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Swiss Transportation Safety Investigation Board STSB

Aviation Division

Final Report No. 2267 by the Swiss Transportation Safety Investigation Board STSB

concerning the accident involving the helicopter Cabri G2, HB-ZLJ,

on 13 July 2013

Neuhaus, Municipality Wichtrach/BE

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Ursachen

Der Unfall ist auf die Desintegration des Gebläserades des Kühlsystems zurückzuführen, was zu einem Triebwerksausfall mit anschliessender Notlandung führte.

Als direkte Ursachen der Desintegration des Gebläserades wurden folgende Faktoren ermittelt:

- Ungeeignete Konstruktion des Gebläserades;
- Produktionsfehler bei der vorderen Scheibe des Gebläserades.

General information on this report

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

In accordance with Article 3.1 of the 10th edition, applicable from 18 November 2010, of Annex 13 to the Convention on International Civil Aviation of 7 December 1944 and Article 24 of the Federal Air Navigation Act, the sole purpose of the investigation of an aircraft accident or serious incident is to prevent accidents or serious incidents. The legal assessment of accident/incident causes and circumstances is expressly no concern of the investigation. It is therefore not the purpose of this investigation to determine blame or clarify questions of liability.

If this report is used for purposes other than accident/incident prevention, due consideration shall be given to this circumstance.

The definitive version of this report is the original in the German language.

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 Summer Time (CEST) applied as local time in Switzerland. The relation between LT, CEST and coordinated universal time (UTC) is:
LT = CEST = UTC + 2 h

Final Report

Aircraft type	Cabri G2	HB-ZLJ
Operator	Swiss Helicopter AG, Hartbertstrasse 11, 7000 Chur	
Owner	Swiss Helicopter AG, Hartbertstrasse 11, 7000 Chur	

Flight instructor	Swiss citizen, born 1981			
Licence	Commercial pilot licence, helicopter – CPL (H), according to the European Aviation Safety Agency (EASA), issued by the Federal Office of Civil Aviation (FOCA). Flight instructor – FI(H)			
Flying hours	**total**	1279 h	**during the last 90 days**	81:30 h
	on the accident type	250 h	**during the last 90 days**	30:02 h

Trainee pilot	Swiss citizen, born 1983			
Licence	---			
Flying hours	**total**	58:25 h	**during the last 90 days**	4:46 h
	on the accident type	56:26 h	**during the last 90 days**	4:46 h

Location	Neuhaus, Municipality Wichtrach/BE	
Coordinates	610 004 / 189 706	**Altitude** 532 m AMSL
Date and time	13 July 2013, 12:25	

Type of operation	VFR, training flight
Flight phase	Cruise flight
Type of accident	Engine failure due to disintegration of cooling fan

Injuries to persons

Injuries	Crew members	Passengers	Total no. of occupants	Others
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
Other damage	Slight damage to the ground

1 Background

1.1 Flight preparations and flight details

1.1.1 General

The following description of the flight preparations and flight details is based on the footage from the video camera fitted in the cockpit as well as statements from the flight instructor, the trainee pilot and a mechanic.

1.1.2 Flight preparations

On 13 July 2013, the flight instructor and trainee pilot planned to carry out a training flight between 08:00 and 10:00 from the Bern-Belp base. They intended to initially complete a navigation flight in the mountains, followed by a few circuits for outside landings and a few landings on sloped terrain. After the trainee pilot had completed all the usual preparations, he discussed the planned route for the mountain flight with the flight instructor. After that, they went to the Cabri G2 helicopter, registered as HB-ZLJ, to prepare it for the flight.

After the aircraft had been filled with 39 litres of AVGAS 100LL aviation fuel, the tank contained 70 litres. When the external checks had been completed, the trainee pilot fitted a small video camera to the middle of the rear bulkhead in the cockpit. This camera was on during the entire flight and the quality of the recorded video and audio was very good.

The crew in the aircraft HB-ZLJ took off from Bern-Belp at 08:50 and headed towards the Bernese Oberland. The navigation flight went according to plan.

On their return flight from the Alps, the crew headed towards the Schwarzenegg region, which is north-east of Thun. The flight instructor was aware of a suitable location in that area where the remaining exercises could take place. He pointed out the cables and adviced on suitable flight tactics to the trainee pilot. Subsequently, they headed for the aforementioned location. At first, a standard landing took place. Thereafter they discussed further exercises. The helicopter was then hovering approx. one meter above ground and various landing exercises were carried out. Shortly before a further landing on sloped terrain, the crew heard a loud bang, which was followed by an odour similar to that when using a cutting disc on metal. The trainee pilot asked the flight instructor what this could be, whereupon the latter took control of the helicopter and landed immediately. Control of the helicopter as well as the indications in the cockpit were normal. After the landing, the flight instructor closed the fuel shut-off valve between the pilots' seats. The engine came to a standstill after 10 to 20 seconds. After that, the flight instructor carried out all further manipulations. Finally, the trainee pilot applied the rotor brake.

The crew disembarked and the flight instructor opened the cowling to the engine bay to look for a potential cause. In addition, he checked all areas in the engine bay that are also part of pre-flight checks. He could not identify any anomalies.

Subsequently, the flight instructor telephoned a mechanic located at the Bern-Belp base and described what had occurred. The mechanic asked the flight instructor to check various items, including that the air inlet grille mounted to the housing of the air cooling system had been fitted firmly with a Velcro strip. The flight instructor established that this grille had been mounted correctly. Through the grille he saw the flywheel, in which the starter motor engages when starting the engine, and he noticed that 6 teeth of the flywheel's ring gear were worn. Thereafter the mechanic decided to inspect the helicopter himself. Another helicopter took him to the location of HB-ZLJ. After his arrival, he started looking for a possible cause.

First he checked the ring gear on the flywheel. The mechanic rated the wear and tear of the 6 teeth as normal. Then he checked the firm fit of the cooling fan. He could not establish any anomalies here either. Subsequently, he started to examine the helicopter focusing on the entire drivetrain. In a cavity next to the main rotor transmission, top left in the direction of the flight, he found the power supply unit for the strobelight which had come loose from its mounting. This unit had only been attached with Velcro and must have come loose during the flight. He asked the flight instructor to take a seat in the helicopter and then knocked on the rear bulkhead using the loose part. The flight instructor confirmed that the noise could have sounded similar. After a functional check, the mechanic reattached the unit using the Velcro and some additional duct tape.

Thereafter, the flight instructor and the mechanic agreed to carry out a check flight. The intention was to fly the mechanic to the nearest point from where he could then be collected by car. Hovering took a normal course. On the flight towards the school in Eriz Bieten, the mechanic noticed an odour. He believed that this was most likely caused by an electrical fault. He adjusted the controls of the cabin heater; but the odour remained unchanged. After they had landed at the school, they switched off the engine once more. The mechanic opened the cowling again and inspected the engine bay. In doing so, he noticed that the plastic surface coating of the air filter foam was singed in the vicinity of the exhaust. Additionally, he inspected all electrical cables without finding any clues with regards to the detected odour. He removed the air filter and thus noticed that a nut and bolt had come loose on the control flap of the carburator heating. He promptly tightened both. Subsequent functional checks revealed no further defects. The mechanic then asked the flight instructor to start the engine and to collect the trainee pilot. Prior to take-off, he checked a few items once more with the engine running. He did not notice any anomalies in the process and closed the cowling.

The flight instructor took off and flew to the trainee pilot. After the latter had strapped into the left seat, the flight instructor informed him about the preceding inspection flight. Furthermore he briefed the trainee pilot that they would return to the mechanic, in case the odour returned. Shortly after take-off, an intense odour developed in the cockpit and the flight instructor landed HB-ZLJ next to the school in Eriz Bieten once again. During the landing, the mechanic noticed the odour again. This odour then evaporated again. After the mechanic had been provided with the relevant information, he opened the cowling with the engine running and inspected the engine bay. He could not identify any abnormal odours. He focused on the air filter again. He cut off a small piece of the foam and held the side with the surface coating next to the hot exhaust. Subsequently he took a smell at it. The odour seemed to be similar to the odour he had detected in the cockpit. The flight instructor also took a smell at it. Together they came to the conclusion that the odour detected during the flights must have been caused by the singed surface coating of the foam. Subsequently they decided to fly the helicopter back to the base in Bern-Belp. The flight instructor judged the 25 litres of aviation fuel in the tank to be sufficient for the approx. 10 minute return flight to the base.

1.1.3 Flight details

HB-ZLJ took off at about 12:10 from the grounds next to the school in Eriz Bieten. Take-off was carried out by the flight instructor who sat in the right seat of the cockpit. During the climb, the trainee pilot took control of the helicopter. Flying along the River Zulg, HB-ZLJ gained altitude and climbed up to 4500 ft QNH heading towards Oberlangenegg. The crew then headed towards Oberdiessbach and passed over it at an altitude of 4200 ft QNH.

Approximately eight minutes after take-off, HB-ZLJ was descending slightly between Wichtrach and Münsingen when the crew once again noticed the same odour in the cockpit. At that moment the helicopter was at 3880 ft QNH. The flight instructor opened the right door and looked to the rear. He observed "*greyish smoke*" coming from the engine cowling. His first thought was that this could be a fire. He immediately took control of the helicopter and informed the aerodrome control tower in Bern-Belp that they would initiate a precautionary landing. HB-ZLJ was at 2900 ft QNH with an airspeed of approximately 75 KIAS (knots indicated airspeed).

The flight instructor reduced the power to about 40 % and initiated the descent with a steep turn to the right. The airspeed was reduced to 50 to 60 KIAS. At 12:19, when the steep turn was almost completed and the helicopter was at 2500 ft QNH, when a rattling noise originated from the engine bay, followed by marked vibrations. Four seconds later, the yellow warning light for low rotor speed (<515 RPM) illuminated. Another two seconds later, the engine stopped. The flight instructor immediately initiated an autorotation. For the landing he chose a short cut grass field, located in front of a crop field. In the meantime, the rotor speed had stabilised in the normal range and the speed was around 70 KIAS. As the flight instructor also suspected tail rotor failure, he decided to carry out a flared glide landing.

When the helicopter flew over the grass field, the speed was still almost 60 KIAS and the warning light for high rotor speed (>540 RPM) came on. The flight instructor realised that the landing would end in the crop field. He further discovered that there was a relatively high fence around the cut grassland. He subsequently tried to overfly the fence. Nevertheless, HB-ZLJ still clipped the top line of the fence. Performing a glide landing, HB-ZLJ subsequently touched down in the crop field. During the sliding phase, the flight instructor pulled the cyclic control to the back in order to prevent the helicopter from tilting forward. After the helicopter had come to a standstill, the crew released their seat belts. As they suspected a fire, they immediately left the cockpit while the rotor was still turning. This was ordered by the flight instructor: "[First name of the trainee pilot]*, duck and exit...!*" When doing so, the trainee pilot caught his right leg on the cyclic control on his side of the aircraft, moving it to the left. As a result of this control input the helicopter did not move around its longitudinal axis.

The crew was unhurt and HB-ZLJ was severely damaged. No fire broke out.

1.2 Meteorological information

1.2.1 General weather conditions

Switzerland was on the edge of a high-pressure system centered west of Ireland.

1.2.2 Weather at the time of the accident

The weather was sunny with 1/8 to 2/8 of the sky covered with cumulus clouds. There was light wind at ground level. In the Aare valley there was a mixture of valley wind and an intermittent light north-easterly wind.

