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Swiss Transportation Safety Investigation Board STSB

Aviation Division

Final Report No. 2275 by the Swiss Transportation Safety Investigation Board STSB

Concerning the accident involving the Bell UH-1H helicopter, registration HB-RXC

on 20 December 2012

Alberli Au, municipality Rüthi/SG

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Ursachen

Der Unfall ist darauf zurückzuführen, dass der Helikopter bei einer Notlandung hart aufsetzte und der Hauptrotor in ein Gartenhaus schlug.

Durch das Versagen zweier Schraubverbindungen am Kreuzkopf sowie der Rückhaltemutter wirkte eine massive Unwucht auf die Heckrotorwelle, was schliesslich zum Aufreissen des Heckrotorgetriebes und zum Ausfall des Heckrotors führte.

Folgender Faktor hat zur Entstehung des Unfalls beigetragen:

- Mangelhafte Instandhaltungsarbeiten am Heckrotor.

Als systemische Faktoren wurden ermittelt:

- Mangelhafte Aufsichtstätigkeit des BAZL.
- Lückenhafter Prozess beim BAZL im Umgang mit historischen Luftfahrzeugen.

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 Annexe 13, effective from 18 November 2010, to the Convention on International Civil Aviation of 7 December 1944 and Article 24 of the Federal Aviation Act, the sole purpose of an aircraft accident or serious incident investigation 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 definitive.

All information, unless otherwise indicated, relates to the time of the accident.

All times in this report, unless otherwise indicated, are stated in local time (LT). At the time of the accident, Central European Time (CET) applied as local time in Switzerland. The relation between LT, CET and Universal Time Coordinated (UTC) is:
LT = CET = UTC + 1 h

Contents

Final Report

Summary

Owner	Private
Operator	Private
Manufacturer	Bell Helicopter Company, Fort Worth, Texas, USA
Aircraft type	Bell UH-1H
Country of registration	Switzerland
Registration	HB-RXC
Location	Alberli Au, municipality Rüthi/SG
Date and time	20 December 2012, 16:20

Investigation

The accident took place at 16:20. The cantonal police in St. Gallen received the notification at 16:23. In collaboration with St. Gallen cantonal police, the former Swiss Accident Investigation Board opened the investigation on the same day. The Swiss Accident Investigation Board informed the National Transportation Safety Board (NTSB) – as the authority of the manufacturing country – of the accident. NTSB appointed an authorised representative to work with the investigation.

The current final report is published by the Swiss Transportation Safety Investigation Board (STSB).

Synopsis

On Thursday 20 December 2012, the pilot intended to fly from Balzers heliport (LSXB) to St. Gallen-Altenrhein airport (LSZR) in the Bell UH-1H helicopter, registered as HB-RXC. Three passengers boarded during a stop in Buchs/SG. After take-off, the pilot flew along the motorway in the direction of St. Gallen-Altenrhein. Directly next to the motorway at the gravel quarry before coming to Rüthi, the occupants noticed very strong vibrations and an abrupt yaw to the right on the helicopter's vertical axis. One passenger heard a bang. The pilot partially lost control of the helicopter during this phase. The pilot therefore decided on an emergency landing. The helicopter made a hard touchdown and the main rotor hit a shed. The helicopter rolled approximately 270 degrees to its left side and came to a standstill lying on its right side. All of the occupants were able to exit the destroyed helicopter by themselves. One passenger was seriously injured as a result of the accident.

Helicopter HB-RXC was registered in the special category of the aircraft register, within the 'historic' subcategory.

Causes

The accident is attributed to the fact that the helicopter made a hard touchdown during the emergency landing and the main rotor hit a shed.

The failure of two bolted connections on the crosshead as well as of the retaining nut, an enormous imbalance affected the tail rotor driveshaft, which ultimately led the tail rotor transmission to burst and the tail rotor to fail.

The following factor contributed to the development of the accident:

- Inadequate maintenance work on the tail rotor.

Determined as systematic factors:

- Inadequate supervisory activity by FOCA.
- Incomplete process at FOCA with regards to dealing with historic aircraft.

Safety recommendations

Two safety recommendations were made within the scope of this investigation.

1 Factual information

1.1 Background and history of the flight

1.1.1 General

The recordings from the navigation device carried on board the helicopter as well as documents and statements from respondents were used for the following description of the background and the history of the flight. Over the course of the investigation, he exhibited passive behaviour on occasions during collaboration. With the assistance of the pilot, the course of the accident was reconstructed in the wreckage, and recorded using video. This information was used for this report.

The pilot was the operator and owner of the helicopter, registered as HB-RXC. The terminology is used analogously in the report.

The flight was carried out according to visual flight rules (VFR). It was a private flight.

1.1.2 Background

1.1.2.1 History

On 13 October 1998, the pilot purchased a Bell UH-1H helicopter in the USA with the American registration N6195G. In November 1998, the company US Helicopter Inc. carried out an annual inspection on this helicopter in the USA, and it was repainted.

On 14 March 2002, helicopter N6195G was imported into Switzerland and based at St. Gallen-Altenrhein airport (LSZR). The operator made an application to the Federal Office of Civil Aviation (FOCA) to register the helicopter in the ‘historic’ category of the Swiss aircraft register. As the helicopter did not fulfil the criteria for approval at this time, the application was rejected. On 30 June 2002, FOCA granted the operator special permission for flights with helicopter N6195G in Swiss airspace under the condition that the helicopter had to be based in Switzerland. The USA type certificate (TC) was applicable for this special permission (see chapter 1.6.2). In addition, the helicopter was only permitted to land at approved airports or heliports in Swiss territory and territory in the principality of Liechtenstein.

1.1.2.2 Swiss registration of the helicopter

In 2009, the operator of the helicopter, registered as N6195G, applied once again to FOCA to register the helicopter in the Swiss aircraft register. The helicopter now fulfilled the requirements. This application was considered by FOCA and was approved on 12 November 2009. The N6195G helicopter was registered as HB-RXC in the special category of the Swiss aircraft register within the ‘historic’ subcategory.

As a result of this registration, the airworthiness of helicopter HB-RXC was approved by FOCA on 13 January 2010 and a certificate of airworthiness was issued.

Upon the operator’s application, the extension for night visual flight rules (NVFR) with the helicopter, registered as HB-RXC, was granted by FOCA on 16 September 2010.

On the grounds that helicopter HB-RXC was a historic aircraft, FOCA replaced the certificate of airworthiness with a permit to fly on 22 December 2010 (see chapter 1.6.1).

Illustration 1: The UH-1H helicopter with the Swiss registration HB-RXC. (Photo provided by the operator).

1.1.3 History of the flight

Following the completion of maintenance work carried out by the company Swiss Helicopter Maintenance AG (SHM) in Balzers (see chapter 1.6.4.2), the pilot planned to fly helicopter HB-RXC from Balzers to St. Gallen-Altenrhein on 20 December 2012. He intended to carry out a stopover in Buchs/SG to pick up a colleague.

At 14:48, the pilot took off with the Bell UH-1H helicopter, registered as HB-RXC, from Balzers heliport (LSXB) and flew in the direction of Buchs. At 15:05, he landed in a field close to the waste incineration plant and switched off the engine. At about 15:45, the pilot rang his colleague and informed him that he had landed.

Two other people, who were known to the pilot, saw the helicopter stationary in the field and went there. The pilot offered to fly both people to St. Gallen-Altenrhein as passengers.

At 16:14, the pilot took off with three passengers on board and flew along the Rhine valley in the direction of St. Gallen-Altenrhein. The flight path was at an altitude of about 3,000 ft AMSL[1] and with a speed of about 80 knots following the course of the motorway.

At the passengers' request, the pilot deviated from the planned route and flew to the right into the principality of Liechtenstein and returned to the original route via Schellenberg. The pilot continued the flight above the motorway.

[1] AMSL: above mean sea level

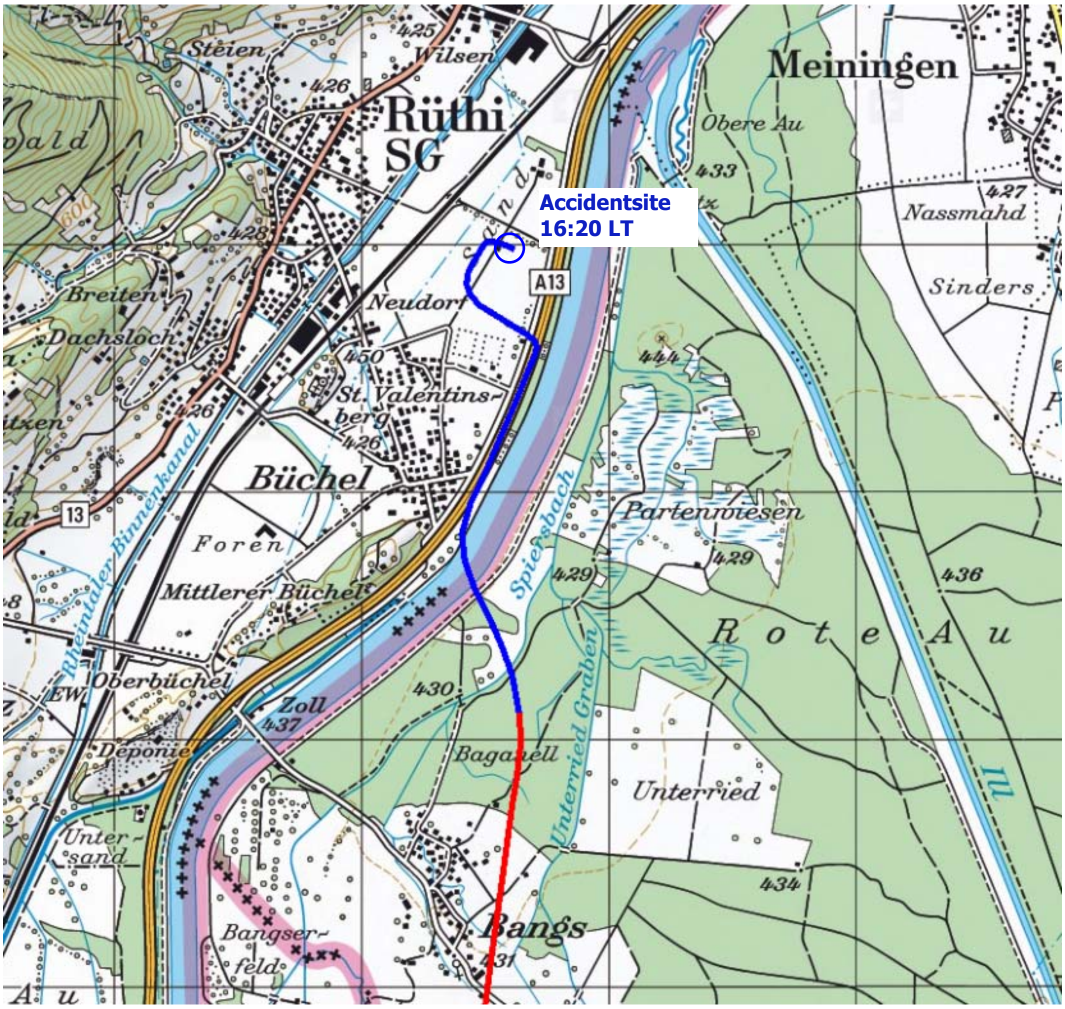


Illustration 2: The flight path of helicopter HB-RXC according to the recordings of the navigation device (red) and the pilot's description (blue). (base map reproduced with authorisation of the Federal Office of Topography, Swisstopo (JA150149)).

Directly next to the motorway at the gravel quarry before coming to Rüthi, the occupants noticed very strong vibrations and an abrupt yaw to the right on the helicopter's vertical axis. One passenger heard a bang. The pilot tried to level the helicopter in the direction of the flight by using the left foot pedal. According to the pilot, he did not perform any other control input at that time. He partially lost control of the helicopter during this phase.

The pilot also stated that he noticed engine overspeed at this time. He stated that the engine speed was far above the limit on the cockpit instrument, which is marked in red. He then reduced the fuel flow using the twist-grip throttle.

Illustration 3: The cockpit instrument displays the rotor speed in the inner circle and the engine (power turbine) speed in the outer circle.

