-XSL in the area of the engine looking in the direction of flight; the punctures are evident in the left engine cowling (red circle).

1.4 Information on the aircraft

1.4.1 General

Registration	HB-XSL
Aircraft type	Bell 206B 'Jet Ranger II'
Characteristics	Single-engine multipurpose helicopter with five seats and a semi-rigid two-blade main rotor system, conventional torque balancing with an exposed tail rotor and low landing skids[2]
Manufacturer	Bell Helicopter Textron Inc., Canada
Year of manufacture	1974
Operator and owner	Helitrans AG, Post Box, 4030 Basel
Engine	Manufacturer: Rolls-Royce Type: Allison M250-C20 Serial no: CAE 822060
Operating hours	Airframe: 8,238 h TSN[3] Engine: 8,238 h TSN
Max. permissible mass	3,200 lb
Mass and centre of gravity	On take-off at Bern Belp, the mass of the helicopter was around 2,716 lb.

[2] This helicopter type can be fitted with either low or high landing skids.

[3] TSN: time since new

	Both the mass and the centre of gravity were within the permissible limits of the flight manual (FM).
Technical restrictions	There were no outstanding issues recorded in the technical log.
Quality of the engine oil	The engine oil conformed to the specifications of Mobile Jet Oil 254.

1.4.2 Maintenance

1.4.2.1 General

The last piece of maintenance work on the helicopter HB-XSL was certified on 1st June 2016 at 8,226:42 operating hours with the entry "*100 hrs / 6-month insp. skid tube*". No work report is available for this. The last inspection of the airframe and the engine was certified on 24th November 2015 at 8,195:40 operating hours with the entry "*100 hrs / 300 hrs / 600 hrs / 12 month / 24 month airframe, 100 hrs / 300 hrs / 500 hrs / 12-month engine insp. i.a.w.*" A corresponding work report is available for this.

1.4.2.2 Engine maintenance

The Allison M250-C20 engine was installed in the newly built Bell 206B helicopter in 1974 and had reached 8,238 operating hours by the time of the accident. The last piece of certified maintenance work on the engine took place on 24th November 2015 at 8,195:40 operating hours. This was a 100-hour / 300-hour / 500-hour / annual inspection. Between this inspection and the accident, HB-XSL had flown for around 42 hours.

The last overhaul of the turbine module was carried out at 6,938:48 engine operating hours and was certified on 12th June 2002 with the entry "*Turbine Mod O/H inst.*"

Cleaning of the compressor was certified in the job sheet dated 24th November 2015. The compressor inlet was very dirty at the time of the accident. Between the compressor being cleaned and the accident, the helicopter had been in operation for around 42 hours. As a fundamental principle, the manufacturer prescribes such cleaning every 100 operating hours and at shorter intervals when operated in saline air such as that in coastal area.

1.4.3 Airworthiness directives

1.4.3.1 General

Airworthiness directives (ADs) are publications from the responsible aviation authorities concerning the airworthiness and maintenance of aircraft and aircraft parts. ADs contain measures which must be taken within a specified timeframe in order to ensure airworthiness and are addressed to the operators of the aircraft concerned and the organisations responsible for their maintenance.

Since 1st January 2009, operators have been obliged to obtain information on new ADs for aircraft and aircraft parts actively and regularly.

1.4.3.2 Energy-absorbing ring

The AD HB-2005-259 which entered into force on 30th June 2005 was published by the Federal Office of Civil Aviation (FOCA). This AD is based on Airworthiness

Directive No. 2005-10-13, issued by the US Federal Aviation Authority (FAA), and was applicable to the engine installed in HB-XSL.

The AD was introduced due to cases of uncontained engine failure, that is to say parts being ejected from the engine as a result of the first-stage turbine wheel rupturing. In accordance with the AD, an energy-absorbing ring is installed around the first-stage turbine wheel, thus reducing the risk of debris being ejected which could damage the airframe and subsequently lead to a loss of control over the aircraft. Equally, third parties are protected from the danger posed by any parts that are catapulted out.

In the AD, the engine manufacturer prescribes that the protective ring must be installed the next time the turbine is removed, but after a maximum of 1,750 hours since manufacture, the last overhaul, the last round of heavy maintenance or the last inspection of the hot section, which comprises the combustion chamber, turbine and exhaust system, and no later than 31st October 2011.