Weather/clouds	1/8 - 2/8 cumulus
Visibility	Approx. 20 km
Wind	Variable 1 kt
Temperature / dew point	23 °C / 14 °C
Atmospheric pressure QNH	1019 hPa
Hazards	None

1.2.3 Astronomical information

Solar conditions	Azimuth: 144°	Elevation: 61°
Light conditions	Daytime	

1.3 Aircraft information

1.3.1 General

Registration	HB-ZLJ	
Aircraft type	Cabri G2	
Characteristics	Single-engine light helicopter with two seats and skid landing gear. Main rotor with three blades. Torque balancing with encased tail rotor.	
Manufacturer	Hélicoptères Guimbal, Aix-en-Provence/F	
Year of manufacture	2011	
Serial number	1023	
Engine	Lycoming Engines 0-360-J2A Air-cooled, four-cylinder horizontally opposed engine, serial number L-41795-36E, year of manufacture 2011, continuous power 108 kW (145 HP) at 2700 RPM.	
Operating hours	Airframe:	1179.8 h (TSN[1])
	Engine:	1179.8 h (TSN)
Max. permissible mass	Max. permissible take-off mass: 700 kg	

[1] TSN – time since new

Mass and centre of gravity	The mass of the helicopter at take-off was just short of 643 kg. The mass of the helicopter at the time of the accident was just short of 600 kg. Both mass and centre of gravity were within the permissible limits according to the flight manual.
Maintenance	The last scheduled maintenance work, a 100-hour inspection including an annual inspection, was certified at 1100.6 hours on 4 June 2013.
Technical restrictions	The following items were entered into the hold item list: *"#29, 28.06.13: Alt. warning light goes on* *Action taken: Checked, if light goes on, check both ind. on EPM, if green ➔ OK. Will be repaired later* *#30, 11.07.13: Alternator fails* *Action taken: on monitoring"*
Approved fuel quality	Aviation fuel AVGAS 100LL
Fuel quality at the time of the accident	According to the analysis, the fuel conformed with the specifications for aviation fuel 100LL.
Fuel quantity	According to the flight preparation, the fuel quantity at take-off was 70 l of AVGAS 100LL. This amount of fuel was sufficient for a flight time of approximately 1:45 hrs.
Certificate of registration	Issued by FOCA on 1 July 2012 / no. 2, valid until deletion from the aircraft register.
Certificate of airworthiness	Issued by FOCA on 29 May 2013, valid until revoked.
Airworthiness review certificate	Date of issue: 28 May 2013 Date of expiry: 24 June 2014
Type of use	Private VFR[2] by day and by night, commercial VFR only by day

1.3.2 Engine and air cooling system

1.3.2.1 General

The air-cooled horizontally opposed engine is mounted in the engine bay behind the cockpit. The output shaft is at the front of the engine. Power is transmitted from the engine to the main transmission or rather to the freewheel clutch via a poly v-belt. The engine pulley is mounted on the front of the engine's flywheel. The engine

[2] VFR – visual flight rules

pulley with the poly v-belt is located behind the rear bulkhead of the cockpit and in front of the housing for the air cooling system. Engaging and disengaging of the engine is achieved by tensioning and slackening the poly v-belt.

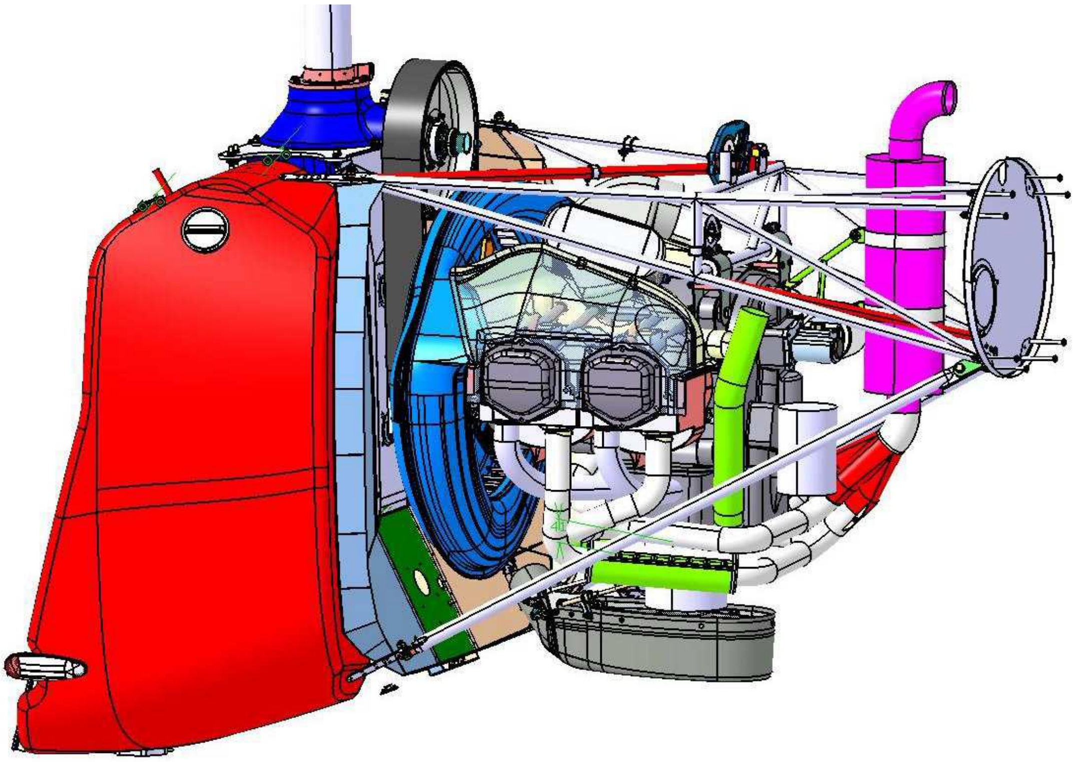


Illustration 1: Cockpit (red), engine pulley with poly v-belt (dark grey), housing of the air cooling system (blue).

The air cooling system consists of a rotating cooling fan and the associated housing with ventilation plates. The cooling fan is also mounted to the flywheel using 12 screws.

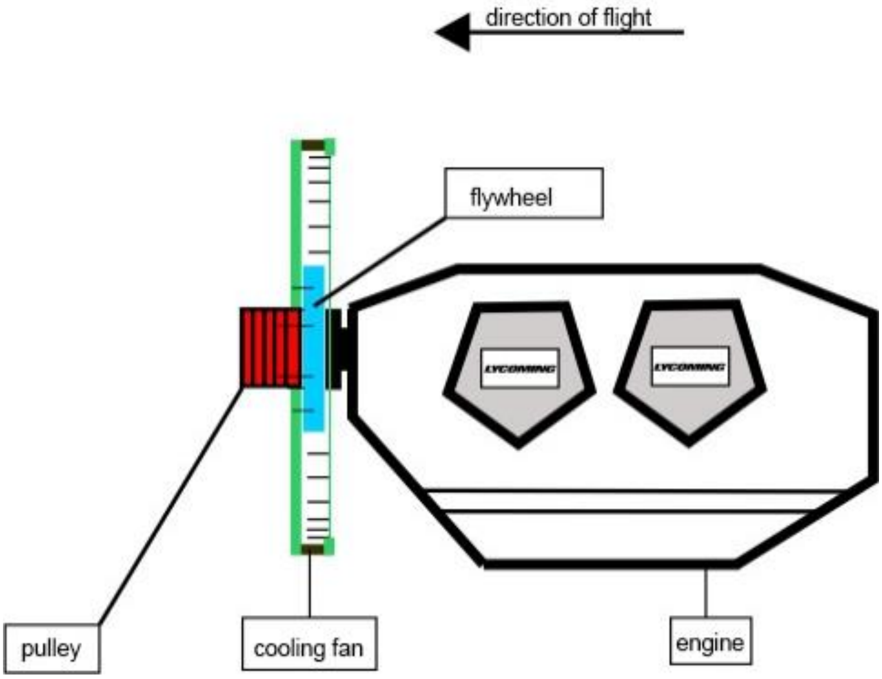


Illustration 2: Schematic showing the order in which powertrain and cooling components are installed.

1.3.2.2 Cooling fan

The cooling fan (see Annexe 1) consists of:

- The plate-shaped front disc made from 2024 T351 aluminium. The outer diameter is 560 mm. The inner diameter which is used for centering during assembly is 255 mm;
- The rear ring with U-profile, machine-manufactured from 6061 T651 aluminium;
- The 64 fan blades, also made from aluminium.

All these parts are held together with a total of 128 countersunk screws with a 4 mm shaft diameter and a length of 58 mm. The fan blades also serve as spacers between the front disc and the rear ring. The assembly positions of the fan blades are numbered from 1 to 64. If necessary, the cooling fan is balanced on the rear ring using small steel discs, 22 mm in diameter and 1 mm in thickness. The screws retaining the cooling fan are used for mounting these steel balancing weights.

When mounting the cooling fan to the flywheel, the front disc is bolted to the flywheel of the engine from the front with 12 short countersunk M6 × 15 screws. The inner diameter of the front disc fits onto the spigot of the flywheel.

1.3.2.3 Visibility and accessibility of the air cooling system

The majority of the flywheel and the cooling fan is covered by the air cooling housing. This air cooling housing is made of carbon-fibre reinforced plastic; with a thickness of approx. 1.3 millimetres. In certain places there is very little clearance between the rotating parts and the non-rotating air cooling housing. The cooling airflow generated by the cooling fan is collected in the housing and guided to the cylinders.

When the cowling of the engine bay is open, the area of the air intake opening is not easily visible. In particular, only a small part of the back of the front disc is visible (see illustration 3). Visibility is additionally restricted by the air inlet grille and other engine components. The rear ring is not visible in any case.

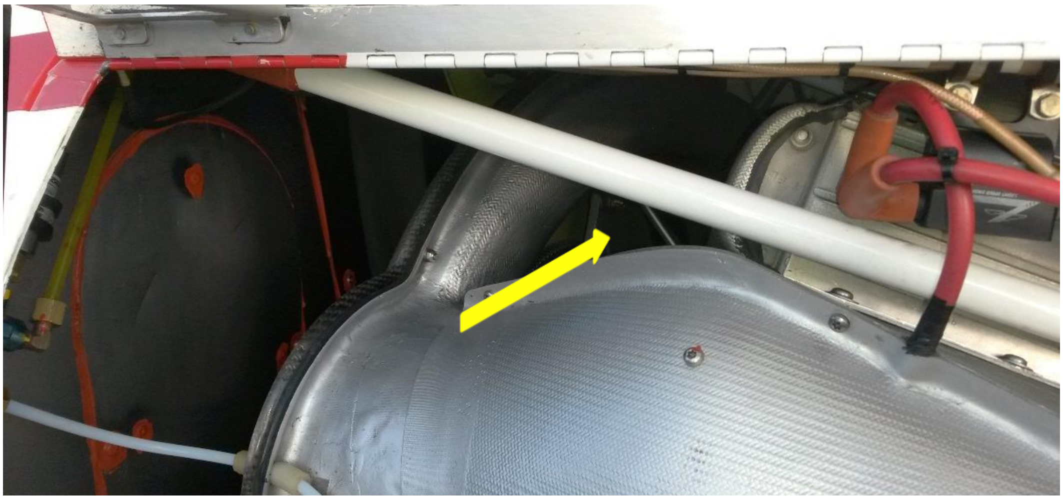


Illustration 3: View of the air cooling system in the engine bay. The yellow arrow points to the area of the air intake.

Illustration 4: Close-up view of the air intake with the grille removed.

To inspect the rear ring and the mounting screws of the fan blades, the air cooling system must be disassembled in the area of the cylinders (see Annexe 3). The entire area can then be inspected by turning the cooling fan. In order to do so, the spark plugs must be removed from the engine. To inspect the front of the cooling fan including the area where it is bolted to the flywheel, the engine has to be removed.

1.3.3 System displays

1.3.3.1 General

In the Cabri G2, a centrally located display, called electronic pilot monitor (EPM), displays the status of various systems.

The indicators displayed on this EPM include:

- Multiple limit indicator (MLI)
- Engine- and rotor-speed
- Amount of fuel and flow rate
- Fire warning
- Operating status of the carburettor pre-heating and carburettor temperature
- Cylinder head temperature
- Oil temperature
- Oil pressure
- Fuel pressure
- Operating status of the battery
- Outside air temperature

The EPM is controlled using five buttons located on the right hand side of the display panel.

Illustration 5: Image of the EPM with French labels and SI units.

Above the EPM there are seven visual indicators which display system status or warnings independent of the EPM by illuminating a yellow or red light. From left to right, these are the indicators for the electric starter, the automatic governor, the rotor brake, the oil pressure, the temperature in the main transmission, the low fuel warning and the alternator.

The manufacturer uses the acronym BARC for the fuel and rotor alarm device; whose indicators are located to the left of the EPM. As a backup to the EPM, the system generates visual and acoustic signals to inform the pilot on the current speed of the main rotor. If in doubt, these indications should take precedence to the indicators on the EPM.

Illustration 6: Overview of indicators above and left of the EPM.

1.3.3.2 Engine speed ranges and limitations

The speed of the rotor and engine is displayed on a dial in analogue format. In addition, a field on the bottom left of the dial displays the rotor speed digitally in white digits on a black background. The following relevant ranges and limitations are displayed on the EPM with regards to engine and rotor speed:

Rotor:

Minimum:	450 RPM
Lower yellow range:	450 - 515 RPM
Green range:	515 - 540 RPM
Upper yellow range:	540 - 610 RPM
Maximum:	610 RPM

As soon as the rotor speed reaches the yellow range, the background colour of the field for the digital rotor speed indicator changes to yellow and the digits are displayed in black. In addition, the “high NR horn” alert sounds when the rotor speed is above 594 RPM, whereas the “low NR horn” alert sounds when the rotor speed is below 466 RPM.

Engine:

Minimum:	2585 RPM
Green range:	2585 - 2700 RPM
Maximum:	2700 RPM

1.3.4 Emergency procedures

1.3.4.1 General

Amongst other things, the flight manual of HB-ZLJ defines the emergency procedures.