Subsequently, the rotor speed reduced and the pilot noticed the acoustic low RPM warning. The pilot then slightly increased the fuel flow again, and changed the power turbine governor switch (GOV) from automatic into manual mode. He adjusted the engine speed manually from this point onwards. The pilot then navigated helicopter HB-RXC to the left in the direction of Rüthi and decided on an emergency landing. Moments later, he turned right and flew the landing approach roughly parallel to the motorway.

According to the pilot's statement, he was no longer able to notice any vibrations at that time.

As there was a dense row of trees across the approach direction and the distance for the planned approach was not sufficient, the pilot turned the helicopter to the right using the cyclic stick and continued the landing approach parallel to the row of trees. In this phase, the acoustic low RPM warning sounded once again. The helicopter made a hard touchdown and the main rotor hit a shed on the left-hand side. The helicopter rolled approximately 270 degrees to its left side and came to a standstill lying on its right side. After all occupants had exited the helicopter by themselves, the pilot returned to the helicopter and turned off the engine.

One passenger was seriously injured during the accident and had to be taken to hospital.

1.1.4 Time and location of the accident

Accident location	Alberli Au, municipality Rüthi/SG
Date and time	20 December 2012, 16:20
Light conditions	Dusk
Coordinates	759 610 / 239 980 (Swiss grid 1903)
	N 047° 17' 29.03'' / E 009° 32' 56.07'' (WGS 84)
Altitude	426 m AMSL, 1,397 ft AMSL

1.2 Injuries to persons

Injuries	Crew members	Passengers	Total no. of occupants	Third parties
Fatal	0	0	0	0
Serious	0	1	1	0
Minor	0	0	0	0
None	1	2	3	n/a
Total	1	3	4	0

1.3 Damage to aircraft

The helicopter was destroyed.

1.4 Third-party damage

Damage to the ground was sustained and the shed was destroyed.

1.5 Information on people concerned

1.5.1 Pilot

1.5.1.1 General

Person	Swiss citizen, born 1953
Licence	Private pilot licence helicopter PPL(H) under Joint Aviation Requirements (JAR), first issued by FOCA on 3 December 1992.
Ratings	Bell 204/205/UH-1D, valid until 31 May 2013
	Night flight (NIT)
	Approval for landings outside airports and heliports for non-commercial flights, valid until 12 March 2013
Medical certificate	Class 2, restrictions: VML (shall wear multifocal lenses), valid from 29 November 2012 to 30 November 2013
Last aviation medical examination	29 November 2012
Flight training commenced	11 October 1990

1.5.1.2 Flying experience

Total	537:30 h
On the accident type	174:20 h
During the last 90 days	14:06 h
On the accident type	6:05 h
Total no. of landings	2,901
Landings during the last 90 days on the accident type	5

1.5.1.3 Ratings on the Bell UH-1H helicopter type

Based on an American pilot licence, which had been issued on 3 February 1995, the pilot began training to acquire the type rating (TR) on the Bell 204/UH-1B helicopter on 20 January 1996 in the USA. During this phase, he accumulated a flying time of three hours. In January 1997, he continued this training on the Bell 204/UH-1B helicopter, again in the USA, and completed the type rating. In the process, he flew 5:45 h over two days. In February 1998, the pilot gained a type rating at the same flight school on the Bell 205/UH-1H helicopter with a total flying time of 5:40 h.

The pilot applied to FOCA to add the Bell 205/UH-1H model to his licence. On 14 August 1998, this application was granted after lengthy clarification. In the pilot's flight logbook, this approval by FOCA was described as follows: "*Bell 205/UH-1H is accepted and approved by Swiss FOCA!*"

On 12 May 2009, the pilot carried out what is known as a practical proficiency check on the Bell UH-1H helicopter type, registered as N6195G. The respective protocol reads: "*Proficiency check after rating expiry with theoretical test.*"

The last proficiency check for the 204/205/UH-1D model took place on 30 April 2012 on helicopter HB-RXC.

1.5.1.4 Technical training

The operator of helicopter HB-RXC completed a four-year apprenticeship as a mechanic. Subsequently, he continued training to become a motorcycle mechanic. He has worked in this job for the last 30 years. He has regularly attended further training courses relating to motorcycles.

When the maintenance work on the Bell UH-1H helicopter was carried out by aircraft mechanic A (see chapter 1.5.2.2), the operator was always present and was therefore able to gain experience.

For aircraft in the special category, within the ‘historic’ subcategory, the possibility exists for the operator to request approval from FOCA to carry out and certify maintenance work. The necessary requirements are defined in the Technical Communications (TM) guidelines (see chapter 1.17.1.1).

On 12 December 2010, the operator of helicopter HB-RXC applied to FOCA for such approval. In November 2011, two FOCA inspectors carried out an assessment concerning this matter at St. Gallen-Altenrhein airport. The following handwritten note was recorded on the application: “*The findings were judged as very good.*” The operator was granted approval on 4 January 2012. The scope of the authorisation was defined as follows: “*Non-complex maintenance work according to TM 02.020-00 on the airframe, engine, propellers and on-board systems*” (see chapter 1.17.1.2.3).

1.5.2 Maintenance staff

1.5.2.1 General

Mechanics A and B participated in the maintenance work on helicopter HB-RXC.

1.5.2.2 Mechanic A

Mechanic A completed a three-year apprenticeship as a sheet metal worker at a helicopter manufacturer in Germany. Subsequently, he spent four years working as a mechanic in the German Army, which included working on helicopters of the Bell UH-1D type. From 1983 to 1994, the mechanic worked mainly on fixed-wing aircraft at different maintenance companies. In 1992, he acquired the American FAA A&P licence and has been self-employed in this field since 1994.

The mechanic applied for approval from FOCA for carrying out and certifying maintenance work on the helicopter registered as HB-RXC, and was granted this approval on 11 March 2010. On 25 July 2011 the approval was extended to 25. July 2016.

The approval stipulated that he may only carry out maintenance work and certifications within the scope of his personal aircraft mechanic licence.

1.5.2.3 Mechanic B

Mechanic B was in possession of a valid licence as an aircraft mechanic to work on various models.

The mechanic carried out maintenance work on helicopter HB-RXC for six years under the supervision of mechanic A and was therefore able to gain experience of this helicopter type. On 25 July 2011, the mechanic submitted a request to FOCA for authorisation for this model. This was rejected. The mechanic was neither in possession of a valid authorisation, nor was he otherwise approved to carry out and certify maintenance work on the Bell UH-1H helicopter type.

Mechanic B certified maintenance work on helicopter HB-RXC.

1.6 Information on the aircraft

1.6.1 General

Registration	HB-RXC
Aircraft type	Bell UH-1H
Specification	Single-engine multipurpose helicopter with 13 seats, a semi-rigid and anticlockwise main rotor system and a conventional two-bladed tail rotor for torque balance.
Manufacturer	Bell Helicopter Company, Fort Worth, Texas, USA
Year of manufacture	1965
Serial number	65-09688
Owner	Private
Operator	Private
Engine	Honeywell turboshaft (Textron Lycoming) T53-L-13B with a maximum power output of 1,400 SHP, equivalent to 1,044 kW. Year of manufacture: 1965 Serial number: LE-15154
Operating hours	Airframe: 10,845 h (TSN[2]) Engine: 745.8 h (TSN)
Fuel control unit (FCU)	Chandler Evans Control Systems Part number 300991101 Serial number: 672AS1811
Maximum permissible take-off weight	9,498 lb
Mass and centre of gravity	Both mass and centre of gravity were within the permissible limits of the aircraft flight manual (AFM).
Technical restrictions	No outstanding points were recorded in the flight logbook.
Fuel quality at the time of the accident	The fuel met the required specifications.
Fuel quantity	At the time of the accident, there were approximately 814 lb (462 l) of fuel on board, which corresponds to a flying time reserve of approx. 1:30 h.
Certificate of registration	Issued by FOCA on 21 December 2010, valid until deletion from the aircraft register.
Permit to fly	Issued by FOCA on 22 December 2010:

[2] TSN: time since new

	"*Approval is valid for the following non-commercial purposes:* *Demonstrations at approved aviation events.* *Ferry and training flights for such events.* *Flights for maintaining the crew's training level, including the necessary instruction and retraining flights without basic training.* *Inspection flights and ferry flights for technical reasons.*"
Test certificate	On 6 December 2011, a review was carried out by FOCA. No complaints were logged.
Approved operation	Private
Category	VFR during the day/night

1.6.2 Certification for civilian use of the helicopter

The type certificate (TC)[3] H3SO was implemented in order to allow civilian use of the UH-1 helicopter type, decommissioned by the U.S. Army. This was issued by the American Federal Aviation Authority (FAA) in 1974. The original operator of the H3SO type certificate was the company Wilco Aviation. In the years following, the operator of this TC changed many times.

Between 27 December 1995 and 22 August 2001, US Helicopter Inc. was in possession of this TC.

In the H3SO type certificate, revision 15 from 22 March 2010, the following relevant points were recorded:

"*Production basis:*	*No helicopter may be produced under this approval. Prior to adding serial numbers to this type certificate, each candidate helicopter must undergo a conformity inspection.* *[…]*
Note 5:	*This helicopter is prohibited from carrying cargo for compensation or hire.* *[…]*
Note 11:	*No person may be carried in this helicopter during flight unless that person is essential to the purpose of the flight.*"

On 28 June 1990, helicopter HB-RXC received the civilian certificate of airworthiness from the FAA for the first time in the restricted category, registered as N6195G.

1.6.3 Maintenance

1.6.3.1 General

After the import of the UH-1H helicopter into Switzerland, it was initially operated with the registration N6195G. During this time, i.e. up to 11 November 2009,

[3] The type certificate is a type approval or an individual aircraft approval, which represents an official rating (certification) for operating an aircraft. It is granted by the aviation authority of the country in which the aircraft will later be registered. As part of the approval, it is checked as to whether the underlying design specifications are fulfilled.

maintenance work on the helicopter was carried out and certified by mechanic A, who had travelled from Germany. He was in possession of a valid American licence (FAA A&P licence). In each instance, the maintenance work was carried out in a hangar in Bonaduz. According to the operator personal tools were used for work on the helicopter. Specialist tools were borrowed from Swiss Helicopter Maintenance AG (SHM) and tools from the company Rotortec AG when needed.

On 12 November 2009, the helicopter was registered in the Swiss aircraft register as HB-RXC and declared airworthy by FOCA on 13 January 2010. As a result of this, a maintenance work programme for a historic aircraft had to be drawn up by the operator, which was reviewed and approved by FOCA on 15 January 2010. Because of the Swiss registration, mechanic A had to apply to FOCA for approval to carry out and certify maintenance work on helicopter HB-RXC. Maintenance work was carried out in a hangar at St. Gallen-Altenrhein airport.

1.6.4 Information on the maintenance work carried out

1.6.4.1 Work carried out by the operator, mechanic A and mechanic B

Between 21 August and 4 September 2011, the most recent maintenance work on the helicopter airframe and engine was certified. A work report was produced for this work. Both mechanics A and B as well as an avionics engineer also certified this work in the technical files.

The accident occurred just over 15 months later; the helicopter flew for approximately 27 hours during this time. There are no certificates in the technical files showing that the mandatory maintenance work had been carried out during this time. A work report was not created. The operator certified the inspection carried out on 4 March 2012 in the flight logbook only. The following text was also recorded by the operator on 1 September 2012: "*Annual inspection B-205 HB-RXC; next before 04/09/2013.*" There are no entries on this within the technical files.

According to the technical files dated 4 March 2012, the operator's work included removal and replacement of the fuel control unit (FCU).

Further work carried out was recorded by the operator in the form of notes in the technical files. There are no work reports available, nor was the work certified in the technical files (see annexe 1). It is not evident from these notes what work had actually been carried out.

According to the operator's verbal statements, he had replaced all the bolts and nuts on the tail rotor gearbox housing and on the tail rotor. Together with mechanic B, he had replaced the seal between the tail rotor driveshaft and tail rotor gearbox. The tail rotor gearbox does not have to be disassembled for this work.

No other work on the helicopter was documented.

1.6.4.2 Maintenance work carried out by Swiss Helicopter Maintenance AG

After the operator had replaced the FCU in St. Gallen-Altenrhein, he instructed Swiss Helicopter Maintenance AG (SHM) in Balzers to check the installation of the FCU and then make the necessary adjustments. According to SHM's work report, the adjustment work on the FCU and on the helicopter was carried out by an SHM mechanic on 12 December 2012 in the presence of the operator and finally checked by carrying out a static test.

In consultation with the operator, SHM subsequently cleared the helicopter for technical flights.