The AD HB-2005-259 was entered in the technical files in the Record of Airworthiness Directives by the maintenance company responsible for HB-XSL at the time (see annex 1). "*31st Oct. 11, next O/H*[4]" was recorded as the compliance interval. Under the heading 'accomplished on/by', the entry read "*25/08/05*" and was accompanied by a company stamp and signature.

From October 2011 until the time of the accident, HB-XSL was maintained by a different maintenance company. At the handover of the helicopter, the existing list of ADs was transferred to a specially created Excel spreadsheet with the title 'AD Engine BAZL, FAA, EASA' (see annex 2). The following note was added to this spreadsheet next to the relevant AD: "*Extension until next PT*[5] *down by Rolls-Royce*".

By the time of the accident, this AD had not been implemented.

1.4.4 Engine

The Bell 206B helicopter is fitted with a two-shaft Allison M250-C20 engine. The engine consists of an axial compressor with a radial final stage as well as a two-stage free power turbine (FPT) and a two-stage gas producer turbine (GPT, see illustration 4). The GPT drives the compressor as well as a part of the accessory gearbox. The FPT drives the gearbox assembly and also a part of the accessory gearbox.

[4] O/H: overhaul

[5] PT: power turbine

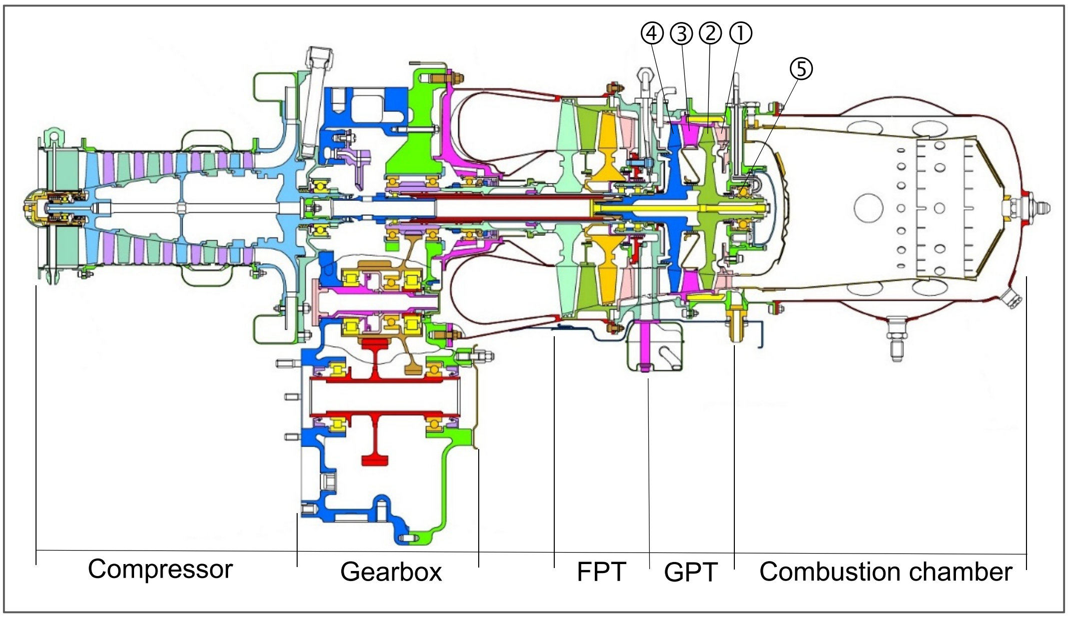

Illustration 4: Cross-sectional view of an Allison M250-C20 engine: ① GPT first-stage turbine nozzles ② first-stage turbine wheel, ③ second-stage turbine nozzles, ④ second-stage turbine wheel and ⑤ no. 8 GPT bearing. Illustration from the manufacturer, adapted by the STSB.

The speed of a turbine is regulated by the flow of fuel in relation to speed, temperature and air pressure. This results in a higher or lower turbine outlet temperature (TOT). In standard operation, the fuel control unit (FCU) performs this regulatory function in conjunction with the power turbine governor (PTG). During the start-up process, the pilot uses the twist-grip throttle to control the flow of fuel on the basis of the TOT indicator. The TOT limits are exceeded most often during the start-up process.