1.3.4.2 Loss of power

The following relevant points can be found in the chapter "power failures":

"General

<u>Engine failure</u> can be detected by:

- *Yaw acceleration, nose to the right,*
- *Engine noise level decreases,*
- *Tachometer needles desynchronization on the EPM* (*engine decreases*)
- *OIL P warning on the EPM and OIL P red light coming ON.*
- *Plasma beeper,*
- *Rotor speed decreasing and "low NR" horn.*

[…]

<u>Primary transmission failure</u> can be detected by:

- *Yaw acceleration, nose to the right,*
- *Engine noise level decreases,*
- *Tachometer needles desynchronization on the EPM* (*engine increases*). *Eventual engine overspeed <u>only if the governor is OFF</u>*
- *Rotor speed decreasing and "low NR" horn.*

[…]

<u>All cases:</u>

1. *Lower the collective immediately and maintain full down,*
2. *Use pedals to control yaw,*
3. *Maintain IAS between 30 and 50 kt IAS (50 kt IAS recommended),*
4. *Select landing area and manoeuvre to land into the wind,*
5. *Adjust collective to centre NR in green arc,*
6. *When the landing is ensured, consider engine restarting* […].
7. *At about 60 ft AGL, apply cyclic to raise the helicopter nose smoothly and continuously. Below 50 kt IAS this manoeuvre will not stop sink rate.*
8. *As ground closes-on, apply forward cyclic to level the helicopter while raising the collective to stop sink rate.*
9. *Use pedals to minimize ground drift,*
10. *Once stopped, lower the collective.*

<u>Note</u>: Average manoeuvre requires about 200 to 300 m (650 to 1000 feet) free of obstacle.

Note: During an emergency autorotation, always monitor airspeed carefully. Increasing airspeed above 50 kt IAS makes the landing easier, but requires a longer landing area.

[…]*”*

1.3.4.3 Engine fire

The emergency procedures in case of an engine fire are defined as follows:

“Engine fire can be detected when the EPM fire warning lights up:

[…]

In flight:

Once fire is confirmed:

LAND IMMEDIATELY

1. *Shut cabin heater OFF,*
2. *Lower the collective to enter autorotation as per procedure page* […]*,*
3. *Shut fuel valve OFF,*
4. *Shut fuel pump OFF,*
5. […]*,*
6. *Perform an autorotation landing according to pages* […]*,*
7. *Pull rotor brake,*
8. *Wait for complete rotor stop before evacuating the cabin.”*

1.4 Details on the wreckage, the impact and the accident site

1.4.1 Accident site

The accident site was approximately 1 km north-northwest of the village Wichtrach and almost 100 m east of the road leading from Wichtrach to Münsingen. The helicopter landed on dry ground in a field with crops up to one-metre high.

1.4.2 Impact

The helicopter performed a glide landing, touching down in the crop field and stopped after few metres.

1.4.3 Wreckage

1.4.3.1 General

Lap and shoulder belts were worn and withstood the impact forces. The flight instructor was wearing a helmet. The trainee pilot was wearing a headset.

The following facts could be established from the wreckage in detail:

- The master switch, the strobelight, the electric fuel pump, the alternator, the position lights and the landing lights were all switched off.
- The main rotor clutch was in the engaged position.
- The lever for the collective was in the lowest position.
- The circuit breakers were all pushed.
- The main switch for the fuel supply was in the OFF position.

- The automatic emergency locator transmitter (ELT) was in the ARMED position but was not activated.
- The rotor brake was in the OFF position.
- The mixture lever was in the FULL RICH position.
- One main rotor blade had cut through the top of the tail boom, severing the driveshaft of the encased tail rotor.

A visual check of the connections, the connecting rods and bell cranks provided no evidence of pre-existing faults.

At the accident site, it was established that the air cooling housing was destroyed and the cooling fan severely damaged. A large segment was torn off (see illustration 7). As a result of the cooling fan's disintegration, the mixture control cable wound up to the point that it ruptured. This caused the engine to stop at a height of almost 2400 ft, which corresponds to around 200 m above ground.

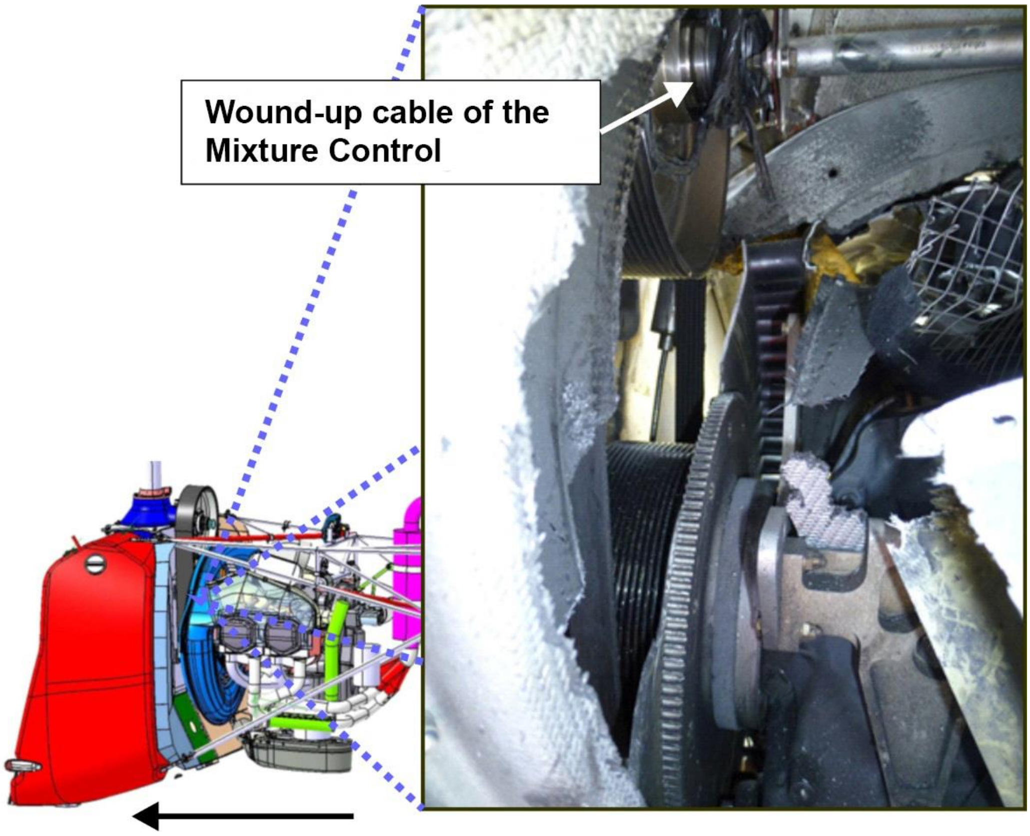


Illustration 7: Damage in the area of the cooling fan. The black arrow indicates the flight direction.

For further investigations, the engine and the air cooling system were removed.

The visual inspection of the air cooling housing showed:

- The housing had been torn apart and fractured into several pieces.
- These parts were of varying sizes.
- Several parts showed abrasion marks on the inside of the housing.
- The direction of these abrasion marks was consistent with the direction of rotation of the cooling fan.

1.4.3.2 Damage to the cooling fan

A first assessment of the severely damaged cooling fan showed (see illustration 8):

One segment of the cooling fan was torn off. The innermost diameter of the front disc still remained intact despite the disc's fracture.

The torn-off segment, consisting of a piece of the front disc, a piece of the rear ring and 17 fan blades attached to it, was partially plastically deformed. The affected blades are numbered 49, 50 to 64 and 1. Several blades showed impact marks.

In the area of the eight blades numbered 41 to 48, there were two round balancing weights per blade under each mounting nut towards the rear ring. One balancing weight had a mass of 2.77 g. The total balancing mass was thus 44.32 g.

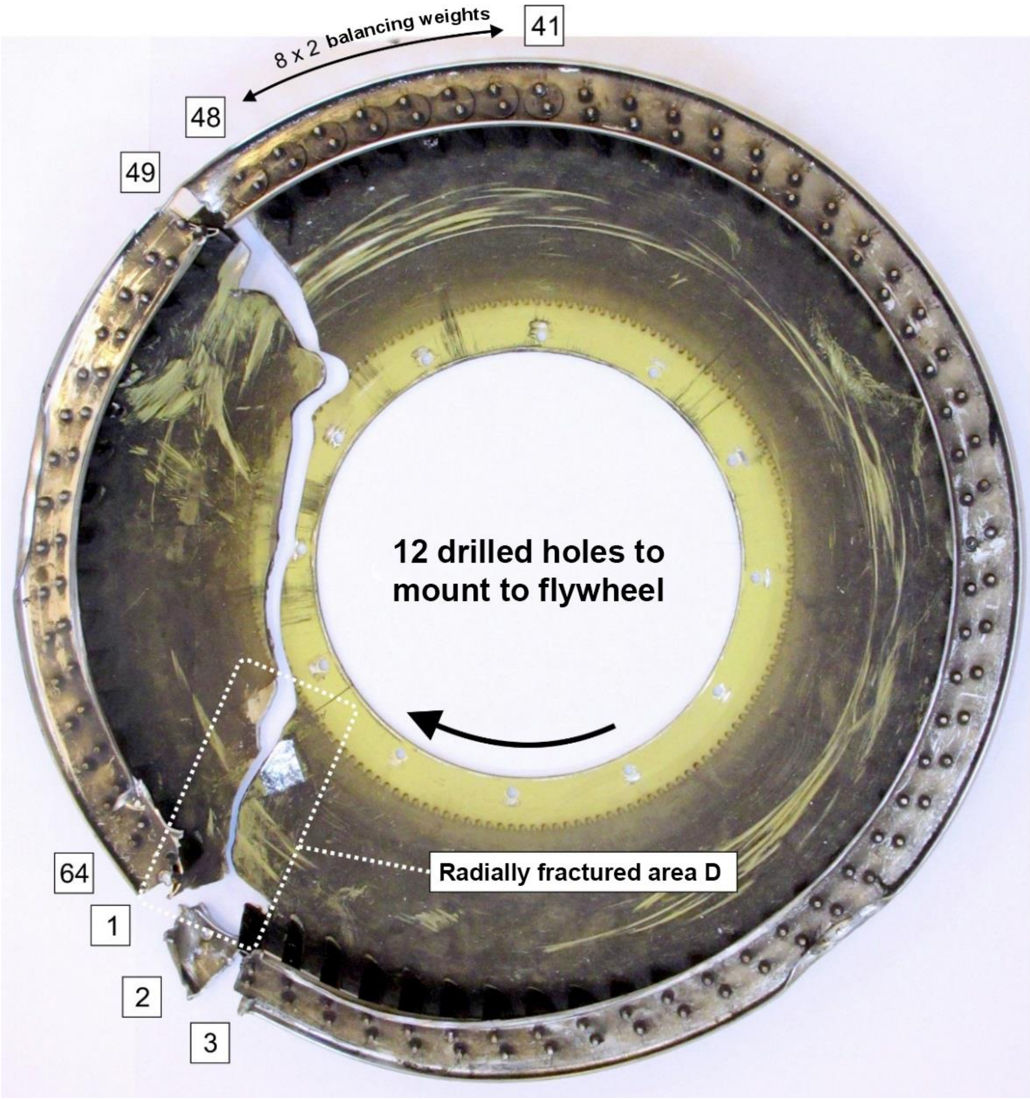


Illustration 8: Rear view of HB-ZLJ's damaged cooling fan. The black arrow indicates the direction of rotation. The numbers in the white squares correspond to the numbering of the fan blades.

1.4.3.3 Damage to the rear ring of the cooling fan

The small missing piece of the rear ring and the matching blade no. 2 were found loose in the engine bay. In order to perform a comprehensive investigation of the rear ring's fractured surfaces, both parts of the fractured areas were available. The inner screw was still in blade no. 2. However, the threaded part with the nut was torn off and could not be found. Only the shaft of blade no. 2's outer screw was found in the engine bay.

1.4.3.4 Damage to the front disc of the cooling fan

Two smaller pieces of the front disc could not be found. The bigger of the two was approximately 10 cm^2. This bigger piece was originally connected to blade no. 2. With a minor exception, all fracture surfaces were available on both sides to allow a fracture surface investigation of the front disc.

Abrasion marks in the direction of rotation of the cooling fan were found on the front of the front disc.

After the accident, the larger part of the cooling fan was still fixed to the flywheel of the engine with the 12 countersunk screws. The fracture ran through the bore hole of one of these screws. This part of the front disc showed plastic deformations, particularly in the outer area, in close proximity to the radial fracture area D (see illustration 8). The outer edge of the front showed significant abrasion marks in area A. There were also abrasion marks in the areas B and C (see illustration 9).