On the same day, the operator flew helicopter HB-RXC to SHM in Balzers. Between 13 and 20 December 2012, further adjustment work was carried out on the

FCU and the helicopter. In addition, vibration measurements on the main rotor were carried out during the technical flights.

This work was certified by SHM as follows:

"*Clearance for use of the aircraft in compliance with article 34/4 VLL (aircraft airworthiness directive) regarding the work carried out (TM 02.010-40).*"

According to SHM no maintenance work was carried out on the tail rotor system.

1.6.5 Tail rotor system

1.6.5.1 General

The UH-1H model is a helicopter of conventional design with a main and tail rotor. These are powered by the engine via a transmission.

Dependent on the rotor blades' angle of attack, the main rotor produces torque, which acts on the helicopter's airframe against the main rotor's direction of rotation. The propulsion created by the tail rotor counteracts this torque. This torque balancing prevents, for example, the helicopter from rotating on its vertical axis when hovering. Besides the torque balancing, the tail rotor is also used for manoeuvring the helicopter on its vertical axis.

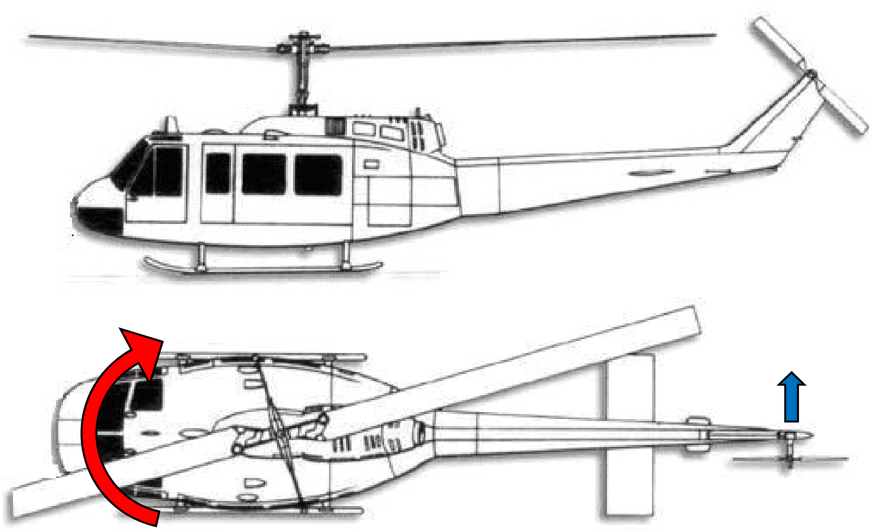


Illustration 4: Torque acting on the airframe (red arrow), propulsive force acting on the tail (blue arrow), in hover flight and slow forward flight.

The main rotor's torque changes depending on the operating situation. The more power the engine generates, the bigger the torque. The pilot must therefore adjust the torque balance accordingly. On the UH-1H, this is done using the control pedals. By pressing the pedals, the pitch angle of the tail rotor blades is altered via the pitch change rod, subsequently affecting the propulsion of the tail rotor.

1.6.5.2 Tail rotor transmission

The tail rotor transmission (90° gearbox) is a single-stage bevel drive. The main transmission drives the tail rotor transmission via a driveshaft. The tail rotor transmission with the tail rotor driveshaft, which incorporates the tail rotor and the associated pitch mechanism, is located (viewed in flight direction) on the helicopter's left-hand side. According to the component history card, the tail rotor transmission had a total of 6,080 operating hours at the time of the accident. Since the last overhaul, the transmission was in operation for 3,620 h.

1.6.5.3 Tail rotor

The tail rotor is two-bladed. Both blades are mounted on the hub and can be rotated on their longitudinal axis, which permits the adjustment of the blade pitch (see annexe 2). The hub is internally splined and located on the transmission's rotor shaft. This is then retained on the driveshaft using a static stop and retaining nut. The nut is tightened to a defined torque and wire-locked to prevent it from becoming loose. When assembled correctly, the connection between hub and shaft is rigid; the hub cannot be moved axially. The static stop has two flanges to restrict tail rotor wobble.

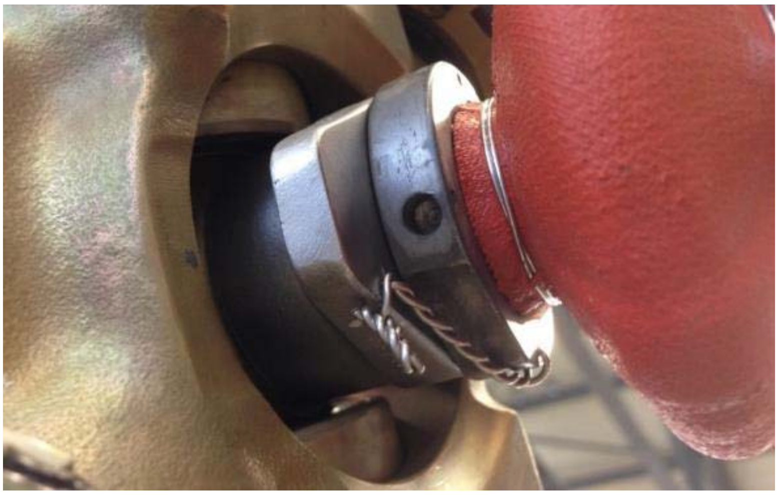


Illustration 5: Tail rotor hub with static stop and wire-locked retaining nut (picture of tail rotor system of same type).

Both blade grips are connected to the crosshead (pos. 20), each with a pitch link (pos. 17). This crosshead is connected to a slider (pos. 8), which is slid onto the splined end of the tail rotor shaft and can be moved axially. The crosshead rotates in synchronisation with the rotor. Moving it changes the pitch of the tail rotor blades. The crosshead is moved by the pitch change rod (pos. 29), which runs through the hollow gearbox shaft. The non-rotating pitch change rod and the rotating crosshead are mechanically connected via a bearing set that supports axial loads (pos. 10). The outer ring of the bearing set is held axially in the crosshead by the slider, the retainer plate (pos. 9) and the shim (pos. 13). It is mounted using two ¼-inch bolts (pos. 18), and nuts (pos. 27) secured with a split pin. The bearing set's inner ring is mounted on the end of the pitch change rod also using a nut secured with a split pin.

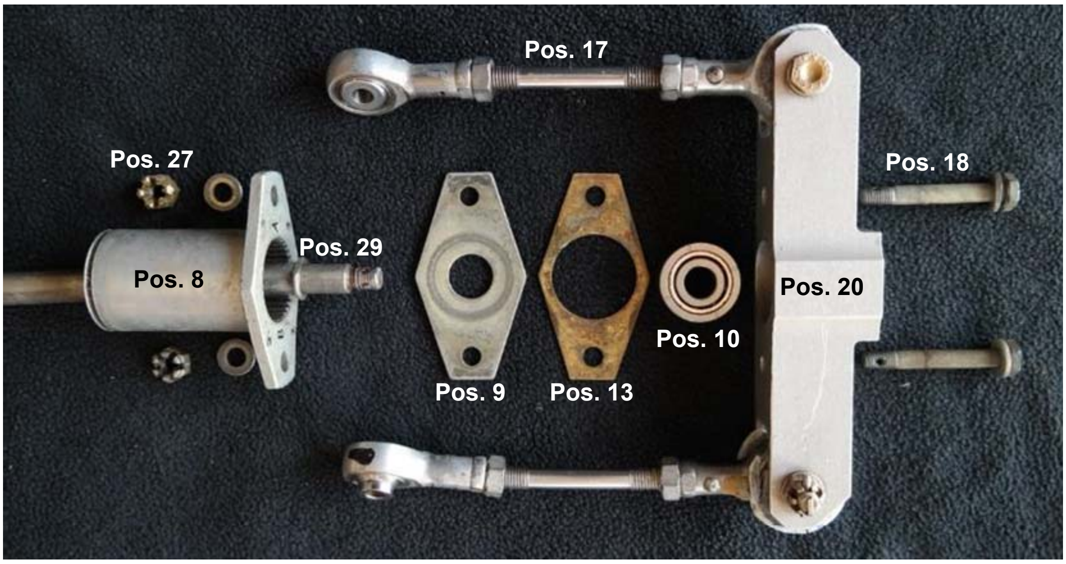


Illustration 6: Individual parts of the tail rotor's blade pitch mechanism. For the purpose of the illustration, the components not found on helicopter HB-RXC after the accident were added from an identical system. The positions of the individual components relate to annexe 2.

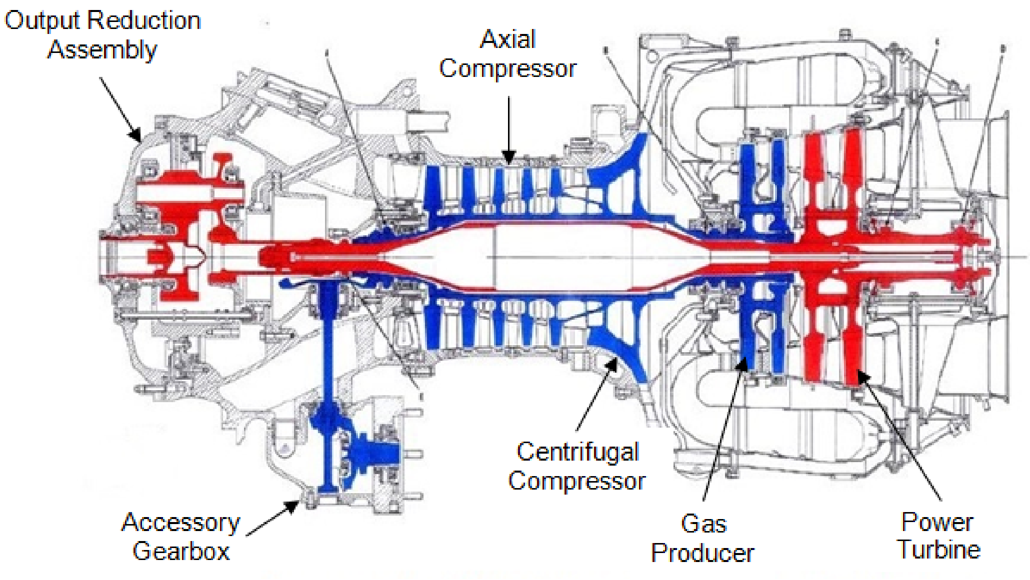
When the pitch change rod is retracted, the tail rotor's propulsion acts against the tail rotor transmission; when the pitch change rod is extended, the propulsion acts away from the tail rotor transmission.

During certain flight manoeuvres, the propulsion acts away from the transmission, i.e. the tail rotor's hub pulls the transmission's driveshaft. In such a case, the tail rotor's propulsion affects the retaining nut, which connects the hub and the driveshaft. When assembled correctly, the tail rotor's propulsion never affects the control rods / crosshead connection.

1.6.6 Engine

1.6.6.1 General

The Bell UH-1H helicopter is fitted with a Honeywell T53-L-13B turboshaft engine. The engine consists of a two-stage free power turbine and a two-stage gas producer turbine, which drives a combined axial and centrifugal compressor.



Gasgeneratorturbinen-System (*gas producer turbine*)

Arbeitsturbinen-System (*free power turbine*)

Illustration 7: Cross-sectional view of a T53 engine

Using a fuel control unit (FCU), constant speed of the free power turbine is achieved by a varying speed of the gas producer turbine.

1.6.6.2 Control panel

The engine control panel is located in the cockpit on the right half of the centre console, i.e. to the pilot's left.

Illustration 8: Engine control panel with governor switch (circled red).

The control panel was installed properly and was functioning.

1.6.6.3 Governor switch

The power turbine governor switch (GOV) has the following two positions:

- AUTO: In this position, the power turbine speed is automatically regulated.

- EMER: In this position, the power turbine speed is manually controlled by the pilot using the twist-grip throttle.

The operation of the switch was checked and it was in working order.

The emergency solenoid valve is activated with the governor switch in the EMER position, and allows manual operation of the main fuel supply control.

1.6.7 Excerpt from the aircraft flight manual

1.6.7.1 General

Pursuant to the FOCA directive TM 02.030-20, an aircraft flight manual (AFM) was compiled for helicopter HB-RXC and "*only viewed by the Federal Office, but not approved*". This AFM was based on TM 55-1520-210-10 of the 'Operator's Manual Army Model UH-1H / V helicopters'. For the helicopter's civilian use, some chapters were deleted by FOCA without replacement.