1.4.5 Recording devices

HB-XSL was not equipped with a data recorder which records the parameters of the helicopter's technical systems. This was not a requirement.

A digital map display was not being carried along, nor did the helicopter have a collision warning device installed.

1.4.6 Indicators and warnings

HB-XSL was fitted with an indicator instrument for the TOT (see illustration 5) with an integrated red warning light which permanently illuminates once the permissible TOT of 793°C has been exceeded for longer than 10 seconds or a TOT of 927°C has been exceeded for longer than 1.5 seconds. The warning light can be reset using a key-operated switch. As long as the circuit has not been reset, the warning light illuminates as soon as the on-board electrical system is switched on. According to the maintenance company responsible, they did not have such a key. It was not possible to establish who did have such a key.

According to the technical files on HB-XSL, the maximum permissible TOT had never been exceeded before the accident flight.

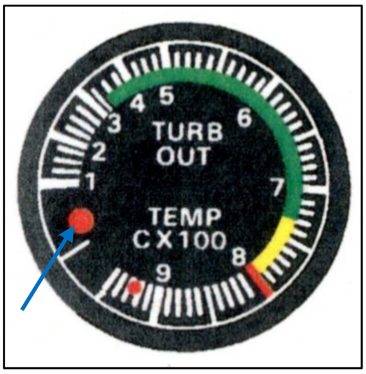

Illustration 5: The TOT indicator instrument installed in HB-XSL includes a red warning light (blue arrow) on the left-hand side, which permanently lights up once the respective limit has been exceeded.

According to the manufacturer, in the event that the TOT of 999°C is exceeded during the start-up or shut-down process, which corresponds to the maximum value on the TOT indicator, or 927°C during power transient, the engine must be removed from the helicopter and overhauled.

After the accident, the TOT indicator instrument and its cables leading to the four temperature sensors in the engine were inspected in accordance with the procedure prescribed in the maintenance manual. The instrument showed the correct temperatures.

1.5 Examination of the engine

1.5.1 Initial findings

The engine mount was undamaged and the engine was correctly fitted to the helicopter airframe. The connecting rods for the power turbine governor (PTG) and the fuel control unit (FCU) showed no signs of damage and were correctly installed. The twist-grip throttle, which had been turned to the idle position, was correctly adjusted to the PTG and the FCU. The bleed valve had opened correctly and all air, fuel and oil line connections were attached securely.

Part of the gas generator turbine support had been torn open, exposing part of the damaged first-stage turbine wheel (see illustration 6).

The cables for the four TOT sensors were cut through in two places, as was the oil supply line to the no. 8 rear bearing sump.

In the left-hand discharge tube, punctures were evident level with the first-stage turbine wheel which were caused by metal parts that had been ejected. The discharge tube was dislodged from the outer combustion case (OCC) and the snap ring was loose on the tube.