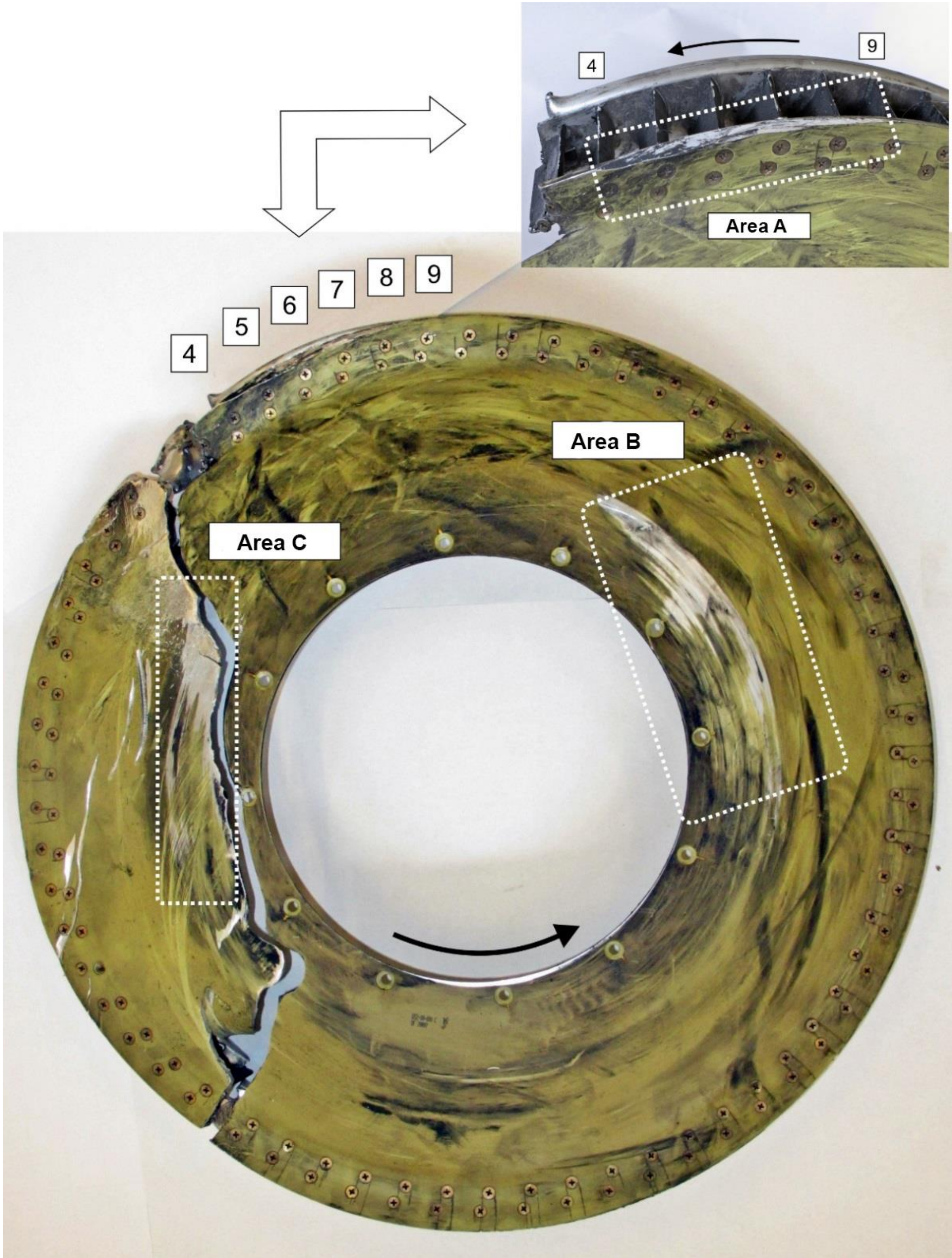


Illustration 9: Front view of HB-ZLJ's damaged cooling fan with detail of the abraded outer edge. The black arrow indicates the direction of rotation.

1.5 Tests and research results

1.5.1 General

The fractured cooling fan of HB-ZLJ was thoroughly examined. For comparison, two cooling fans in working condition, manufactured to identical specifications and from helicopters of identical construction were available for the investigation. One cooling fan with around 400 operating hours was from VH-ZZT, registered in Australia. The other cooling fan came from HB-ZLS. The latter was only used for surface investigations and had about 400 operating hours.

The source material 2024 T351 aluminium was also made available. According to the manufacturer, the front disc of the cooling fan is manufactured from such material. The high strength of this material results from heat treatment followed by ageing at room temperature. This material is susceptible to lose its mechanical properties and strength when exposed at temperatures above 100 °C.

With this material and the drawings of the manufacturer, the following examinations and investigations were carried out:

- Establishment of the design features
- Identification of the manufacturing process
- Dimensional checks
- Examination of the chemical composition and metallographic microstructure
- Examination of the mechanical material properties
- Examination of the fracture surfaces
- Assessment of the surfaces

1.5.2 Design features

Power is transmitted from the flywheel of the engine to the main transmission and to the cooling fan. Torsional and lateral vibrations caused by the four-cylinder engine affect the flywheel additionally.

In addition to the power, these torsional and lateral vibrations are also transmitted from the flywheel through the bolted connection to the front disc of the cooling fan. These dynamic loads have to be considered in the design of the front disc of the cooling fan.

1.5.3 Manufacturing process

1.5.3.1 Rear ring

The examination confirmed that the ring had been machined. The ring surface had been anodically oxidised and electrolytically dyed. There was no evidence of surface corrosion anywhere, not even under the nuts of the blade fixing.

1.5.3.2 Front disc

No facts could be established with regards to the manufacturing process. During the examination of the engine-facing surface of the front disc, circular grooves were discovered. The source material is however free of such grooves. It must be assumed that these grooves were created during the manufacturing process of the front disc. Grooves like these normally develop during forming under pressure on a spinning lathe. During such manufacturing processes, the unprocessed blank is often heated. A manufacturing process like this leads to a degradation of quality in aluminium 2024 T351; it loses strength and becomes brittle.

1.5.4 Dimensions

The dimensions of the rear ring and the fan blades corresponded with the details on the manufacturer’s drawings.

When checking the front disc, large discrepancies were found with regards to the thickness. The manufacturer’s drawing specifies 4 mm (P.M.) thickness. The measurements taken were between 3.1 and 3.9 mm. According to the manufacturer, the label (P.M.) stands for “*pour memoire*”. The source material has a thickness of 4 mm. All other measurements on the drawing which could be checked were complied with.

Examining the front disc thickness of helicopter VH-ZZT produced measurements between 3.7 and 4.1 mm.

1.5.5 Examination of the chemical composition and metallographic microstructure

The chemical composition of the rear ring, the front disc and one fan blade was analysed. With regards to the chemical composition, the material of all three parts complied with the specification.

An analysis of the metallographic microstructure of the front disc showed a very high brittleness of the material.

1.5.6 Mechanical material properties

1.5.6.1 Rear ring

In the core material of the rear ring, Vickers hardness values[3] between 114 and 118 HV 5 were measured.

This ring is manufactured from aluminium 6061 T651. The respective norms specify a Brinell hardness value[4] of 88 HBW for this material. This is equivalent to a Vickers hardness of approximately 108 HV 5. The measured values show that the material had been heat-treated correctly.

1.5.6.2 Front disc

According to the specification, the aluminium 2024 T351 used for the manufacturing of the front disc should have a Brinell hardness of at least 124 HBW. The following Brinell hardness values were measured in the source material, the front disc of the accident helicopter and the helicopter VH-ZZT:

Source material:	133 - 138 HBW
Accident helicopter:	103 - 137 HBW
Helicopter VH-ZZT:	102 - 126 HBW

In addition to these measurements, the hardness values according to Vickers HV 5 were determined. The respective hardness values were:

Source material:	141 - 145 HV 5
Accident helicopter:	108 - 110 HV 5
Helicopter VH-ZZT:	90 - 130 HV 5

The wide spread and the low measured values of the two discs from the two helicopters are remarkable.

Static tensile tests were conducted with the source material, the material from the front rotor disc of the accident helicopter and the material from helicopter VH-ZZT.

According to the specification, the following minimum values apply:

Tensile strength:	440 MPa
Yield strength:	290 MPa
Elongation at fracture:	14 %

[3] Hardness test, indentation according to the Vickers procedure

[4] Hardness test, indentation according to the Brinell procedure

The results of these tests are summarised in table 1:

	Source material	HB-ZLJ	VH-ZZT
Tensile strength [MPa]	467 - 477	427 - 473	410 - 429
Yield strength [MPa]	321 - 327	292 - 416	308 - 340
Elongation at fracture [%]	19.8 - 24.1	4.6 - 6.4	4.3 - 7.0

Table 1: Results of the tensile tests (see Annexe 2)

1.5.7 Examination of fracture surface

The examination was carried out using the following three methods:

- Visually
- With stereomicroscope
- With scanning electron microscope SEM

The analysis of the fracture surfaces of the rear ring produced the following result:

No signs of fatigue fracture marks could be identified on the rear ring fracture surfaces. The fractures are ductile[5] overload fractures.

The analysis of the fracture surfaces of the front disc produced the following results:

The entire length of the fracture surface of the circular fracture area showed striations typical for a fatigue fracture. These striations were also present in the radial fracture area E in close proximity of the circular area (see illustration 10). In the outer radial fracture area E – near the blade fixing – the fracture surface showed a honeycomb-like structure. This suggests a ductile overload fracture.

The characteristic striations of a fatigue fracture were found at several places in the radial fracture area D.

[5] Ductile overload fractures are fractures that follow prior plastic deformation. They are also known as plastic fractures.

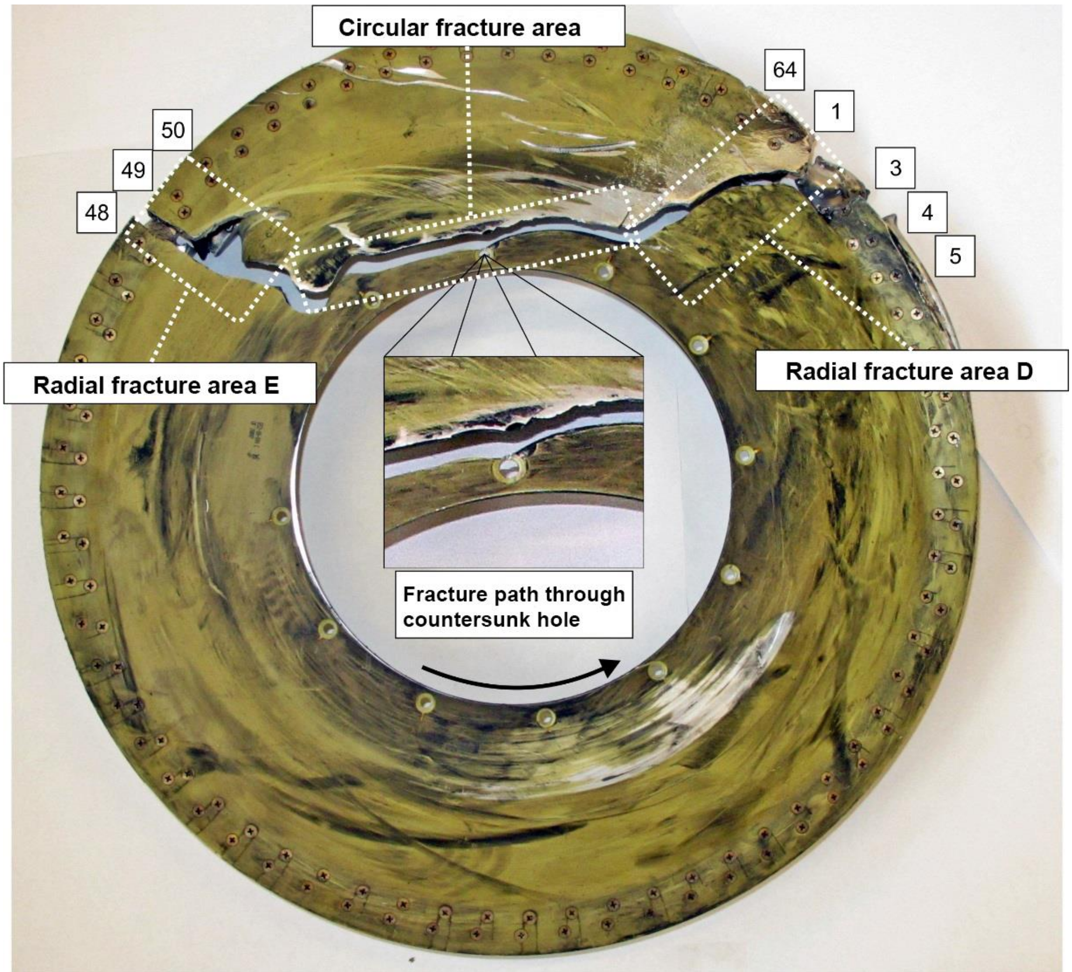


Illustration 10: Circular and radial fracture areas with close-up view.