The relevant emergency procedures are described in the following (bold in the original).

1.6.7.2 Engine overspeed; chapter 9, paragraph 9-17

"*Engine overspeed will be indicated by a right yaw, rapid increase in both rotor and engine RPM, RPM warning light illuminated, and an increase in engine noise. An engine overspeed may be caused by a malfunctioning N2 governor or fuel control. Although the initial indications of high N2 RPM and rotor rpm are the same in each case, actions that must be taken to control rpm are distinctly different. If the N2 governor malfunctions, throttle reduction will result in a corresponding decrease in N2 RPM. In the event of a fuel control malfunction, throttle reduction will have no effect on N2 RPM. If an overspeed is experienced:*

1. Collective – increase to load the rotor in an attempt to maintain rpm below the maximum operating limit.

2. Throttle – reduce until normal operating RPM is attained. Continue with manual throttle control. If reduction of throttle does not reduce RPM as required:

WARNING

Land even if manual throttle corrects the overspeed since there is a chance of an impending engine failure due to the debris generated by the initial N2 failure.

3. EMER GOV OPNS"

1.6.7.3 Definition of emergency terms; chapter 9, paragraph 9-3

"*For the purpose of standardization the following definitions shall apply:*

[…]

e. The term EMER GOV OPNS is defined as manual control of the engine RPM with the GOV AUTO/EMER switch in the EMER position. Because automatic acceleration, deceleration, and overspeed control are not provided with the GOV switch in the EMER position, throttle and collective coordinated control movements must be smooth to prevent compressor stall, overspeed, overtemperature, or engine failure.

1. GOV − switch − EMER.

2. Throttle − adjust as necessary to control RPM.

3. Land as soon as possible. […]"

1.6.7.4 Complete loss of tail rotor thrust; chapter 9, paragraph 9-21

"*This situation involves a break in the drive system, such as a severed driveshaft, herein the tail rotor stops turning or tail rotor controls fail with zero thrust.*

a. Indications.

(1) In-flight.

(a) Pedal input has no effect on helicopter trim.

(b) Nose of the helicopter turns to the right (left sideslip).

(c) Roll of fuselage along the longitudinal axis.

(d) Nose down tucking will also be present.

WARNING

At airspeeds below 30 to 40 knots, the sideslip may become uncontrollable, and the helicopter will begin to revolve on the vertical axis (right or left depending on power, gross weight, etc.).

(2) Hover.

Helicopter heading cannot be controlled with pedals.

b. Procedures.

(1) In-flight.

(a) If safe landing area is not immediately available and powered flight is possible, continue flight to a suitable landing area at above minimum rate of descent airspeed. Degree of roll and sideslip may be varied by varying throttle and/or collective.

(b) When landing area is reached, AUTOROTATE using an airspeed above minimum rate of descent airspeed.

(c) If landing area is suitable, touchdown at a ground speed above effective transitional lift utilizing throttle as necessary to maintain directional control.

(d) If landing area is not suitable for a runon landing a minimum ground run autorotation must be performed, enter autorotation descent (throttle off) start to decelerate at about 75 feet altitude so that forward ground speed is at a minimum when the helicopter reaches 10 to 20 feet, execute the touchdown with a rapid collective pull just prior to touchdown in a level attitude with minimum ground speed."

1.7 Meteorological information

1.7.1 General weather conditions

A low pressure area with its centre over the British Isles directed a warm front with mild and humid air towards Central Europe. In Eastern Switzerland, the local cold air was locked in the topography until the evening.

1.7.2 Weather at the time and at the accident location

The sky was overcast. There was little wind and light snowfall; however this did not reach the ground.

At 16:20, a cloud base at 1,800 m AMSL was observed at St. Gallen-Altenrhein airport. On the webcam picture of Oberschan from the same time, the 1,899-m-high summit of the Mittlerspitz and St. Luzisteig Pass were visible.

Weather/clouds	Overcast, with base at 6,200 ft AMSL
Visibility	8 km
Wind	Variable, 1 kt
Temperature / dew point	1 °C / -3 °C
Atmospheric pressure QNH	1,014 hPa
Hazards	None

1.7.3 Astronomical information

Position of the sun	Azimuth: 233°	Altitude: 1°
Light conditions	Dusk	

1.7.4 Webcam picture from the region

Illustration 9: Oberschan webcam, 20 December 2012, 16:15, viewing direction south east towards Mittlerspitz (1,899 m AMSL)

1.8 Navigational aids

N/a

1.9 Communication

N/a

1.10 Airport information

N/a

1.11 Flight recorder

The helicopter was neither equipped with a flight data recorder, nor with a voice recorder. These were not compulsory.

1.12 Information on the wreckage, the impact and the accident site

1.12.1 Accident site

The accident site was located approx. 170 metres west of the A13 Rhine valley motorway in an uninhabited area, surrounded by meadows and farmland. There were isolated obstructions such as power lines and dense rows of trees. The final position of the wreckage was next to one of several sheds that were built along an agricultural road.

The ground was soft at the time of the accident because of previous precipitation.

Illustration 10: Final position of the wreckage and tail rotor with crosshead lying underneath. The tail rotor was located on the ground – viewed in the approach direction – approximately 10 metres in front of the helicopter's impact point (circled in red).

1.12.2 Impact

The helicopter landed at low forward speed and high vertical speed on its landing skids next to a shed located on meadow land. The landing skids were pushed apart by the great level of force. Subsequently, the main rotor collided with the shed.

1.12.3 Wreckage

1.12.3.1 General

The wreckage was located between the shed and the agricultural road. The tail boom was almost completely detached at the point where it meets the cabin structure. In relation to the tail, the cabin structure lay twisted on its right side (see illustration 10). The landing gear was pushed apart and partially fractured. The left front door lay next to the wreckage, as the occupants had detached it from the airframe using an emergency jettison system in order to exit the helicopter. The tail skid was bent upwards.

The main rotor transmission with the rotor blades was ripped from the helicopter's mounting points and lay approximately 30 metres away on farmland.

The power turbine governor switch on the engine control panel was found in the AUTO position.

1.12.3.2 Tail rotor transmission

During the initial inspection of the accident site, it was established that the tail rotor transmission had been burst open and the transmission oil had leaked. With regards to the transmission's tail rotor driveshaft, which looked more or less intact, the tail rotor and its associated components were missing. The tail rotor blade pitch mechanism was also completely missing.

No contamination caused by the soil could be found on the tail rotor driveshaft or burst-open transmission.

Illustration 11: Burst-open tail rotor transmission with tail rotor driveshaft.

1.12.3.3 Tail rotor and blade pitch mechanism

The tail rotor was found near the wreckage, along with the crosshead and both pitch links; it lay on the ground – viewed in the approach direction – approximately 10 metres in front of the helicopter's impact point; one tail rotor blade was fractured (see illustration 10). The crosshead was connected to the blade grips by both of the bent pitch links. The static stop, from which both flanges had broken off, was found in the area surrounding the tail rotor. The slider lay at the same location; both flanges were bent.

The parts in pos. 4, 6 and 31 could not be found. The tail rotor had been mounted onto the transmission's tail rotor driveshaft with these (see annexe 2).

The parts in pos. 7, 9, 10, 11, 12, 13 and 22 as well in pos. 18, 19, 26 and 27 are part of the blade pitch mechanism and could also not be found (see annexe 2).

1.12.4 Marks

Impact marks caused by the landing skids were found at the helicopter's initial impact point on the ground. It was evident that the landing skids were pushed apart on the ground as a result of the significant force of impact. A small tree was knocked over by the helicopter at the impact point.

No marks whatsoever indicating contact with the ground could be found on the tail rotor blades.

A further impact mark on the ground could be attributed to the tail skid's contact with the ground.

1.13 Medical and pathological findings

The pilot's blood analysis for alcohol, medication and drugs produced negative results.

1.14 Fire

Fire did not break out.

1.15 Survival aspects

1.15.1 General

The accident was survivable because the landing gear absorbed a large amount of the force on impact and also because of the helicopter's general sturdy construction. Lap and shoulder belts were worn by all occupants and withstood the stress.

1.15.2 Search and rescue

The helicopter was fitted with an automatic EBC-502 emergency locator transmitter (ELT). No signals were received by the Search and Rescue Service (SAR).

1.16 Tests and research results

1.16.1 Engine

The engine was disassembled into individual components and thoroughly examined by the manufacturer Honeywell in the USA under the supervision of NTSB. The significant findings are presented in the subsequent chapters.

1.16.1.1 General

- The engine appeared generally intact and no external damage as a result of the accident could be found.
- Foreign material was found within the engine inlet, and the air inlet's guide vanes were damaged.
- From the twelve sump cover bolts of the free power turbine bearing, four were not correctly tightened and the seal was deformed in this area.
- All rotating components were undamaged and able to rotate freely.

1.16.1.2 Compressor

- The compressor's adjustable inlet guide vanes were cracked and deformed.
- The rotors and guide vanes of stages 1 to 5 of the axial compressor were also cracked and deformed.
- The leading edges of the radial compressor's guide vanes were damaged.

1.16.1.3 Combustion chamber

- Deposits of pulverised metal and metallic micro particles were present in the combustion chamber.

1.16.1.4 Free power turbine

- Rotational score marks were found in the area of the first stator stage's inner seal.
- The guide vanes' trailing edges of the first stator stage were damaged.
- The mantle ring of the rotor vanes displayed grinding marks.
- The first-stage rotor displayed part marking 81996.

The power turbine's rotor with part marking 81996 was not manufactured by the engine manufacturer Honeywell and was therefore not subject to its quality system. As a result, Honeywell could neither provide information on the rotor dimensions at the time prior to the accident, nor the material properties. According to Honeywell, no components procured by the military and fitted in the helicopter are permitted in civilian and certified engines.

The power turbine's first-stage rotor is most susceptible to plastic deformation caused by engine overspeed. The turbine disc was measured and compared to the original measurements of Honeywell, the manufacturer. In doing so, an excess was found.

If the rotor dimension of the turbine disc was manufacturer-compliant prior to the accident, the excess of the first power turbine stage would be attributable to engine overspeed. The manufacturer calculated an engine speed from the excess, which was 42% above the nominal value. It could not be established when this engine overspeed took place.

1.16.2 Fuel control unit and governor

1.16.2.1 General

At the time of the accident, helicopter HB-RXC was equipped with a fuel control unit (FCU) that the operator had purchased from the German Army and which was fitted in helicopter HB-RXC at the end of 2012. This FCU was last overhauled in Germany by the company United Technologies Aerospace Systems (UTAS), formerly the company Goodrich Control Systems GmbH, for the German Army in the period between 3 and 21 June 2012; a compulsory modification was carried out at the same time.

In the initial phase, the external condition of the FCU and the power turbine governor (PTG) was examined under the supervision of NTSB by the company Triumph Group Inc., based in the USA:

- The outer appearance of the FCU and PTG was good.
- Goodrich's lead seals were present on all of the adjustment bolts' respective lock wires.
- The electric connection of the idle throttle solenoid valve was in good condition.
- The torque values of the FCU and PTG driveshaft were within the tolerance range defined by the manufacturer.

In the second phase, the operation of the FCU and PTG was checked using a testing device.

1.16.2.2 Fuel control unit

- The emergency solenoid valve was in the manual position EMER.
- No leaks could be found during the test.

- With a compressor speed of 4,200 rpm, the fuel flow value was 865 pph[4]. The tolerance range is between 915 and 945 pph.
- With a fuel flow value of 748 pph, the compressor speed was 4,088 rpm. The tolerance range is between 4,458 and 4,506 rpm.
- Despite these deviations, no malfunctions could be found that would have prevented normal operation of the FCU.

1.16.2.3 Governor

- The low- and high-speed stops were both set to 'high'.
- The stop of the minimum fuel flow value was within the tolerance range.
- No malfunctions were found that could have contributed to engine overspeed of the power turbine.

Following the tests, the governor was disassembled and thoroughly examined. Nothing unusual was found.

1.16.3 Tail rotor transmission

1.16.3.1 Overview

The tail rotor transmission was removed from the helicopter, disassembled into its individual components and subsequently thoroughly examined.

Illustration 12: Burst-open housing of the tail rotor transmission. The fact that the tail rotor driveshaft appears to be intact is remarkable.