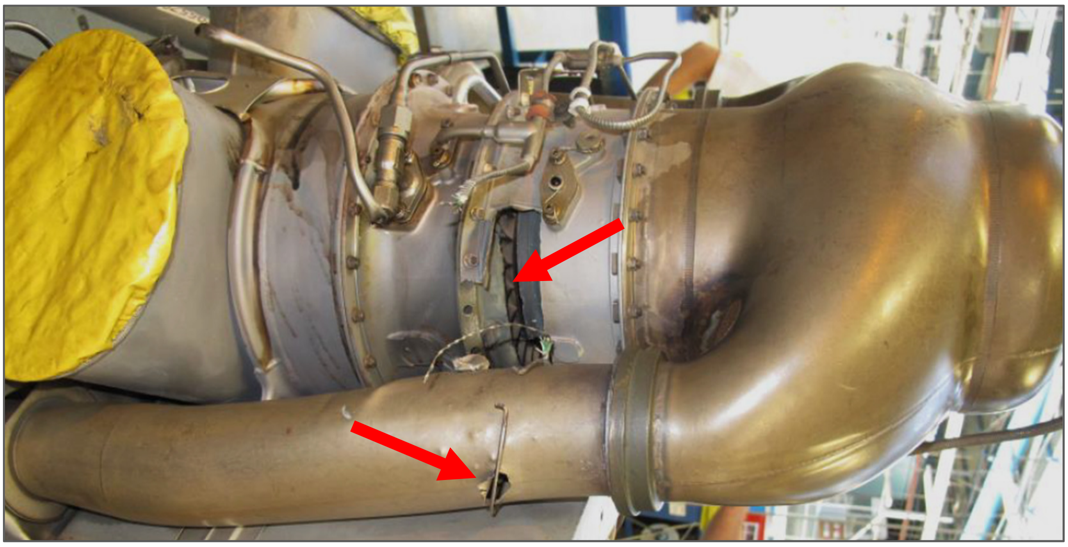

Illustration 6: Removed engine of HB-XSL with destroyed turbine module and damaged discharge tube (red arrows)

No contaminants could be found in the return flow filter for the engine oil. As intended for this operating status, the bypass valve was closed.

When the battery master switch was switched on, the warning light illuminated due to an excessively high TOT (see section 1.4.6).

1.5.2 In-depth examination

1.5.2.1 Compressor

- The compressor inlet was very dirty, but exhibited no foreign-object damage (FOD).
- The exterior appearance of the compressor module showed no abnormalities.
- Following the disassembly of the blocked turbine, the compressor wheel could turn freely.
- After the compressor had been partially disassembled, it exhibited no signs of damage.
- The gear train for the starter generator was connected fully and correctly.

1.5.2.2 Turbine

- The temperature sensors were undamaged and had taken on a dark colour.
- The couplings between the free power turbine (FPT) and the drive gear as well as between the gas producer turbine (GPT) and compressor were intact.
- The bearings rotated smoothly; the no. 8 bearing was fractured.
- The turbine tie bolt was fractured into three pieces and its aft end had pierced the sump cover of the no. 8 bearing.
- A free flow was guaranteed for all engine oil lines.
- A relatively large segment of the first-stage turbine wheel had broken off and was no longer present on the wheel (see illustration 7).
- All of the airfoils on this turbine wheel were largely broken off and the gas outlet side exhibited noticeable dark discolouration.

Illustration 7: Gas outlet side of the first-stage turbine wheel

- The first and second-stage turbine nozzles (see illustration 8 and illustration 9) had been severely damaged by the debris from the ruptured first-stage turbine wheel.

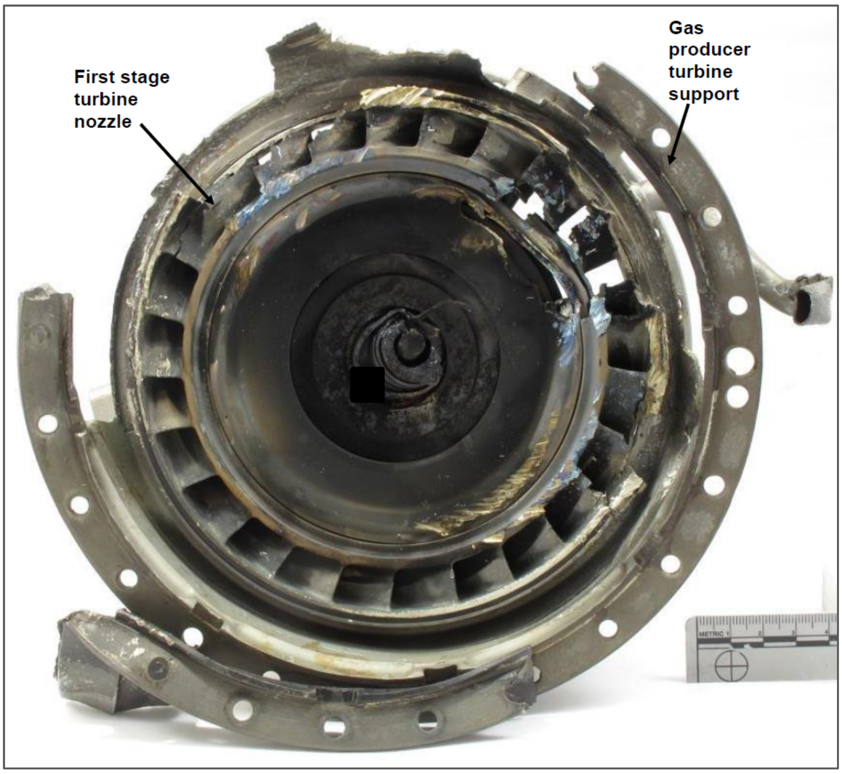

Illustration 8: Gas inlet side of the first-stage turbine nozzles with gas producer turbine support