1.5.8 Assessment of the surfaces

1.5.8.1 General

If a component is constantly stressed by impact on the surface, impact wear of the surface layer occurs. This depends on the type and frequency of the stress. The examination of the surface in contact with the front disc of the cooling fan after mounting to the flywheel showed abnormal impact wear in the area of the 12 mounting points.

Visually, such an area can easily be confused with corrosion marks. No corrosion damage was found on the front disc or on the flywheel.

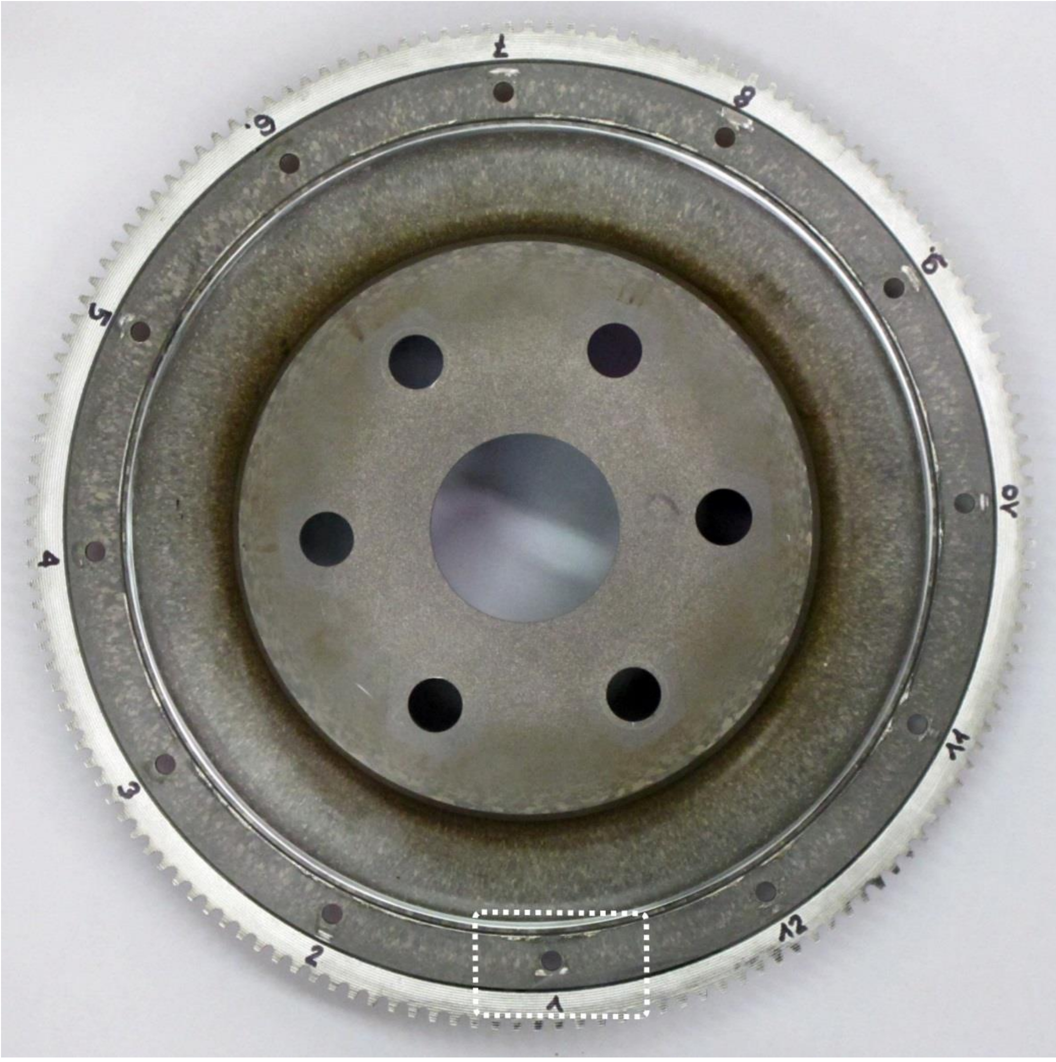


Illustration 11: Mounting surface of the flywheel to which the front disc of the cooling fan was mounted. The area of mounting point 1 is framed.

1.5.8.2 Impact wear

Signs of impact wear were found at all 12 mounting points. The impact wear between the flywheel and the part of the cooling fan still mounted after the accident was very distinctive at mounting point 1. The worn surfaces of disc and flywheel were consistent (see illustration 12). The circular fracture propagated through mounting point 1. The impact wear on the flywheel surface was very advanced in the contact area of the broken-off segment of the cooling fan.

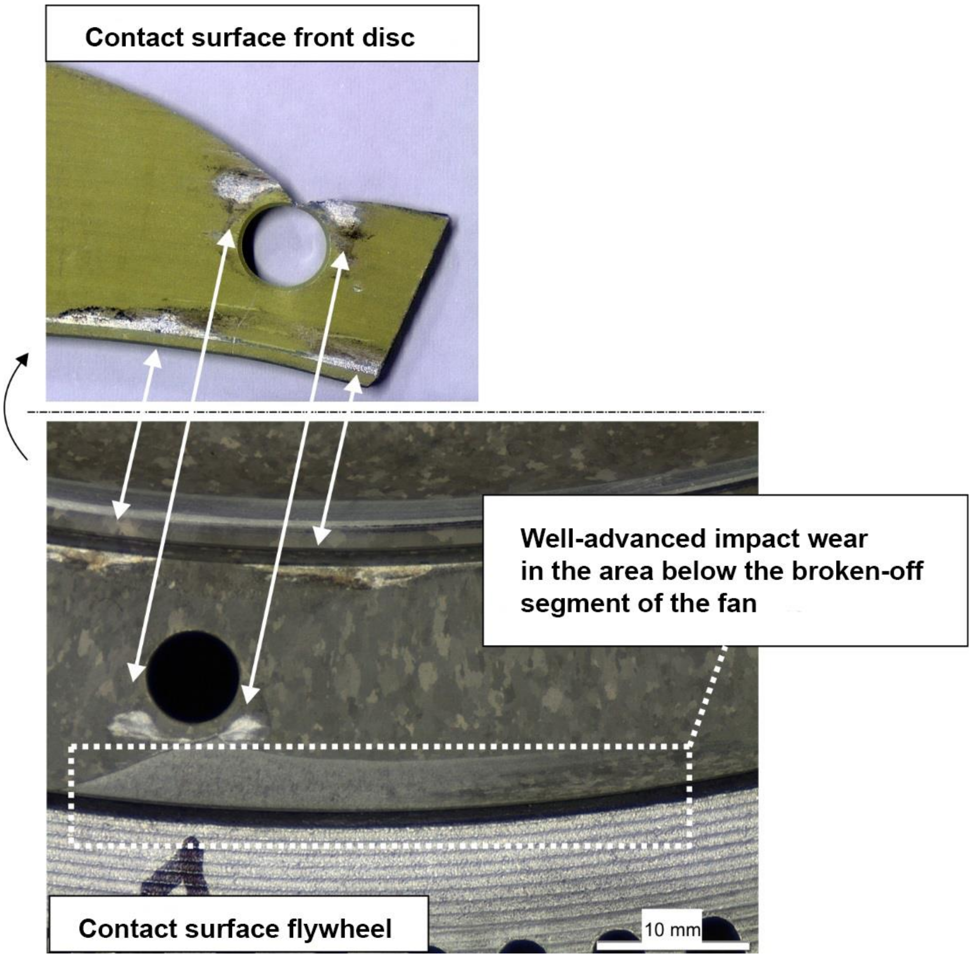


Illustration 12: Contact surfaces between flywheel and cooling fan with the consistent impact wear in the area of mounting point 1.

In addition, this contact area aligns with the well-advanced impact wear of the broken-off segment of the cooling fan (illustration 13).

Remarkable is the clearly visible mark of the fracture path of the cooling fan's front disc on the mounting surface of the flywheel.

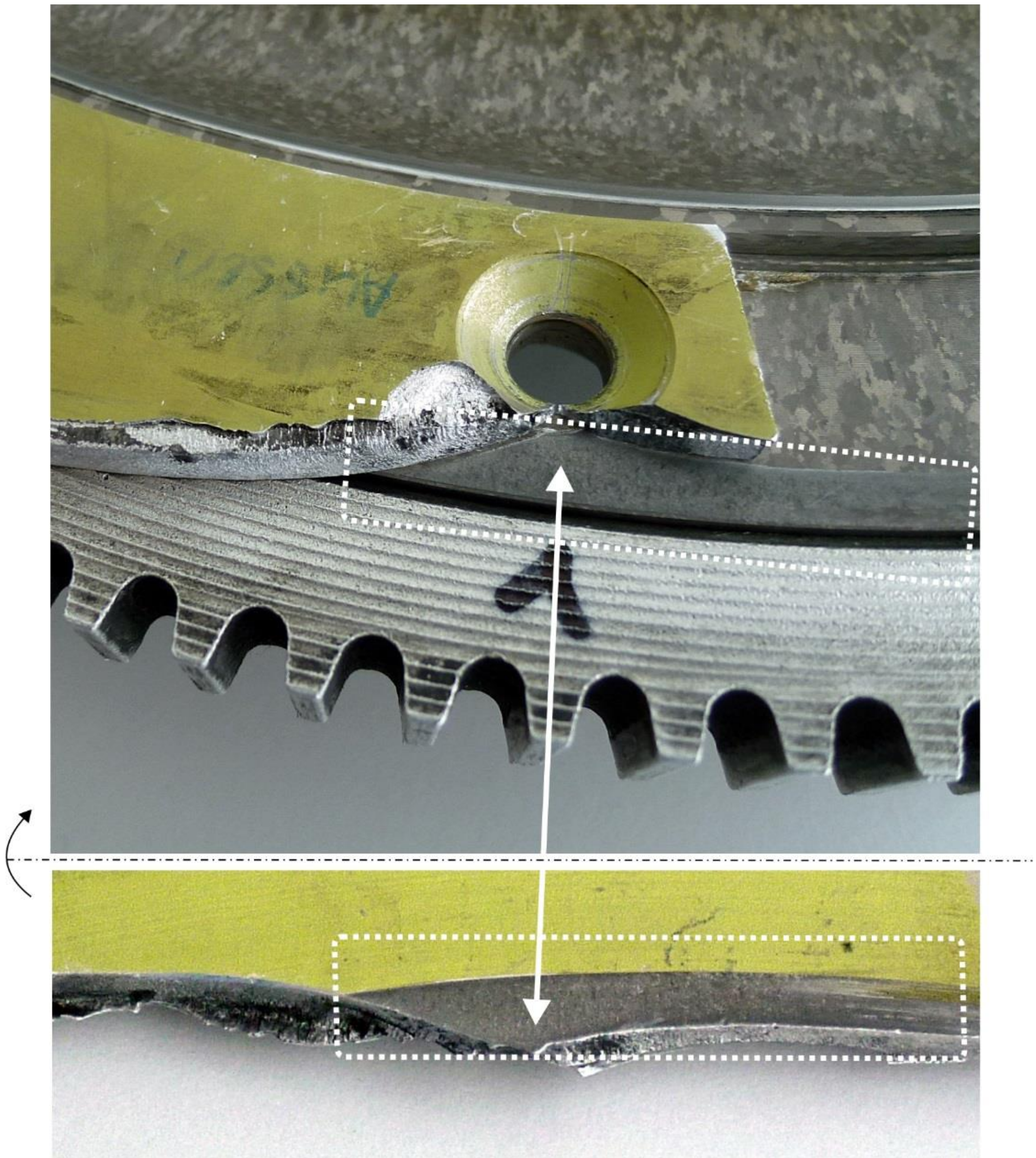


Illustration 13: Consistent, well-advanced impact wear on the flywheel and the broken-off segment of the cooling fan.

The impact wear in the countersink of the broken-off segment was very deep. At mounting point 1, there were only abrasion marks on the disc surface of the broken-off segment (see illustration 14).