[4] pph: pound per hour

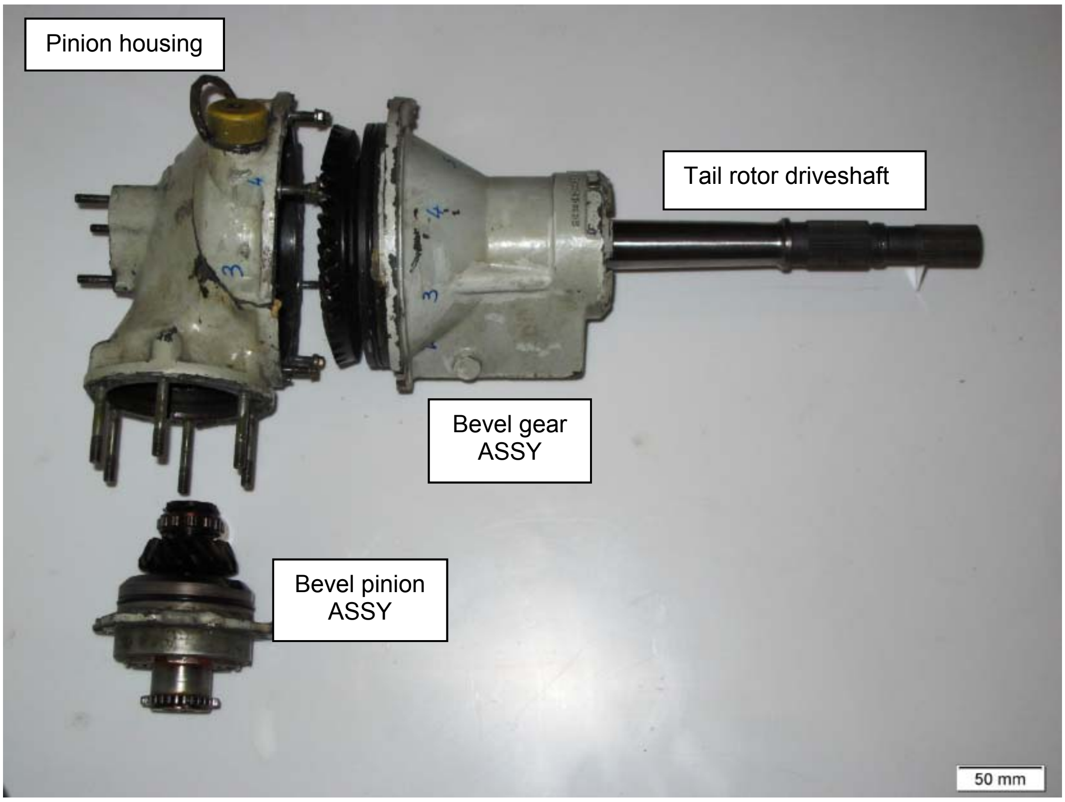


Illustration 13: Individual components of the tail rotor transmission

1.16.3.2 Housing

The pinion housing unit as well as the bevel gear ASSY housing were thoroughly examined in a laboratory.

In terms of materials characteristics, both housing halves matched a magnesium alloy and the manufacturing technology from 1965. Certain casting defects, such as porosity and others were found in the structure. The surface exhibited some corrosion. These defects are not related to the cause of fracture.

The fracture surfaces examined by the scanning electron microscope (SEM) are consistent with spontaneous fractures. Vibration or fatigue fractures could not be located.

In the area of the burst segment, helical marks were found on the inside of the pinion housing unit. These marks on the surface were metallically bright.

Illustration 14: Burst segment with helical marks

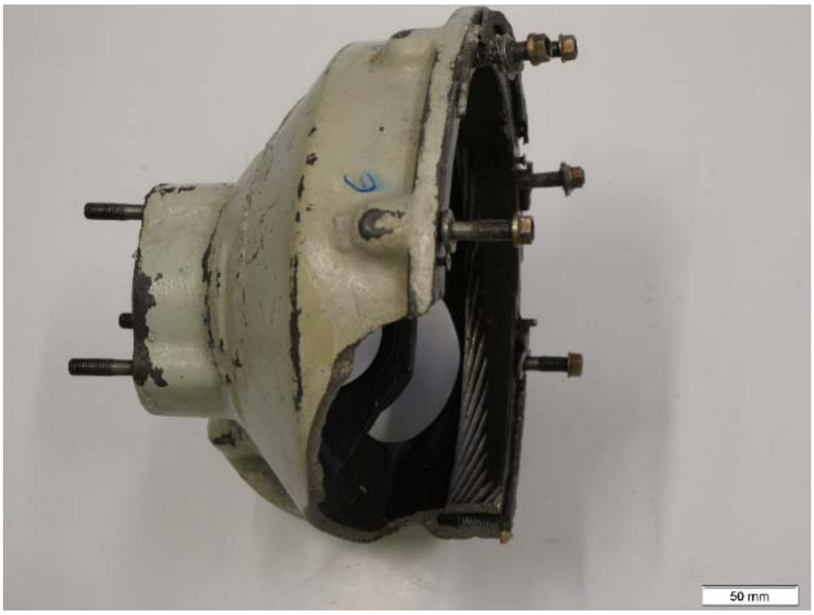


Illustration 15: Pinion housing unit with helical marks and burst segment

1.16.3.3 Bevel pinion and bevel gear

The bevel pinion's tooth flanks as well as those of the bevel gear showed no wear. There were no indications that material had broken off from the tooth flanks. Both bevel gears were in good condition and showed little signs of wear. In terms of the bevel gear, the flanks of three successive teeth were damaged and on the following fourth tooth, the tooth crest edge was damaged. In terms of the bevel pinion, the crest edges of two successive teeth were damaged. All of this was abrasion damage. The type of damage indicates the following: when the transmission housing broke apart, the tooth meshing was no longer aligned, which made the tooth crest edges touch each other causing the damage.

Illustration 16: Damaged tooth flanks of the bevel gear (circled red)

Illustration 17: Damaged tooth crest edges of the bevel pinion (red arrows)

1.16.4 Tail rotor

1.16.4.1 Tail rotor driveshaft

The strength of the driveshaft was measured using the Vickers hardness test method. It was 379 to 386 HV[5]. The tensile strength of the material can be determined from this test value. The measured value corresponds to an ultimate tensile strength of 1,200 MPa.

The tail rotor driveshaft was bent. The run-out, measured on the outermost splined end of the shaft, was 1.46 mm. This value is exceptionally high.

The thread on the outer end of the tail rotor driveshaft was severely damaged. The retaining nut for mounting the tail rotor is screwed onto this thread. The result shows shearing damage, which was caused by a free-moving tail rotor hub that was no longer held in place by the nut. It can be inferred from this kind of damage that the hub jammed on the driveshaft.

[5] Hardness test, indentation of a test device according to the Vickers test method.

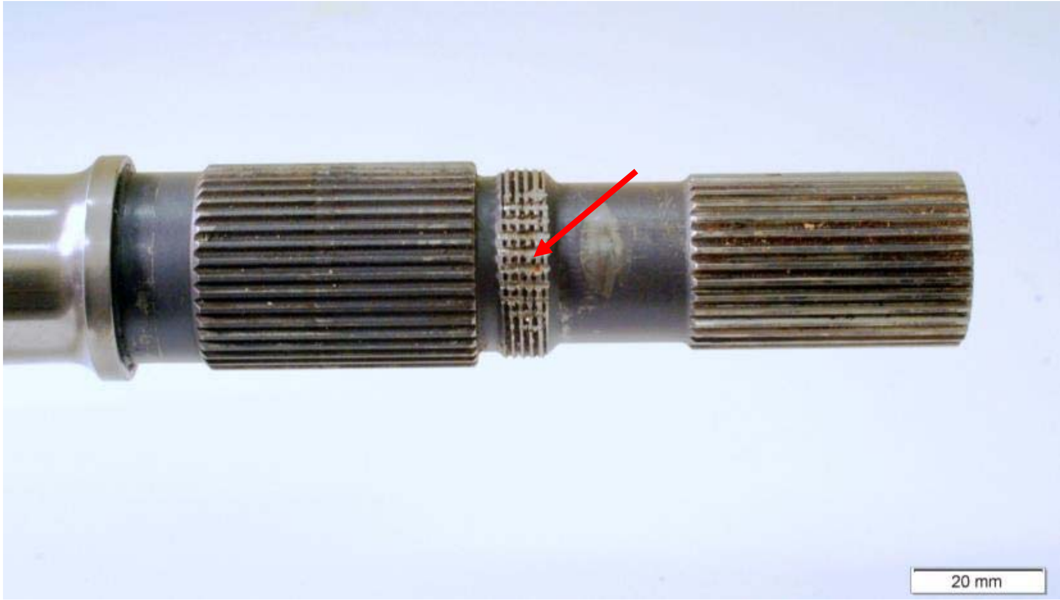


Illustration 18: Tail rotor driveshaft with visible notches on the thread for fitting the retaining nut (red arrow)

1.16.4.2 Blade pitch mechanism

The crosshead is connected to the tail rotor (see annexe 2, pos. 17) by two pitch links. Both of these pitch links were bent.

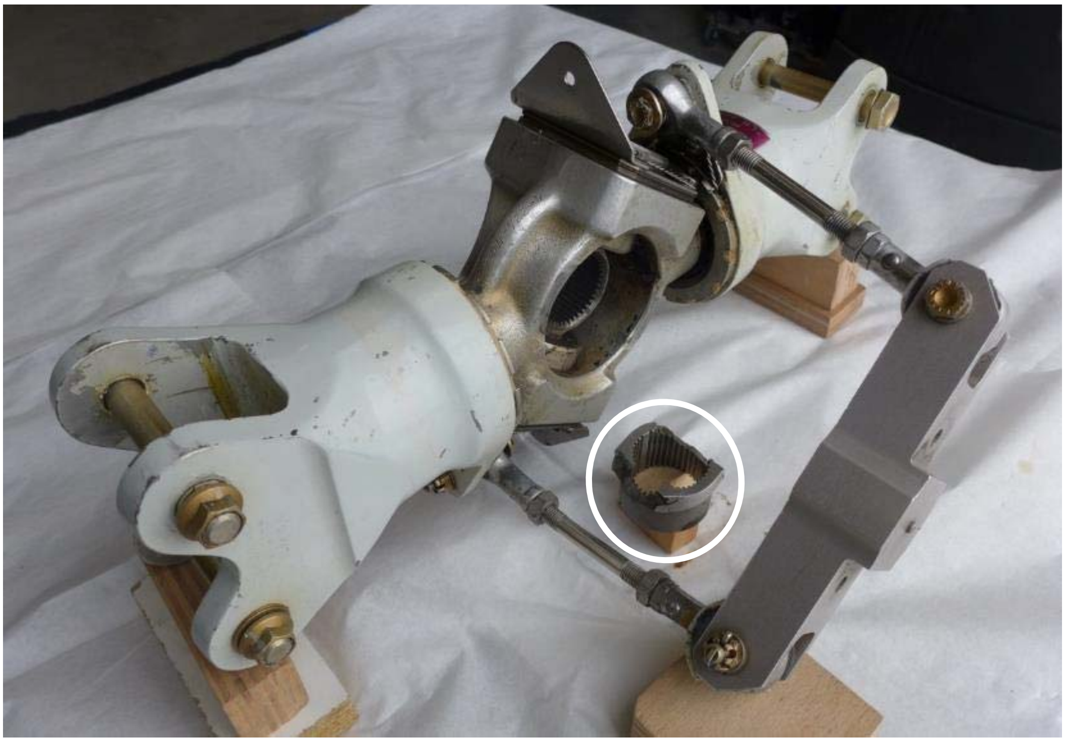


Illustration 19: Tail rotor hub with pitch links, crosshead and static stop (circled white) with broken-off flanges

Plastic indentations were found on the front surface of the tail rotor hub. In terms of their shape, this plastic deformation corresponds to the two broken-off flanges of the static stop (see annexe 2, pos.5).