Illustration 9: Gas inlet side of the second-stage turbine nozzles

- Damage of various types and degrees from mechanical impacts was evident on the airfoils of the second-stage turbine wheel as well as the third- and fourth-stage turbine wheels and turbine nozzles.
- No energy-absorbing ring was installed around the first stage of the turbine (see section 1.4.3).

1.5.2.3 Combustion chamber

The combustion chamber had a normal appearance.

1.5.2.4 Reduction gearbox

- Externally, absolutely no damage could be found on the gearbox module.
- The upper and lower magnetic chip detector plugs in the gearbox were clean and free from metal particles.
- The gear train turned freely and was fully connected to the accessories and the power output drive gear.

1.5.2.5 Fuel system

The fuel control unit (FCU) was examined on a test bench. During this examination, it was established that several values were outside of the stipulated limits. However, these deviations were minor and did not have a causal link to the rupture of the turbine wheel.

The fuel nozzle tested was in compliance with the specifications concerning the flow rate in relation to the pressure. Streaks of different fuel quantities could be found at all test points. However, this had no influence on the failure of the turbine.

1.5.3 Metallurgical examination

The first-stage turbine wheel and the non-rotating second-stage turbine nozzle ring were examined thoroughly in a laboratory. The findings were as follows:

- One segment of the turbine wheel, consisting of wheel rim, web and 13 airfoils, was torn off the wheel. The crack began as the result of thermal fatigue on the wheel rim and spread radially inwards as an interdendritic fracture[6]. This damage was the cause of the subsequent, segment-like overload fracture of the wheel. The damage to the fracture surface on the opposite side to where the fracture originated was consequential damage. The stub shaft fractured due to the overload of the turbine wheel, with all of the airfoils on the wheel breaking off in the process.
- Examination of the damaged turbine wheel rim using the fluorescent penetration testing method revealed cracks in a further four places on the outside of the wheel rim extending over the gas inlet and gas outlet sides.
- The microstructure of the first-stage turbine wheel showed re-solutioning of gamma prime crystals[7] and re-precipitation of fine gamma prime crystals found at the tip as well as on the trailing edge of the two largest airfoil oddments remaining on the turbine wheel. Therefore, it can be concluded that the airfoils had been subjected to temperatures of over 1,150°C on at least one occasion.
- The second-stage turbine nozzle ring, consisting of the inner- and outer-vane band, the diaphragm and the airfoils, was severely damaged due to the failure of the first-stage turbine wheel. On the turbine nozzle ring, transverse cracks were also discovered on the leading edge of two adjacent airfoils. One crack extended approx. 0.85 cm transversely through the airfoil, with the other, radial crack running around 1.42 cm from the transverse crack inwards through the inner-vane band and into the diaphragm. The airfoil exhibited an overload fracture due to tensile stress and the outer part of the inner-vane band showed a heavily oxidised surface with interdendritic features. The radial crack, which resulted from fatigue, ran inwards through the inner-vane band into the diaphragm and effected an overload fracture.
- The composition of the material in the first-stage turbine wheel and the second-stage turbine nozzle ring was in compliance with the specifications.
- The damage to the other components assessed resulted from the failure of the first-stage turbine wheel.
- The area of the fatigue fracture in the turbine wheel exhibited alloy depletion and corrosion of the fracture surface.

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[6] An interdentritic fracture is a ramified fracture along the crystalline structure.

[7] Gamma prime crystals are formed through a clearly defined heat treatment and, above all, increase the strength and creep behaviour of a material at high temperatures.

2 Analysis

2.1 Technical aspects

2.1.1 Data recording devices

As the helicopter was not equipped with an engine data recorder, no information relating to this was available for the investigation. As a result, no information regarding the operation of the engine could be provided.