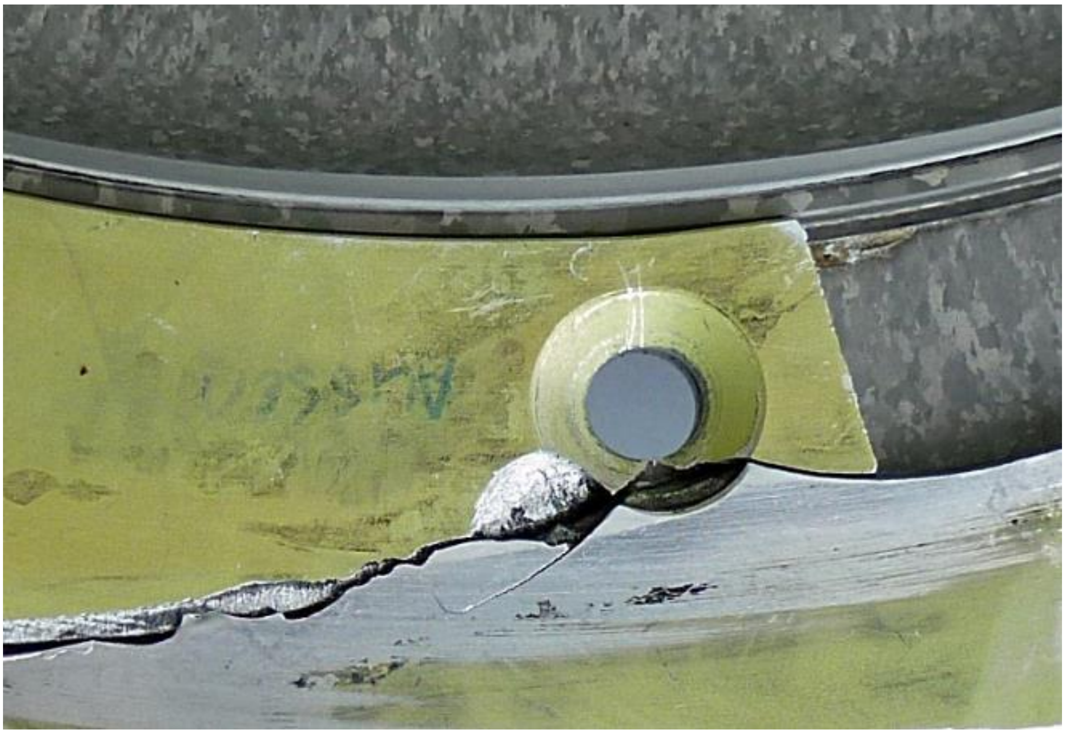


Illustration 14: Deep impact wear in the countersink and distinct abrasion marks on the broken-off segment.

The examination of the 12 mounting screws found that the cone-shaped part of the head of one screw showed impact wear. The mark of this impact wear was consistent in shape and size with the worn countersink of the broken-off segment (see illustration 15).

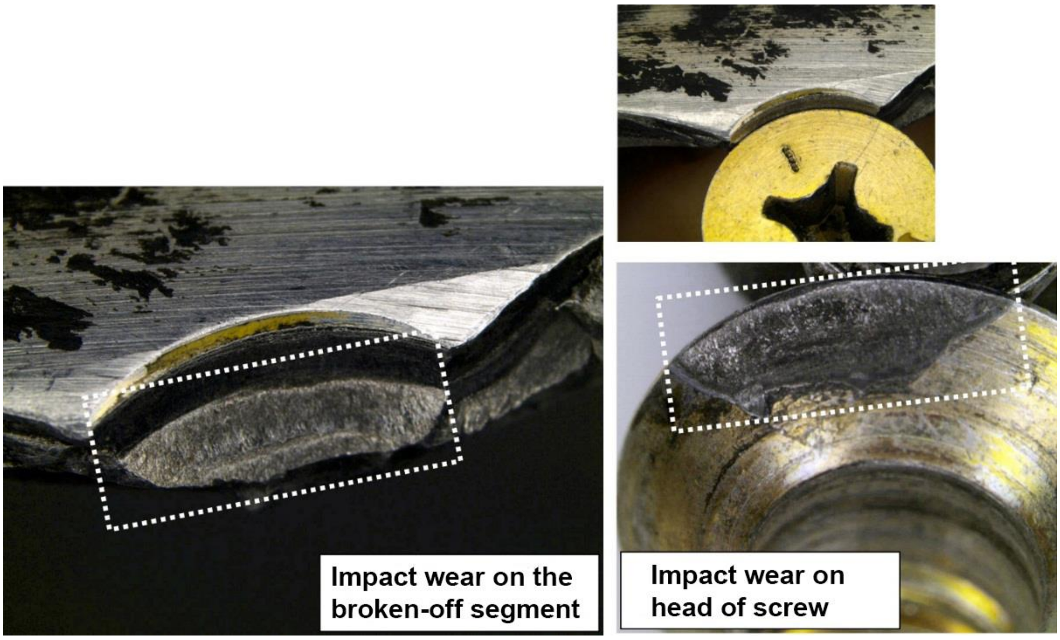


Illustration 15: Comparison of the impact wear on countersink and screw head.

The examination of the two cooling fans from the helicopters VH-ZZT and HB-ZLS also found the beginning of impact wear in the area of the 12 mounting points.

1.5.8.3 Abrasion marks

The inside of the front part of the air cooling housing showed abrasion marks. These abrasion marks are consistent with the abrasion marks and the direction of rotation of the cooling fan (see chapter 1.4.3.4). Aluminium residue was found on the abrasion surface of the air cooling housing.

The examination of the outer edge of the disc front provided the following results in area A (see illustration 16):

- The edge was ground down to a sharp burr.
- Deposits found on the ground-down surface contained carbon fibres.
- The ground-down surface structure was fused through overheating.

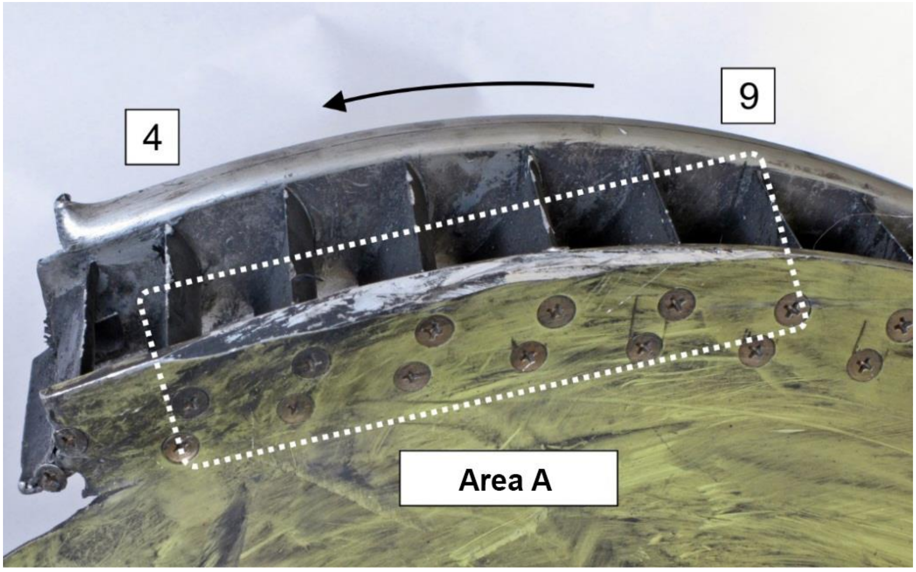


Illustration 16: Ground-down outer edge of the disc front.

1.6 Information on various organisations and their management

1.6.1 Manufacturer

The company Hélicoptères Guimbal was founded in the year 2000. The aim of the company was the development and production of a two-seat helicopter. The development programme for this drew upon the experiences with a technology carrier from the 1990s.

The maiden flight of the Cabri G2 was on 31 March 2005. In 2007, EASA issued the type certificate. At the time of the accident, approximately 50 Cabri G2s were in operation worldwide.

1.6.2 Air operation organisation

The air operation organisation Swiss Helicopter AG has 14 locations throughout Switzerland. The core business of the company includes the areas aerial work flights, passenger flights, film and photo flights, as well as training flights. In addition, the company occasionally offers helicopter rental to third parties at various locations.

In June 2011, HB-ZLJ was introduced as a new model at the base in Bern-Belp. The main use of this helicopter was flight training.

1.7 Additional information

1.7.1 Information to EASA and the manufacturer

On 21 January 2014, the STSB informed the representatives of the *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile* (BEA), the EASA and the manufacturer of the available findings. At the time, the STSB stated in particular that evidence had been found for overload fractures on the rear ring and for fatigue fracture marks on the front disc. The representatives of the BEA shared the view of the STSB.

1.7.2 Continued airworthiness

1.7.2.1 General

After the accident of HB-ZLJ, the manufacturer and EASA published documents regarding continuing the airworthiness. In the following chapters only the most important/relevant points of each document are summarised. The quoted original documents are listed in the annexes of this document.

1.7.2.2 Documents of the manufacturer

On 18 July 2013, the manufacturer published the mandatory Service Bulletin SB 13-021A entitled “cooling fan inspection” (see Annexe 3).

This SB stipulates a visual check of the rear ring for possible fractures, corrosion or damage every 50 operating hours. This check is to be done on the installed rear ring.

On 10 September 2013, the manufacturer published the mandatory Service Bulletin SB 13-022A entitled “cooling fan upgrade”. On 12 September, revision B with the name SB 13-022B was published (see Annexe 4).

This SB essentially stipulates the replacement of the rear ring, replacing it with a reinforced version.

1.7.2.3 Documents of the regulatory authority

On 14 February 2014, the EASA published the Airworthiness Directive AD 2014-0038 (see Annexe 5).

In this AD, the documents quoted in chapter 1.7.2.2 are declared to be mandatory. The reason was given as follows:

“The suspected cause of the cooling fan failure is a crack which had developed in the fan external ring. Although the origin of that crack has not yet been determined, contributing factors could be corrosion, a manufacturing defect or local damage caused by maintenance or foreign object impact.”

1.7.3 Cabri G2 SE-HJR incident on 12 August 2014 in Sweden

1.7.3.1 Short description of the incident

At 2190 operating hours, a 500-hour inspection was carried out on the helicopter Cabri G2 with the serial number 1011, registered as SE-HJR. In the context of this work, the cooling fan was also checked. Because this helicopter had the most operating hours of the whole fleet, the cooling fan was also checked in the manufacturer's plant. This check found a certain surface wear in the area of the 12 mounting holes. The manufacturer carried out standard repair procedures for this by sanding down the worn areas and applying chromate primer.

At 2500 operating hours, the operator of SE-HJR carried out the SB 13-022 in November 2013.

On 12 August 2014, when SE-HJR had approximately 3600 operating hours, an almost identical incident to that involving HB-ZLJ occured during a training flight. After the crew had noticed an unusual noise coming from the engine bay, an emergency landing was initiated immediately. Subsequently, the following damage to the cooling fan of SE-HJR was found (see illustrations 17 and 18):

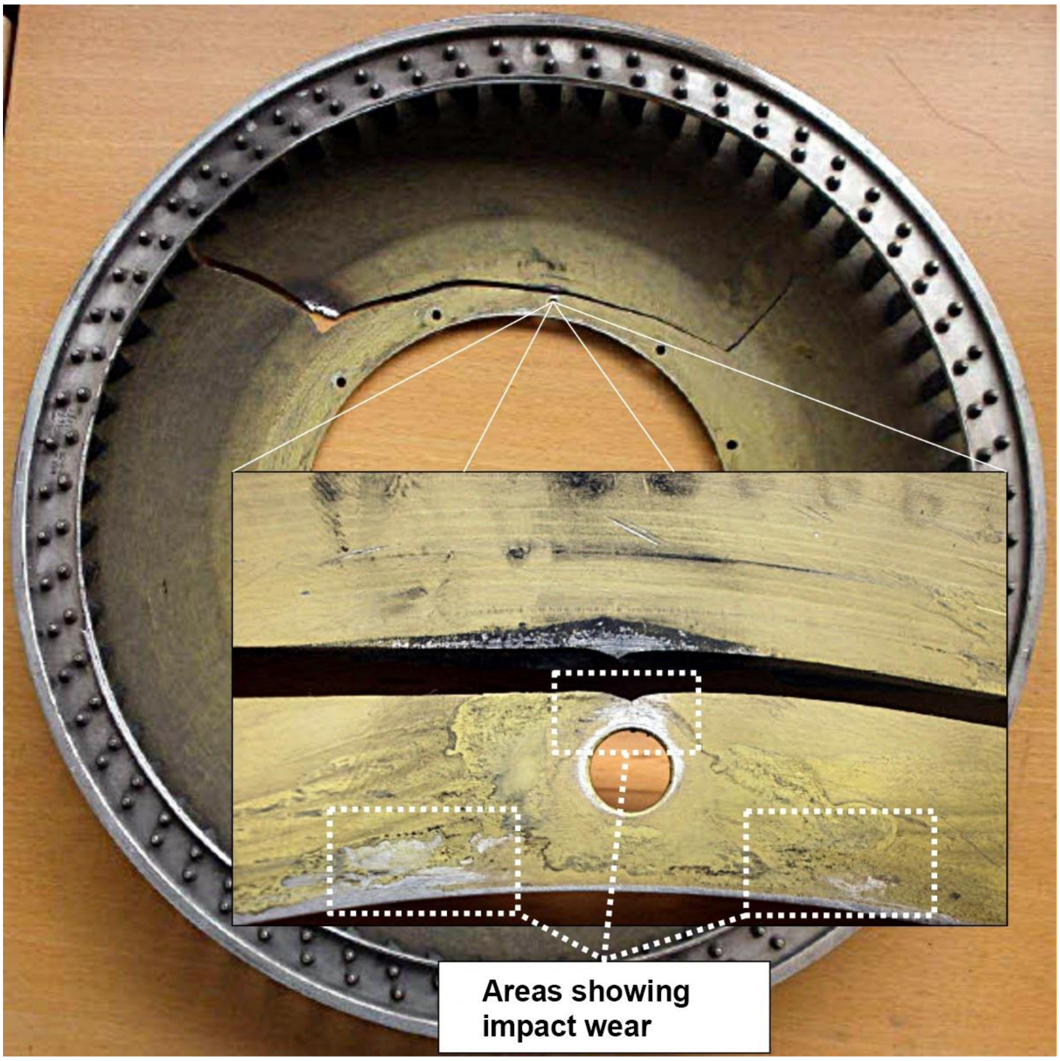


Illustration 17: Rear view of the damaged cooling fan of SE-HJR with close-ups.