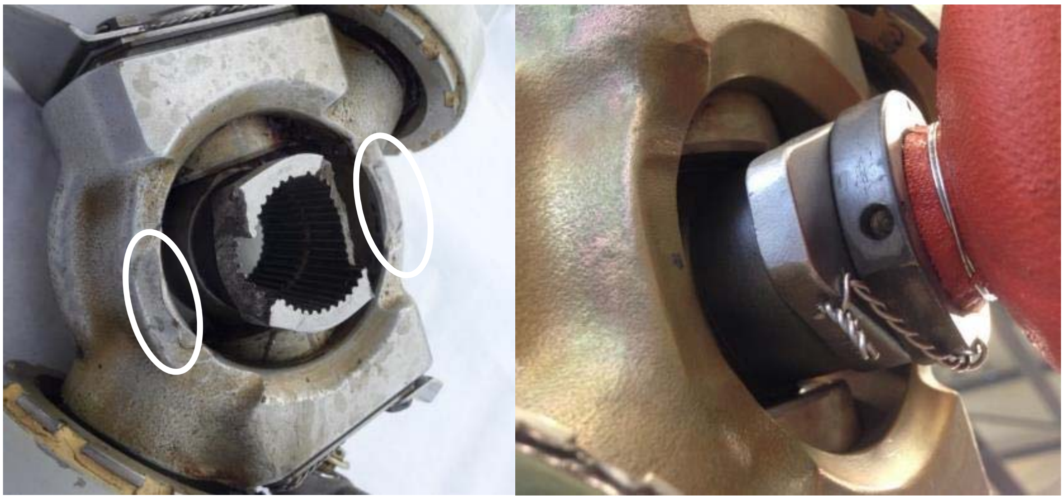


Illustration 20: Plastic indentations on the front surface of the tail rotor hub (circled white) and static stop with the broken-off flanges. The picture on the right shows an intact structurally identical system for comparison.

With regards to the crosshead and the slider, the washers' contact surfaces (see annexe 2, pos. 19) did not display any plastic deformation. It can be concluded from this that the failure of both bolt connections (pos. 18 and 27, also see illustration 6) is not attributable to an overload fracture.

Plastic deformation could be found on one bore hole of the slider, on the side facing the crosshead. It was, in all likelihood, caused by a broken bolt.

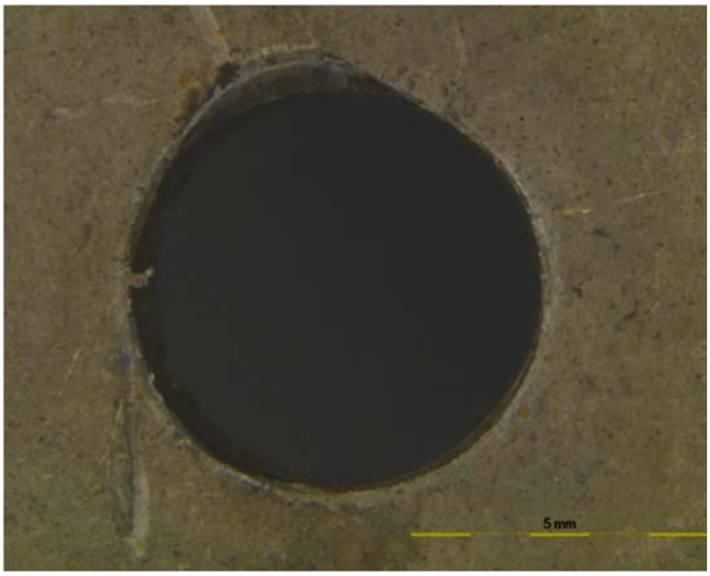


Illustration 21: Plastically deformed bore hole on the slider

As set out in chapter 1.6.6, the pitch of the tail rotor blades is altered via the crosshead using the pitch change rod. The pitch change rod is connected to the crosshead via a bearing set, which is attached to the pitch change rod by a nut. To prevent it becoming loose, this nut is secured using a split pin.

During the examination of the pitch change rod, it was established that the nut, with which the bearing set is attached, as well as the split pin, were sheared off by external blunt force.

Illustration 22: End of the pitch change rod with sheared-off thread and split pin (circled white).

1.17 Information on various organisations and their management

1.17.1 Federal Office of Civil Aviation

Issues regarding airworthiness are published by the Federal Office of Civil Aviation (FOCA) in the form of Technical Communications (TM). Among other things, these cover aircraft approval and maintenance as well as maintenance staff and maintenance organisations.

Guidelines in the TM are recommendations or elaborations with no legal binding effect. They represent the official interpretation of the underlying directives or laws.

1.17.1.1 Guidelines for historic aircraft

Relevant guidelines from the Technical Communication TM 02.030-20 ‘Aircraft of the special category, historic subcategory’ which came into force on 28 September 2012 are listed in the following chapter.

1.17.1.1.1 Scope of application

“*In the ‘historic’ subcategory, aircraft that fulfil the below conditions can be registered and licenced. Based on a written and substantiated application, FOCA decides whether a particular aircraft will be licenced.*

Historic aircraft are in particular:

[…]

2.2 Former military aircraft manufactured at least 35 years prior to the submission of the application for registration in the Swiss aircraft register, and whose licences (provided such exists) are at least 50 years old.

[…]”

1.17.1.1.2 Licence and operational obligations

“*3.3 Flight crew*

FOCA can set minimum crew qualifications for aircraft with special operating requirements.

3.4 Operational responsibility

The operator is responsible for complying with operational obligations. Operator syndicates are to appoint one person to be responsible."

1.17.1.1.3 Airworthiness requirements

"*4.1 Technical documents for the aircraft*

The following documents are required to be submitted in one of the official languages or in English:

a) Maintenance history of the aircraft

- *Pre-existing technical records or equivalent records*
- *Information on the aircraft maintenance to date*
- *Information on the operating hours since new and since the last major overhaul of the airframe, engine and propellers*
- *List of possible life limits for airframe, engines, propellers and other components*
- *Information on alterations and repairs performed*
- *Information on the implementation of airworthiness directives*

[…]

4.3 Maintenance

4.3.1 The operator must provide maintenance proof for the aircraft, the fitted engines, propellers as well as further accessories, showing that the scheduled maintenance work was carried out properly.

4.3.2 A maintenance and inspection programme must be created by the operator. Based on operating experience, this must be adapted if necessary. A complete copy of the programme as well as possible alterations must be submitted to FOCA for approval and filing.

4.3.3 For maintenance work, the operator can consult other specialists in addition to the authorised aircraft maintenance staff. FOCA checks the competence of these people and can authorise them to perform, supervise and certify certain maintenance work. It specifies the extent of the approval and the obligations, and can supervise the maintenance work or specify additional obligations for it (see VLL art. 34, paragraph 4)."

1.17.1.2 Classification of aircraft maintenance work

The relevant guidelines of the Technical Communication TM 02.020-00 'Classification of aircraft maintenance work', which came into force on 17 December 2012, are listed in the subsequent chapters.

1.17.1.2.1 General

"*1.2 Maintenance work*

The term 'maintenance work' refers to the following activities:

Inspection work, repair work, overhaul work, modification work as well as the replacement of parts or a combination of the aforementioned work.

Prior to starting the maintenance work, all tasks must be assessed with regards to their complexity, and subsequently classified as complex or non-complex maintenance work. In case of doubt, the Federal Office of Civil Aviation (FOCA) must be involved before the work begins."

1.17.1.2.2 Decision-making guidance for the classification of maintenance work

"*If one or several of the below questions are answered with 'yes', the tasks are, in addition to the activities listed in chapter 4, defined as complex maintenance work as per art. 27, paragraph 1, letter a. of the VLL.*

Provided the legal guidelines (see art. 32 et seq., VLL) do not provide for an exception, these must be carried out and certified by an appropriately authorised maintenance organisation (or manufacturing company, provided it is authorised).

a) Does the work affect the structural strength of the aircraft or the aircraft part?

b) Are changes in the behaviour or performance of the aircraft, the engine or individual systems expected as a result of the work?

[…]

f) Does the work require the use of specialist tools, specialist equipment or specialist facilities?

g) Is extensive disassembly required before the actual work is carried out?

[…]"

1.17.1.2.3 Complex maintenance work

The work referred to as 'complex maintenance work' is listed in chapter 4. However, this applies solely to aircraft with a piston engine and propeller. The terms 'helicopter' and 'turbine' are not mentioned.

1.18 Additional information

N/a

2 Analysis

2.1 Technical aspects

2.1.1 Data recording devices

As the helicopter was not equipped with either an engine data recorder (EDR) or a flight data recorder (FDR), no information was available to the safety investigation regarding this, which substantially impeded the investigation.

2.1.2 Engine control panel

The governor switch was in the AUTO position after the accident. The examinations of the fuel control unit and the governor show that the governor switch was last set in the EMER position. This means that the governor switch was actuated during the operation of the engine. Consequently, the switch position must have been changed after the accident.

2.1.3 Engine

No existing faults that could have influenced standard operation could be found in the engine.

The engine speed, which was calculated from the excess on the power turbine's first-stage rotor, was 42% above the nominal value. It could not be established when the engine overspeed took place.

The damage to the compressor, combustion chamber and the free power turbine arose during the course of the accident on the ground.

On the sump cover of the turbine bearing, four of the twelve bolts were not correctly tightened and the seal in this area was deformed. Deformation of the seal occurs if assembled incorrectly. It can be ruled out that these bolts loosened by themselves.

2.1.4 Fuel control unit and governor

No existing defects were found on the fuel control unit and governor that could have caused or influenced the accident.

2.1.5 Tail rotor system

2.1.5.1 Initial situation

The burst-open transmission, the damaged tail rotor driveshaft and the driveshaft components, which lay approximately 10 metres away from the helicopter's impact point, stood out at the accident site. The damage to the tail rotor driveshaft found in the area of the thread was caused by the hub of the tail rotor.

The tail rotor components found lying near the helicopter were in all probability separated during the impact.

Among other things, the retaining nut, which fixes the rotor to the tail rotor driveshaft, was not found at the accident site. It must be assumed that the retaining nut had come loose before the helicopter's impact. It is unlikely that the nut was not fitted. With correct installation and secured with lock wire, the nut coming loose on its own can, in all likelihood, be fundamentally ruled out.

2.1.5.2 Tail rotor transmission

Laboratory examinations show that the manufacturing technology of the housing is consistent with the time when the helicopter was manufactured. The defects found, such as porosity, casting defects and others, did not affect the failure of the housing.

All fracture surfaces were spontaneous fractures. Fatigue fractures could not be located.

The helical marks on the inside of the pinion housing were caused by the rotating bevel gear during the fracture process.

It can be inferred from the fracture pattern that a load impacting transverse to the driveshaft, e.g. an imbalance force, had led to the failure of the housing. Contact with the ground as a cause can be excluded for forensic reasons.

The possibility that a foreign object disrupted the meshing on the inside of the transmission and therefore caused the transmission to burst can also be excluded because no traces could be found on the tooth flanks of the bevel gears regarding this (see illustration 17).

The bevel gear and the bevel pinion were in good condition, except for damage to the tooth crest edges and tooth flanks, and showed minimal traces of wear. According to the tail rotor transmission's component card, this was overhauled 3,620 operating hours ago.

The damaged bevel pinion's tooth crest edges and the bevel gear's tooth flanks indicate that the meshing was separated within a very short period of time. The abrupt yaw of the helicopter to the right, which took place at the same time, is attributed to the loss of torque balance by the tail rotor.

2.1.5.3 Tail rotor driveshaft and blade pitch mechanism

The connection of tail rotor and tail rotor driveshaft is designed to transfer all tail rotor forces, except for those for blade pitch, to the helicopter's tail via the tail rotor driveshaft, which is rigidly bolted to the tail rotor hub.

Incorrect installation of the tail rotor components can result in an unstable operating state of the system.

Based on the available parts of the blade pitch mechanism, it must be assumed that the bolted connections for the bearing set installation, consisting of the two ¼-inch bolts and the associated nuts, failed. The absence of plastic deformation under the washers originally fitted with the bolts indicates that this failure could be due to fatigue. An incorrectly tightened bolted connection reacts very sensitively to dynamic loads and fails after a certain period of time. The bolted connections concerned were therefore in all likelihood not fitted correctly.

Following the failure of the bolted connections, the bearing set, fitted at the end of the pitch change rod, was pulled out from the crosshead's bearing set. This resulted in unstable control of the tail rotor blades and therefore generated vibrations.

As a result, the tail rotor's components were subject to an excessive amount of stress and partially failed. In such a situation, these mechanical connections are put under stress by static and dynamic forces, for which they are not designed.