The investigation of this accident showed how valuable such data recordings can be for the operation and maintenance of an aircraft. Amongst other things, regular evaluation of the data would show where limits have been exceeded, as with the turbine outlet temperature in the present case, and the maintenance work necessary to address this could be carried out in a timely manner.

2.1.2 Turbine

2.1.2.1 General

During operation, turbine wheels in gas turbines are subjected to very high mechanical and thermal loads and must withstand these cyclical thermal and mechanical loads at high operating temperatures. The turbine wheel subjected to the greatest thermal load is the first-stage turbine wheel.

As a rule, turbine wheels in gas turbines are made from high-performance alloys which can cope with such high loads. The properties of high-performance alloys are not only based on the chemical composition of the material but rather, amongst other things, are also achieved through clearly defined heat treatment processes. These heat treatments create the microstructure of the material and thereby its properties such as strength, susceptibility to cracking, fatigue behaviour and many others.

As long as a component does not exceed a certain temperature limit, the microstructure and properties of the material are retained. In the event that this limit is exceeded, the microstructure of the material changes and important properties are lost.

A structural examination allows an assessment of whether this temperature limit has been exceeded for a component on one or multiple occasions whilst in operation. In addition, the micrograph helps to identify the temperatures to which the component was exposed over a given period of time.

2.1.2.2 Metallurgical examinations

The fractured first-stage turbine wheel consists of a nickel-based high-performance alloy. The examination of the material's microstructure showed that the turbine was subjected to a thermal overload at least once some time before the event. From the structural examination, it can be concluded that the outer area and the trailing edges of the airfoils on the first-stage turbine wheel were exposed to a temperature of at least 1,150°C, which was well above the maximum permissible TOT specified by the manufacturer (see section 1.4.6). This excessive temperature changed the material properties and in particular reduced the strength, resulting in the formation of cracks due to thermal fatigue.

In the area where the crack began, the fracture surface was oxidised to a depth of 18 mm from the outside to the inside when viewed in a radial direction. From this oxidation, it can be unequivocally concluded that the crack formed a relatively long time ago and is related to excessive temperature. The depletion of the alloy found at the origin of the crack and re-precipitation of fine gamma prime crystals in the examined structure confirm this conclusion.

The failure of the engine can be attributed to the first-stage turbine wheel breaking apart due to the aforementioned crack formation as a result of previous thermal overload on one or multiple occasions.

The second-stage turbine nozzle ring was severely damaged by parts of the first-stage turbine wheel as it broke apart. The pronounced oxidation damage on the turbine nozzle ring and the fatigue cracks which were found were caused by the excessive temperature that has been verified. The damage to the turbine nozzle ring did not cause the engine failure.

2.2 Human and operational aspects

2.2.1 Crew

The crew were surprised by the sudden engine failure in the final phase of the autorotation. There were no prior indications of a potential engine problem for the crew. The pre-existing defect in the turbine wheel was such that the engine could have failed at any time, also in a less favourable flight phase. It was appropriate for the expert to take control of the helicopter without hesitation.

Both autorotation exercises were carried out from the same initial position and used the same landing point. Consequently, in the second autorotation exercise the crew were already familiar with the phases of the landing approach as well as the other external conditions such as the wind on the ground, which facilitated a safe landing following the engine failure.

The measures taken by the expert after landing were correct and safety-conscious.

2.2.2 Maintenance work

According to the technical files, the cleaning of the compressor was certified at the inspection dated 24th November 2015. Since that time, the helicopter had been in operation for around 42 hours. At the time of the accident, the compressor inlet was very dirty, from which it can be concluded that, in all likelihood, this had not been cleaned at the last inspection.

The investigations showed that the maximum permissible TOT had been exceeded at least once and the red warning light must have permanently illuminated as a result (see section 2.1.2). From the metallurgical examination, it was not possible to determine the times at which the TOT had been exceeded.

There were no entries in the technical files which mentioned the TOT being exceeded or the permanently illuminated warning light being reset using the key-operated switch. The findings of the investigation permit no other explanation than that the permanently illuminated warning light must have been reset using the key-operated switch after the occurrence of the excessively high temperature had been detected. Subsequently, the measures which the manufacturer deems necessary and are prescribed if the TOT has been exceeded have never been implemented.