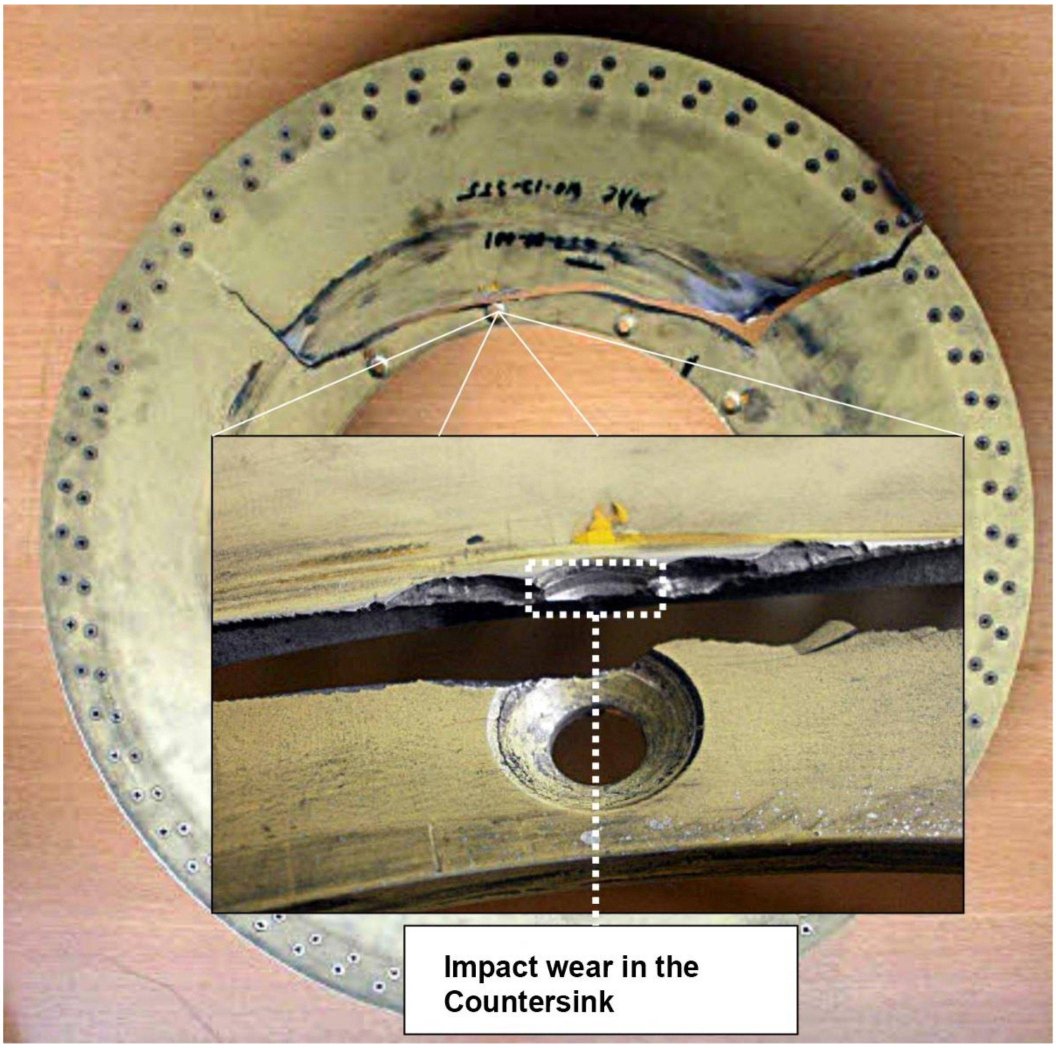


Illustration 18: Front view of the damaged cooling fan of SE-HJR.

The manufacturer of the helicopter included the findings of the HB-ZLJ accident investigation in the analysis of the incident involving SE-HJR and concluded that the failure of the cooling fan had the same cause in both cases.

1.7.3.2 Measures taken by the manufacturer

On 27 August 2014, the manufacturer published the mandatory Service Bulletin SB 14-018A entitled “cooling fan inspection” (see Annexe 6).

This SB stipulates a visual check of the installed front disc every 50 operating hours. Particular attention is to be paid to fractures in the front disc in the area of the flywheel.

In addition, the manufacturer holds out the prospect of a new design for the front disc.

1.7.3.3 Measures taken by the regulatory authority

On 2 September, the EASA published the Airworthiness Directive AD 2014-0196.

In this AD, both SB 13-022B and SB 14-018B are declared to be mandatory.

1.7.4 Additional cases of damage to the cooling fan on Cabri G2 helicopters

On 14 September 2014, five radial cracks were detected on the front disc of the cooling fan on the Cabri G2 with the serial number 1043. This helicopter was built in 2013 and had 1104 hours of operation.

On the 7th October 2014 a small crack was found on the cooling fan on the helicopter with the serial number 1013. This machine, manufactured in 2009, had recorded 3521 operating hours.

2 Analysis

2.1 Technical aspects

2.1.1 Assessment of the design

The cooling fan that is mounted to the front of the flywheel of the air-cooled horizontally opposed engine rotates with 2585 to 2700 RPM during operation. The cooling fan is subject to centrifugal forces that put tensile stress on the material of the rear ring as well as on the material of the front disc. This tensile stress varies only slightly during operation and has no impact to component fatigue if the component is designed and manufactured correctly.

The connection between flywheel/cooling fan is subject to lateral vibrations which mainly come from the engine. These lateral vibrations are coupled from the flywheel to the cooling fan via the 12 mounting screws and cause vibration stress in the front disc at each of the 12 mounting points. In addition to the static tensile stress resulting from the centrifugal forces, the front disc is therefore dynamically stressed in this area by reverse bending. This additional dynamic stress has significant impact to component fatigue.

In the present case it was established that the front disc of the cooling fan did not have the required stiffness. The structural design of the disc is inadequate for the stress-levels occurring during operation. Countersunk screws were used to mount the front disc of the cooling fan to the flywheel. Mounting thin-walled parts with low lateral stiffness using these type of screws leads to high tension peaks in the clamping area of the screws when there is dynamic stress. This results in fatigue damage in such critical areas of the design.

2.1.2 Rear ring and fan blades

The rear ring and the blades of the cooling fan conformed to the specifications of the manufacturer with regards to dimensional accuracy and material properties. No corrosion was found anywhere on the surface of the ring or the blades.

The fracture surfaces are exclusively overload fracture surfaces, pre-existing corrosion and material fatigue can be ruled out as a cause. The rear ring failed after the front disc of the cooling fan had broken apart.

2.1.3 Marks on flywheel and cooling fan

Abnormal marks were found on the contact surfaces between flywheel and cooling fan in the area near the 12 mounting points (see illustrations 11 and 12). The marks on the flywheel were consistent with the marks of the opposite side, i.e. the contact surface of the front disc of the cooling fan. These marks are created by impact wear. This kind of wear is caused by constant impact stress on two surfaces that are in contact with each other. These marks were so unique that contact corrosion can be ruled out.

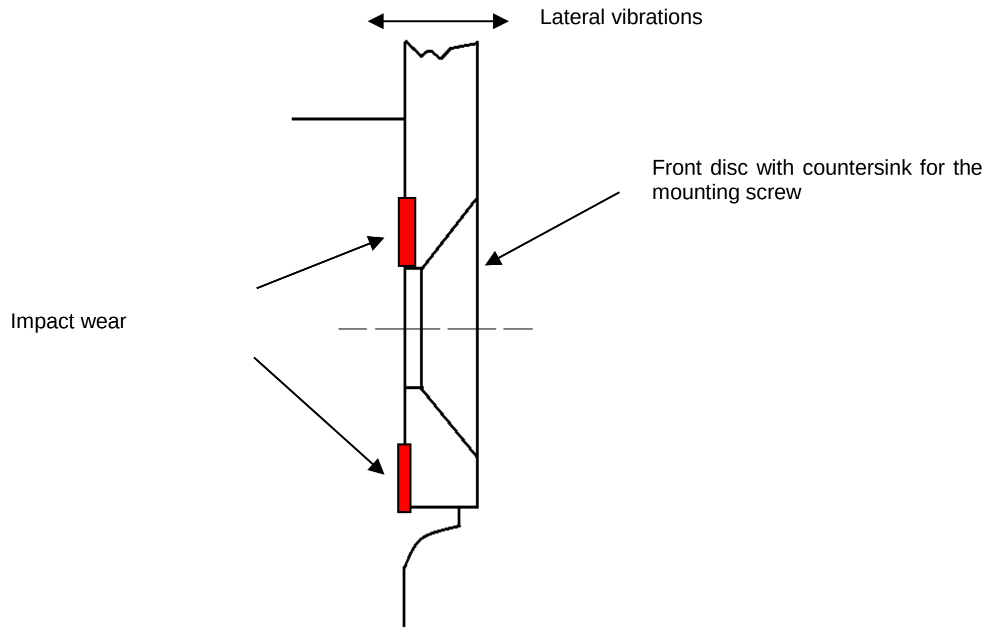


Illustration 19: Area of the impact wear on the contact surfaces of the flywheel and the front disc prior to the start of the crack propagation.

Impact wear is caused by dynamic fretting. From the type of impact wear found here, it can be concluded that the lateral vibrations were transmitted from the flywheel to the front disc of the cooling fan. This was promoted by an inadequate screw connection and insufficient lateral stiffness of the disc.

In the contact area of the broken-off segment of the cooling fan, the impact wear on the flywheel surface is well-advanced. This is consistent with the impact wear on the broken-off segment which is also well-advanced. On the front of the flywheel, the fracture path of the front disc of the cooling fan is clearly visible (see illustrations 12 and 13).

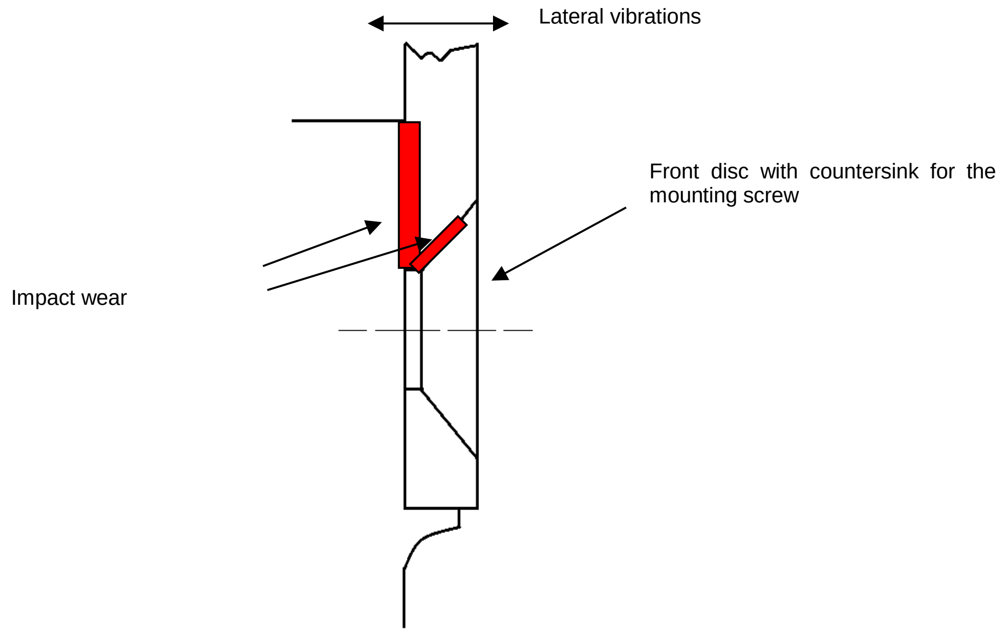


Illustration 20: Area of the well-advanced impact wear on the contact surfaces and in the countersink after the start of the crack propagation.

The impact wear is very deep in the countersink of the broken-off segment (see illustration 15). The mark of this impact wear was also found as wear on the cone-shaped part of a screw head. At mounting point 1, there are abrasion marks only on the disc surface of the broken-off segment.