During this process, the tail rotor was deflected to its static stops. The tail rotor hub was plastically deformed in the contact area of the two flanges. Both flanges broke, meaning that the lock-wire of the retaining nut, which may have been present, was no longer functional. Consequently, the retaining nut could become loose because of the vibrations. The entire tail rotor with the crosshead was subsequently no longer axially attached to the tail rotor driveshaft. The components shifted away from the transmission, pulling out the bearing set from the crosshead. The thread, to which the bearing set was fixed at the end of the pitch change rod, was sheared off.

The tail rotor driveshaft was bent and the transmission burst open by the prevailing forces. In the process, the tail rotor lost power.

2.2 Human and operational aspects

2.2.1 Pilot

After the strong vibrations and an abrupt yaw to the right on the helicopter's vertical axis, the pilot partially lost control. It must be assumed, that the pedal control input lost increasingly its effect. These were clear signs of tail rotor failure. The bursting of the tail rotor transmission meant a sudden relief of load on the drivetrain and led to engine and main rotor overspeed. The pilot stated that he noticed engine overspeed at that time. The fuel control unit (FCU) should compensate such an overspeed.

He stated that the engine speed was far above the limit on the cockpit instrument, which is marked in red. He therefore reduced the fuel flow using the twist-grip throttle. Subsequently, the pilot changed the governor switch into EMER mode, as described in chapter 9, paragraph 9-17, 'engine overspeed', of the aircraft flight manual (see chapter 1.6.7.2). In EMER mode, the speed of the free power turbine must be manually set using the twist-grip throttle. This action requires a certain level of concentration, as the speed deviation from the desired value must be corrected. The pilot did not achieve this. According to his statements, he heard the acoustic low RPM warning even in the final phase of the flight shortly before landing.

The perceptions, described by the occupants, match the effects of a complete loss of tail rotor thrust as stated in the aircraft flight manual (see chapter 1.6.7.4).

The effect of engine overspeed is similar as regards the rotation of the helicopter on its vertical axis to the right. However, the clear differentiating factor is the availability of the tail rotor control, in other words, the control of the helicopter on its vertical axis.

By immediately focusing on the issue of the free power turbine's overspeed, no systematic incident analysis was carried out by the pilot. A possible explanation of this focus might be the fact that prior to that, the pilot had intensively concentrated on the topic of engine control over a long period of time.

In chapter 9, paragraph 9-21, 'complete loss of tail rotor thrust', (see chapter 1.6.7.4) of the aircraft flight manual, the current case is described as follows:

"*b. Procedures.*

(1) In-flight.

(a) If safe landing area is not immediately available and powered flight is possible, continue flight to a suitable landing area at above minimum rate of descent airspeed. Degree of roll and sideslip may be varied by varying throttle and/or collective.

(b) When landing area is reached, AUTOROTATE using an airspeed above minimum rate of descent airspeed.

(c) If landing area is suitable, touchdown at a ground speed above effective transitional lift utilizing throttle as necessary to maintain directional control.

(d) If landing area is not suitable for a runon landing a minimum ground run autorotation must be performed, enter autorotation descent (throttle off) start to decelerate at about 75 feet altitude so that forward ground speed is

at a minimum when the helicopter reaches 10 to 20 feet, execute the touch-down with a rapid collective pull just prior to touchdown in a level attitude with minimum ground speed."

In this case, the engine was producing output and in principle, it would have been possible to continue to fly to the nearby St. Gallen-Altenrhein airport to perform a glide landing on the tarmac runway there. The uncertainty with regards to the damaged tail rotor should be noted. The danger of the tail rotor components becoming separated from the helicopter during the flight was real. This could, amongst other things, have corresponding effects on the helicopter's centre of gravity and controllability.

Due to the uncertainty regarding the cause, the pilot feared a possible deterioration of the situation and decided on an immediate emergency landing, which was appropriate for the situation. The choice of where to perform the emergency landing took place without sufficient consideration of the local conditions and indicates a rushed decision.

2.2.2 Approval and Maintenance

The mechanic A applied for approval from FOCA for carrying out and certifying maintenance work on the helicopter registered as HB-RXC, and was granted this approval on 11 March 2010. On 25 July 2011 the approval was extended to 25. July 2016.

Mechanic B certified maintenance work, although he did not possess an authorisation or approval.

From the STSB's point of view, the operator carried out complex work to a degree, although, according to the scope of TM 02.020-00, he would only have been permitted to carry out non-complex maintenance work. The operator's record keeping was inadequate.

It is probable that insufficient maintenance work on the tail rotor ultimately led to its failure.

2.2.3 Federal Office of Civil Aviation

When the UH-1H helicopter was registered in the Swiss aircraft register as HB-RXC, the Federal Office of Civil Aviation (FOCA) no longer applied the type certificate (TC) H3SO, in which relevant operational restrictions were recorded (see chapter 1.6.2). Consequently, these sensible restrictions lost their validity. Although operational restrictions were made in the permit to fly, these only applied to the type of flight. The number of passengers on board was not limited. This is not prudent.

For aircraft in the special category within the 'historic' subcategory, the option exists for the operator to apply for approval to carry out and certify maintenance work. The Technical Communications (TM) guidelines define the necessary requirements for this.

On 12 December 2010, the operator of helicopter HB-RXC applied to FOCA for such approval. In November 2011, two FOCA inspectors carried out an assessment concerning this matter at St. Gallen-Altenrhein airport. The following handwritten note was recorded on the application: "*The findings were judged as very good,*" whereupon approval was granted to the operator on 4 January 2012.

The scope was defined as follows: "*Non-complex maintenance work according to TM 02.020-00 on the airframe, engine, propellers and on-board systems.*"

The Technical Communication TM 02.020-00 published by FOCA, applies only to fixed-wing aircraft with propeller drive and piston engine and is obviously not intended for helicopters and turbo shaft engines.

The UH-1H helicopter type has complex systems and requires in-depth expertise for maintenance work. From the STSB's point of view, the operator of helicopter HB-RXC was not qualified for such an approval. Normally, maintenance work for such models has to be performed by qualified maintenance staff in appropriately qualified organisations.

During the inspection of the helicopter, it went unnoticed that mechanic B had certified work, although he did not possess an authorisation or approval.

It seems obvious that the registration process of historic aircraft at FOCA was incomplete and must be revised. This process must be carried out with sound judgement, a risk assessment and with appropriate obligations.

These points show that FOCA's supervisory activity was inadequate.

3 Conclusions

3.1 Findings

3.1.1 Crew and passengers

- The pilot was in possession of the required licences for the flight.
- There is no evidence of health problems of the pilot during the accident flight.
- Lap and shoulder belts were worn by all occupants and withstood the stress.
- The occupant in the front left seat was seriously injured.

3.1.2 History of the flight

- On 20 December 2012, the pilot took off at 14:48 with the helicopter, registered as HB-RXC, from Balzers heliport (LSXB) and planned to fly to St. Gallen-Altenrhein (LSZR).
- At 15:05, the pilot landed in Buchs/SG in a field close to the waste incineration plant and switched off the engine.
- At 16:14, the pilot took off with three passengers on board and flew at an altitude of about 3,000 ft AMSL and with a speed of around 80 knots following the course of the motorway in the direction of St. Gallen-Altenrhein.
- Directly next to the motorway at the gravel quarry before coming to Rüthi, the occupants noticed very strong vibrations and an abrupt yaw to the right on the helicopter’s vertical axis.
- The pilot partially lost control of the helicopter during this phase.
- At this time, the pilot noticed engine overspeed. The engine speed was far above the limit on the cockpit instrument, which is marked in red.
- The pilot reduced the fuel flow using the twist-grip throttle. The rotor speed then reduced and the pilot noticed the acoustic low RPM warning.
- Subsequently, the pilot slightly increased the fuel flow again, and changed the governor switch from automatic into manual mode. He adjusted the engine speed manually from this point onwards.
- The pilot decided on an emergency landing.
- As a dense row of trees was located across the approach direction, the pilot turned the helicopter to the right and landed parallel to these.
- At 16:20, the helicopter made a hard touchdown and the main rotor hit a shed on the left-hand side.
- The helicopter rolled approximately 270 degrees to its left side and came to a standstill lying on its right side.
- The occupants were able to exit the wreckage by themselves.

3.1.3 Technical aspects

- The helicopter was registered for VFR flights.
- Helicopter HB-RXC was not formally airworthy at the time of the accident.
- At the time of the accident, both mass and centre of gravity of the helicopter were found to be within the permissible limits of the AFM.

- Between 21 August and 4 September 2011, the most recent maintenance work on the helicopter airframe and engine was certified. A work report was produced for this work.
- According to the technical files dated 4 March 2012, the operator’s work included removal and replacement of the fuel control unit (FCU).
- According to the operator's verbal statements, he had replaced all the bolts and nuts on the tail rotor gearbox housing and on the tail rotor.
- The technical files were inadequately maintained by the operator.
- No existing faults that could have caused or influenced the accident could be found in the engine or the fuel control unit and governor.
- An excess was measured on the first-stage power turbine rotor with part marking 81996. This is attributable to engine overspeed.
- The first-stage power turbine rotor was not manufactured by the engine manufacturer Honeywell and was therefore not subject to its quality system.
- The burst-open transmission, the damaged tail rotor driveshaft and the driveshaft components, which lay approximately 10 metres away from the helicopter's impact point, stood out at the accident site.
- The tail rotor components found lying near the helicopter were in all probability separated during the impact.
- Among other things, the retaining nut, which fixes the rotor to the tail rotor driveshaft, was not found at the accident site. It must be assumed that the retaining nut had come loose before the helicopter’s impact.
- Contact of the tail rotor with the ground can be excluded for forensic reasons.
- All of the examined fracture surfaces of the burst-open tail rotor transmission were spontaneous fractures. Vibration or fatigue fractures could not be located.
- In the area of the burst segment, helical marks were found on the inside of the pinion housing. These marks were caused by the rotating bevel gear during the fracture process.
- Both bevel gears were in good condition and showed little signs of wear.
- The bevel gear as well as the bevel pinion were damaged. The type of damage indicates that this was a result of the tooth meshing no longer being aligned after the transmission housing had broken apart, causing the tooth crest edges to touch each other.
- The tail rotor driveshaft’s run-out, measured on the outermost end of the shaft, was 1.46 mm.
- The thread on the outer end of the tail rotor driveshaft was severely damaged showing notches and plastic deformation. This damage was caused by the tail rotor hub.
- The crosshead was connected to the tail rotor by two pitch links. Both of these pitch links were bent.
- Plastic indentations were found on the front surface of the tail rotor hub. In terms of their shape, this plastic deformation corresponds to the two broken-off flanges of the static stop.

- Based on the available parts of the blade pitch mechanism, it must be assumed that the bolted connections for the bearing set installation, consisting of two ¼-inch bolts and the associated nuts, failed.
- With regards to the crosshead and the slider, the washers' contact surfaces did not display any plastic deformation. It can be concluded from this that the failure of both bolt connections is not attributable to an overload fracture.
- Following the failure of the bolted connections, the pitch change rod was no longer connected to the bearing set, which was fitted to the end of it, and therefore to the crosshead. This resulted in unstable control of the tail rotor blades and generated vibrations.
- Plastic deformation could be found on one bore hole of the slider, on the side facing the crosshead. It was, in all likelihood, caused by a broken bolt.
- The thread, to which the bearing set was fixed at the end of the pitch change rod, was sheared off.

3.1.4 General conditions

- Helicopter N6195G was imported into Switzerland on 14 March 2002 and based at St. Gallen-Altenrhein airport (LSZR).
- On 30 June 2002, FOCA granted the operator special permission for flights in Swiss airspace under the condition that the helicopter must be based in Switzerland.
- On 12 November 2009, helicopter N6195G was registered as HB-RXC in the special category of the Swiss aircraft register, within the 'historic' subcategory, and a certificate of airworthiness was issued.
- On 22 December 2010, helicopter HB-RXC's certificate of airworthiness was replaced by a permit to fly.
- For maintenance of helicopter HB-RXC, FOCA issued approvals to the operator and mechanic A.
- During the inspection of the helicopter, it went unnoticed that work had been certified by mechanic B, who did not possess an authorisation or an approval.
- Weather conditions had no influence on the accident.

3.2 Causes

The accident is attributed to the fact that the helicopter made a hard touchdown during the emergency landing and the main rotor hit a shed.

The failure of two bolted connections on the crosshead as well as of the retaining nut, an enormous imbalance affected the tail rotor driveshaft, which ultimately led the tail rotor transmission to burst and the tail rotor to fail.

The following factor contributed to the development of the accident:

- Inadequate maintenance work on the tail rotor.