According to the Airworthiness Directive (AD) HB-2005-259, an energy-absorbing ring had to be fitted around the first-stage turbine wheel. At the time of the accident, no such ring was fitted to the engine of HB-XSL, meaning that the helicopter had not been airworthy since 31st October 2011, which was identified as a factor to risk by the STSB.

In the technical files, the implementation of this AD had been certified and dated 28th May 2005 in the corresponding AD list (see section 1.4.3.2). This entry was incorrect since the implementation date should not have been entered by the maintenance company until after implementation, which the STSB also identified as a factor to risk.

3 Conclusions

3.1 Findings

3.1.1 Crew

- The flight crew were in possession of the required licences for the flight.
- There is no indication of impairment to the flight crew's health during the flight.

3.1.2 History of the flight

- At 15:50, the crew took off in the helicopter HB-XSL and flew in the direction of Konolfingen via reporting point Hotel Echo (HE).
- During the proficiency check, an autorotation exercise above a large piece of meadowland in the Heimenschwand region was planned.
- Before beginning the autorotation exercise, the crew first carried out reconnaissance of the landing site.
- After that, the pilot commenced the autorotation at an altitude of around 4,500 ft AMSL and continued this until the helicopter was brought to a hover above the ground.
- Subsequently, he carried out a second autorotation from the same starting altitude to the same landing site.
- A few metres above the ground, the pilot initiated the flare in order to reduce the vertical and horizontal speed.
- During this phase the crew suddenly perceived a loud noise.
- At virtually the same time, the ENG OUT (engine out) warning light illuminated and the acoustic warning sound rang out.
- The expert assumed control of the helicopter without hesitation and was able to restore it to a horizontal attitude and set it down on the ground.
- Both occupants were unhurt.

3.1.3 Technical aspects

- The helicopter had the required permissions for VFR flights.
- At the time of the accident, both the mass and centre of gravity of the helicopter were found to be within the permissible limits of the aircraft flight manual.
- The turbine module was last overhauled at 6,938:48 operating hours. Its reinstallation in the engine was certified on 12th June 2002.
- The last piece of certified maintenance work on the engine took place on 24th November 2015 at 8,195:40 operating hours.
- The last piece of certified maintenance work on the helicopter was carried out on 1st June 2016 at 8,226:42 operating hours.
- The last cleaning work on the compressor was certified on the job sheet from 24th November 2015. At the time of the accident, the compressor inlet was very dirty following around 42 hours of operation.
- At the time of the serious incident, the helicopter was not airworthy, because the Airworthiness Directive HB-2005-259 (first-stage turbine wheel – turbine-

energy-absorbing ring), which entered into force on 30th June 2005, had not been implemented.

- After the accident, when the battery master switch was switched on, the warning light illuminated due to an excessively high turbine outlet temperature (TOT).
- The first-stage turbine wheel broke apart as a result of thermal overload leading to subsequent fracture formation.
- From the metallurgical examination, it can be unequivocally concluded that the crack formed a relatively long time ago and is related to excessive temperature.
- The engine was severely damaged due to the ruptured first-stage turbine wheel.

3.1.4 General conditions

- Weather conditions had no influence on the accident.

3.2 Causes

The accident, during which the helicopter's engine failed while performing an autorotation exercise, can be attributed to the rupture of the first-stage turbine wheel.

The following factors were identified as root causes to the accident:

- The engine's turbine outlet temperature had been exceeded at an earlier point on at least one occasion.
- The measures deemed necessary by the manufacturer, which are prescribed after the turbine outlet temperature has been exceeded, were not implemented.

The following factors were identified neither as causes nor as having directly contributed, but nevertheless as factors to risk:

- Failure to implement an airworthiness directive;
- In relation to certain safety-related aspects, the entries in the technical files did not correspond to the actual technical condition of the helicopter.

4 Safety recommendations, safety advice and measures taken since the serious incident

4.1 Safety recommendations

None

4.2 Safety advice

None

4.3 Measures taken since the serious incident

None

This final report was approved by the Board of the Swiss Transportation Safety Investigation Board STSB (Art. 10 lit. h of the Ordinance on the Safety Investigation of Transportation Incidents of 17 December 2014.

Bern, 12 December 2017 Swiss Transportation Safety Investigation Board