Determined as systematic factors:

- Inadequate supervisory activity by FOCA.
- Incomplete process at FOCA with regards to dealing with historic aircraft.

4 Safety recommendations, safety advice and measures taken since the accident

Safety recommendations

According to the provisions of annexe 13 of the International Civil Aviation Organisation (ICAO) and article 17 of (EU) regulation no. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing directive 94/56/EC, all safety recommendations listed in this report are intended for the supervisory authority of the competent state, which must decide on the extent to which these recommendations are to be implemented. Nonetheless, any agency, any establishment and any individual is invited to strive to improve aviation safety in the spirit of the safety recommendations pronounced.

Swiss legislation provides for the following regulation regarding implementation in the Ordinance on the Safety Investigation of Transport Incidents (OSITI):

"*Art. 48 safety recommendations*

1 The STSB shall submit the safety recommendations to the competent federal office and notify the competent department of the recommendations. In the case of urgent safety issues, it shall notify the competent department immediately. It may send comments to the competent department on the implementation reports issued by the federal office.

2 The federal offices shall report to the STSB and the competent department periodically on the implementation of the recommendations or on the reasons why they have decided not to take measures.

3 The competent department may apply to the competent federal office to implement recommendations."

The STSB shall publish the answers of the relevant Federal Office or foreign supervisory authorities at www.stsb.admin.ch in order to provide an overview of the current implementation status of the relevant safety recommendation.

Safety advice

The STSB may publish safety advice in response to any safety deficit identified during the investigation. Safety advice shall be formulated if a safety recommendation in accordance with (EU) regulation no. 996/2010 does not appear to be appropriate, is not formally possible, or if the less prescriptive form of a safety advice is likely to have a greater effect. The legal basis for STSB safety advice can be found in article 56 of the OSITI:

"*Art. 56 information on accident prevention*

The STSB may prepare and publish general information on accident prevention."

4.1 Safety recommendations

4.1.1 Operational restrictions for historic aircraft

4.1.1.1 Safety deficit

On Thursday 20 December 2012, the pilot intended to fly from Balzers heliport (LSXB) to St. Gallen-Altenrhein airport (LSZR) in the Bell UH-1H helicopter, registered as HB-RXC. Three passengers boarded during a stop in Buchs/SG. After take-off, the pilot flew along the motorway in the direction of St. Gallen-Altenrhein.

Directly next to the motorway at the gravel quarry before coming to Rüthi, the occupants noticed very strong vibrations and an abrupt yaw to the right on the helicopter's vertical axis. One passenger heard a bang. The pilot partially lost control of the helicopter during this phase. The pilot therefore decided on an emergency landing. The helicopter made a hard touchdown and the main rotor hit a shed. The helicopter rolled approximately 270 degrees to its left side and came to a standstill lying on its right side. All of the occupants were able to exit the destroyed helicopter by themselves. One passenger was seriously injured as a result of the accident.

Helicopter HB-RXC was registered in the special category of the aircraft register, within the 'historic' subcategory.

When the UH-1H helicopter was registered in the Swiss aircraft register as HB-RXC, the Federal Office of Civil Aviation (FOCA) no longer applied the type certificate (TC) H3SO, in which relevant operational restrictions were recorded. Consequently, these sensible restrictions lost their validity. Although operational restrictions were made in the permit to fly, these only applied to the type of flight. The number of passengers on board was not limited. This is not prudent.

4.1.1.2 Safety recommendation No. 506

The Federal Office of Civil Aviation (FOCA) should assess on a case-by-case basis which restrictions are necessary for the operation of aircraft in the special category, within the 'historic' subcategory.

4.1.1.3 FOCA statement on the safety recommendation

In a letter dated 11 February 2016, FOCA said the following:

"When a new aircraft of the special category within the 'historic' subcategory is registered in the future, the Federal Office of Civil Aviation (FOCA) will, on a case-by-case basis for complex aircraft, review which hazards arise for third parties. This assessment will be carried out by the appropriate department using a simple matrix. The necessary documents will be developed and finalised over the course of 2016. If required, the necessary restrictions will be imposed in selected individual cases."

4.1.2 Maintenance work on historic aircraft

4.1.2.1 Safety deficit

On Thursday 20 December 2012, the pilot intended to fly from Balzers heliport (LSXB) to St. Gallen-Altenrhein airport (LSZR) in the Bell UH-1H helicopter, registered as HB-RXC. Three passengers boarded during a stop in Buchs/SG. After take-off, the pilot flew along the motorway in the direction of St. Gallen-Altenrhein. Directly next to the motorway at the gravel quarry before coming to Rüthi, the occupants noticed very strong vibrations and an abrupt yaw to the right on the helicopter's vertical axis. One passenger heard a bang. The pilot partially lost control of the helicopter during this phase. The pilot therefore decided on an emergency landing. The helicopter made a hard touchdown and the main rotor hit a shed. The helicopter rolled approximately 270 degrees to its left side and came to a standstill lying on its right side. All of the occupants were able to exit the destroyed helicopter by themselves. One passenger was seriously injured as a result of the accident.

HB-RXC was registered in the special category of the aircraft register, within the 'historic' subcategory.

The UH-1H helicopter type has complex systems and requires in-depth expertise for maintenance work. From the STSB's point of view, the operator of helicopter

HB-RXC was not qualified for an approval to carry out maintenance work on helicopter HB-RXC himself. Normally, maintenance work for such models has to be performed by qualified maintenance staff in appropriately qualified organisations.

4.1.2.2 Safety recommendation No. 507

The Federal Office of Civil Aviation (FOCA) should review the process of acquiring approvals for carrying out and certifying maintenance work on aircraft of the special category, within the 'historic' subcategory. They should also define and implement stricter requirements in order to ensure the necessary level of quality.

4.1.2.3 FOCA statement on the safety recommendation

In a letter dated 11 February 2016, FOCA said the following:

"In addition to the safety recommendation, the corresponding TM for differentiating between complex/non-complex maintenance work with regards to helicopters will be reviewed and, if necessary, revised.

Based on the proposed risk assessment, technical restrictions might also potentially be imposed, to ensure that, for example, all maintenance work classified as complex is carried out by an authorised maintenance organisation."

4.2 Safety advice

None

4.3 Measures taken since the accident

None

Payerne, 23 December 2016 Investigation Bureau STSB

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).

Berne, 13 December 2016

Annexes

Annexe 1: Helicopter HB-RXC's maintenance record for the airframe from 4 March 2012.

10'829.8 "Airframe"

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Unterhaltsnachweis – Historique de l'entretien
Maintenance Record

Baumuster / Type / Type	Model 205 (UH-1H)	Serie- Nr. / No de série / Serial No	65-09688

Datum / Date	Betriebsstunden * / Heures de service / Time in service TSN	TSO	Ausgeführte Arbeiten und Unterhaltsbescheinigungen / Travaux effectués et attestations d'entretien / Maintenance actions and releases
04-03-2012	10'829.8		25 Std. Schmierung
		-	REINIGUNG + INSPECTION M/R BLADE
		-	BATTERIE CHECK
		-	HGR-BEARING OVERHAUL EIN-
			GEBAUT (NEUE ORIG. SCHRAUBEN + MUTTERN)
		-	ROTATING CNTL BOLTS AUSGETAUSCHT
		-	COMPRESOR-WASH
		-	OILCOOLER BEARINGS AUSGETAUSCHT
		-	OIL-WECHSEL: ENGINE + TRANSMISSION
		-	FUEL-FILTER + OIL-FILTER AUSGETAUSCHT
		-	OIL-SCHLAUCH 205-062-650-023
			AUSGETAUSCHT
		-	FCU AUSGEBAUT
		-	SPLINE INSPECTION
		-	AUSTAUSCH FCU EINGEBAUT
		-	FEIN-EINSTELLUNG SHM-BALZERS

* TSN: Time since new / Heures de service totales / Gesamtbetriebszeit
TSO: Time since overhaul / Heures de service depuis révision / Betriebszeit seit Überholung

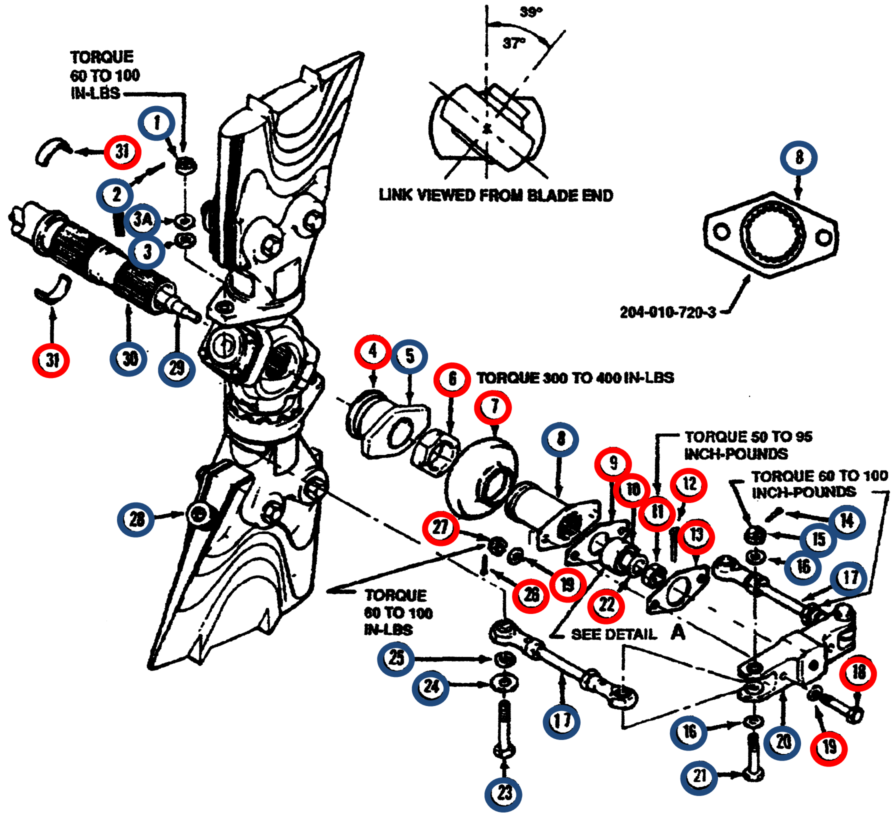
BAZL 5202 dfe

Glossary for Annexe 1

25 Std. Schmierung	25 h lubrication
REINIGUNG + INSPECTION M/R BLADE	Cleaning and inspection M/R blade
BATTERIE CHECK	Battery check
HGR-BEARING OVERHAUL EIN-GE-BAUT (NEUE ORIG. SCHRAUBEN + MUTTERN)	HGR bearing overhaul fitted (new original bolts and nuts)
ROTATING CNTL BOLTS AUSGE-TAUSCHT	Rotating CNTL bolts replaced
COMPRESOR-WASH	Compressor wash
OILCOOLER BEARINGS AUSGE-TAUSCHT	Oil cooler bearings replaced
OIL-WECHSEL: ENGINE + TRANSMIS-SION	Oil change: engine + transmission
FUEL-FILTER + OIL-FILTER AUSGE-TAUSCHT	Fuel filter + oil filter replaced
OIL-SCHLAUCH 205-062-650-023 AUS-GETAUSCHT	Oil hose 205-062-650-023 replaced
FCU AUSGETAUSCHT	FCU replaced
SPLINE INSPECTION	Spline inspection
AUSTAUSCH FCU EINGEBAUT	Replacement FCU fitted
FEIN-EINSTELLUNG SHM-BALZERS	Fine tuning SHM-Balzers

Annexe 2: Tail rotor installation in accordance with TM 55-1520-210-23-1

TM 55-1520-210-23-1



1. Nut
2. Cotter pin
3. Washer
3A Washer
4. Shim
5. Static stop
6. Nut, hub retaining
7. Boot
8. Slider
9. Retainer plate
10. Bearing set
11. Nut
12. Cotter pin
13. Shim
14. Cotter pin
15. Nut
16. Washer
17. Pitch link
18. Bolt
19. Washer
20. Crosshead
21. Bolt
22. Washer
23. Bolt
24. Washer, safety
25. Spacer
26. Cotter pin
27. Nut
28. Hub and blade assembly
29. Pitch change rod
30. Gearbox shaft
31. Split cone set

Figure 5-48. Tail Rotor Installation

5-108 Change 13

existing parts (blue circle)

missing parts (red circle)