The detected impact wear is contact wear as a result of fatigue. The wear starts after a certain number of load changes. The growth depends on the intensity and frequency of the stress. The well-advanced wear on the surfaces of the flywheel, on the broken-off segment in the countersink and on the screw head are evidence of a circular fracture in the front disc of the cooling fan (see illustrations 13 to 15). The type of wear as well as the significant mark of the fracture path on the flywheel lead to the conclusion that the fracture had already been there some time before the accident. Further evidence of this are the abrasion marks that were only found on the broken-off segment at mounting point 1.

2.1.4 Examination of the front disc

Dimensional checks of the front disc found significant discrepancies with regards to the thickness. The manufacturer's drawing specifies a thickness of 4 mm. Measured values were between 3.1 and 3.9 mm. In the extreme case, this represents a decrease in thickness of approximately 25 %. A balancing mass of 44.32 g on the level of the rear ring was supposed to compensate for this inhomogeneity. Compared to the cooling fans from VH-ZTT and HB-ZLS, the balancing mass was significantly higher.

The examination of the material properties showed that the material of the front disc had properties that did not comply with the specifications:

Brinell hardness HBW:	up to	17 %	lower
Tensile strength:	up to	3 %	lower
Elongation at fracture:	up to	67 %	lower

High brittleness of the material and large variations in the measured values were most striking in the examinations. It must be assumed that the cause of all these insufficient material properties of the aluminium 2024 T351 is an unsuitable manufacturing method of the front disc. In addition, this component of the cooling fan, mounted directly on the engine, is exposed to operating temperatures which vary considerably and therefore negatively impact the mechanical properties (see chapter 1.5.1).

The entire length of the fracture surface of the circular fracture area shows striations typical for a fatigue fracture. Striations are also present in the radial fracture area – in close proximity to the circular area. In the outer radial fracture area near the blade fixing, the fracture surfaces show a honeycomb-like structure. This suggests a ductile overload fracture in this area.

2.1.5 Damage to the air cooling housing

The air cooling housing was torn apart by the bursting of the cooling fan. Prior to that, the front disc had become unstable through the fatigue fractures and parts of it rubbed the inside of the air cooling housing. This is likely to be the cause of the production of smoke and the odour before the accident.

2.1.6 Continued airworthiness

On 18 July 2013, i.e. 5 days after the accident, the manufacturer published the mandatory Service Bulletin SB 13-021A entitled "cooling fan inspection" (see Annexe 3). This SB stipulates a visual check of the mounted rear ring for possible cracks, corrosion or damage every 50 operating hours. This is based on the manufacturer's assumption that the cause of the failure of the cooling fan was started by the rear ring. Carrying out this inspection with the cooling fan mounted is problematic as the front disc cannot be inspected this way and only a small segment of the rear ring is visible.

On 10 September 2013, the manufacturer published the mandatory Service Bulletin SB 13-022A entitled “cooling fan upgrade” (see Annexe 4). This SB essentially stipulates the replacement of the rear ring, replacing the rear ring with a reinforced version.

The EASA supported the view of the manufacturer and issued the Airworthiness Directive AD 2014-0038 on 14 February 2014 (see Annexe 5).

At that time, both the EASA and the manufacturer had findings of an STSB investigation available to them which proved a fatigue fracture on the front disc and overload fractures on the rear ring. Therefore, it appears incomprehensible that no measures were taken with regards to the front disc.

On 12 August 2014, an accident happened involving SE-HJR in Sweden with almost identical cooling fan damage to that of HB-ZLJ. On this helicopter, the front disc had been inspected by the manufacturer approximately 1400 operating hours before the accident. The impact wear in the area of the 12 mounting holes had been assessed to be in the norm and had been repaired by sanding down and a new coat of primer. Around 1100 hours before the accident, SB 13-022A was carried out.

Around two weeks after the accident, the manufacturer published the mandatory Service Bulletin SB 14-018A entitled “cooling fan inspection” (see Annexe 6). This SB stipulates a visual check of the mounted front disc every 50 operating hours. Particular attention is to be paid to cracks in the front disc in the area of the flywheel.

The findings of the investigation suggest that the origin of the fracture in the case of HB-ZLJ and probably also in the case of SE-HJR is near one of the 12 mounting holes. This crack grew over a longer period of time in circular direction. This means that, as long as it runs circularly, the crack is not visible as it is covered by the flywheel. Therefore, the part of the crack running in circular direction cannot be discovered with the method described in SB 14-018A.

Fatigue cracks of this type develop progressively. The crack propagation increases corresponding to the crack length and is fastest if the crack grows in a radial direction.

Because of all the reasons given above, the inspection of the cooling fan as stipulated in SB 14-018A is inadequate. In addition, the inspection interval of 50 operating hours appears to be too optimistic to ensure safe operation.

2.1.7 Summary

The investigations have identified that the bursting of the cooling fan was caused by a fatigue crack in the material of the front disc. This material fatigue is attributed to the properties of the disc: its material quality did not comply with the specifications, its thickness was up to approximately 25 % less than specified on the manufacturer’s drawing and its lateral bending stiffness was insufficient. The disc was also attached to the flywheel of the engine with an unsuitable mounting method using countersunk screws.

As a result, a circular fatigue crack grew in the front disc of the cooling fan at first – starting from the mounting point of a countersunk screw. This originated from dynamic stress that was mainly caused by lateral vibrations of the engine. The fatigue crack grew progressively in the disc during operation and finally led to the cooling fan breaking apart.

The dimensions, the manufacturing as well as the material specifications of the rear ring complied with the specifications of the manufacturer. Neither corrosion nor surface defects were established. The fracture surface investigation of the rear ring clearly indicates an overload fracture.

The breaking of the rear ring is consequential damage of the failure of the front disc.

2.2 Human and operational aspects

After the crew had started the last part of the flying lesson in the region of Schwarzenegg, they heard a loud noise during hovering, which was followed by an intense odour. It was appropriate to land the helicopter immediately and to contact a mechanic over the phone. Since it had not been possible to establish the cause of the problem that way, the mechanic was flown on site.

The mechanic systematically inspected the helicopter for abnormalities. In the engine bay he checked the flywheel with the ring gear for the starter and the secure fit of the cooling fan. The air cooling system was difficult to see for the mechanic and only a small part of the cooling fan was visible. Therefore it is safe to assume that the fracture could only have been detected by chance at this time. It should be mentioned that there was no reason initially to look for the cause of the noise and the odour in the area of the air cooling system.

Finally, the mechanic found the power supply unit for the strobelight which had come loose from its mounting. After he had knocked on the rear bulkhead with the loose part, they agreed that this must have been the noise heard before. The mechanic provisionally fastened the loose part. During the subsequent test flight, everything seemed to be normal until the flight instructor and the mechanic noticed an odour again. Various adjustments of the ventilation and the heating did not yield results. The helicopter was parked again. Subsequently, the mechanic inspected the engine bay once more without making new findings. It can be safely assumed that the odour was caused by the rotating cooling fan touching the air cooling housing.

After take-off heading towards the Bern-Belp base, the same odour developed yet again causing the flight instructor to return to the location of the mechanic. The mechanic opened the engine bay cowling. Again, he noticed the singed surface on the air filter foam which was near the exhaust. He removed a piece of it, held it to the exhaust and smelt it. This odour seemed to be similar to the one they had detected in the cockpit. One explanation for this could be that particles of the abraded air cooling housing had built up on the foam of the air filter by this time.

From that, the parties involved concluded that the singed air filter foam was the plausible cause of the odour.

The flight to the base could now be started. Take-off was conducted by the flight instructor who had been sitting on the right seat since the test flights. As everything seemed to be normal, there was no reason not to hand over the controls to the trainee pilot during the climb. A few minutes before the landing in Bern-Belp, the odour was again noticeable in the cockpit. The flight instructor immediately opened the door and looked to the rear. When he saw significant development of smoke coming from the engine bay, he immediately took control and planned a precautionary landing between Münsingen and Wichtrach. This was appropriate for the situation. When the helicopter was around 300 m above ground, the front disc of the cooling fan fractured completely. This was perceived by the crew as loud rattling. Through the disintegration of all components of the air cooling system, the cable of the mixture control was ripped loose and wound up by the tail rotor shaft. As a result the engine cut off which led to autorotation from approximately 200 m above ground. As the flight instructor had aimed at a suitable field for a precautionary landing, the conditions for a successful emergency landing were in place. Because of the suspected loss of the torque balance, the flight instructor spontaneously decided to carry out a glide landing. He carried out the final approach at a speed of 60 to 70 KIAS. As a result, the emergency landing ended successfully in the crop field behind the landing spot he had first aimed at.

After the helicopter had come to a standstill, the crew left the cockpit when the main rotor was still turning. Taking this risk of injury can be attributed to the fear of suspected fire in the engine bay. As the helicopter was fitted with a rotor braking system, braking the rotor prior to evacuation would have been possible without great loss of time. This would have reduced the risk of injury.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects

- The helicopter was registered for VFR traffic.
- The structural design of the cooling fan was inadequate for the stress-levels occurring. The lateral stiffness of the front disc was insufficient.
- The mounting with 12 countersunk screws caused high tension peaks in the clamping area of the screws which led to significant impact wear and to fatigue cracks at one mounting point.
- The front disc had properties that did not comply with the specifications. The material was brittle as well as inhomogeneous and in certain places the thickness of the disc was up to 25 % less than specified.
- The fracture of the front disc of the cooling fan is attributed to material fatigue. The fracture surfaces of the circular and of parts of the radial area showed striations typical for a fatigue fracture.
- The rear ring and the blades of the cooling fan conformed to the specifications of the manufacturer with regards to dimensional accuracy and material properties.
- The breaking of the rear ring is a consequential damage of the failure of the front disc.

3.1.2 Crew

- The flight instructor and the trainee pilot had the required licences for the flight.
- There is no evidence of health problems of the pilots during the accident flight.
- The flight instructor was wearing a helmet and the trainee pilot was wearing a headset.

3.1.3 Flight details

- While carrying out landing exercises in open terrain, the crew heard a loud bang.
- A mechanic and the crew carried out in-depth inspections of the helicopter in open terrain.
- In a recess next to the main rotor transmission, the mechanic found the power supply unit for the strobelight which had come loose from its mounting.
- The mechanic knocked the power supply unit against the rear bulkhead. The crew associated this sound with the previously heard bang.
- During the subsequent test flight, the mechanic noticed an odour, which in his opinion was most likely coming from an electrical fault.
- After the flight, the mechanic opened the cowling again and inspected the engine bay. In doing so, he noticed that the plastic surface coating of the foam air filter was singed next to the area by the exhaust.
- The crew and the mechanic associated the odour of the singed surface coating of the air filter foam with the odour they had experienced several times in flight.
- They decided to return the helicopter to the base in Bern-Belp.

- The flight instructor judged the 25 litres of aviation fuel in the tank to be sufficient for the approx. 10-minute return flight to the base.
- HB-ZLJ took off at approximately 12:10. Approximately 8 minutes after take-off, the crew once again detected the same odour in the cockpit.
- The flight instructor opened the right door and looked to the rear. He observed “greyish smoke” coming from the engine cowling. He then took control of the helicopter and informed the aerodrome control tower in Bern-Belp that he would initiate a precautionary landing.
- At 12:19, when the helicopter was at 2500 ft. QNH, a rattling noise came from the engine bay, followed by marked vibrations.
- Four seconds later, the yellow warning light for low rotor speed (<515 RPM) came on and another two seconds later the engine shut down.
- At 12:20 HB-ZLJ performed a glide landing, touching down in a crop field.
- Because of suspected fire, the crew released their belts and immediately left the cockpit while the rotor was still turning.
- The crew remained uninjured.
- HB-ZLJ was severely damaged. Fire did not break out.

3.1.4 General conditions

- The weather had no influence on the accident.

3.2 Causes

The accident is attributed to the disintegration of the cooling fan of the cooling system which led to engine failure with subsequent emergency landing.

The following direct causes for the disintegration of the cooling fan were established:

- Inadequate design of the cooling fan;
- Deficiencies in manufacturing the front disc of the cooling fan.

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

Safety recommendations

According to the provisions of Annex 13 of the International Civil Aviation Organization (ICAO) and Article 17 of Regulation (EU) 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 advices

The STSB may publish safety advices in response to any safety deficit identified during the investigation. Safety advices shall be formulated if a safety recommendation in accordance with Regulation (EU) No. 996/2010 does not appear to be appropriate, is not formally possible, or if the less prescriptive form of a safety advices is likely to have a greater effect. The legal basis for STSB safety advices 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 Disintegration of the cooling fan in the cooling system in Cabri G2 model helicopters.

4.1.1.1 Safety deficit

On 13 June 2013, a flight instructor and a trainee pilot went on a training flight with the Cabri G2 helicopter, registered as HB-ZLJ. While carrying out landing exercises, the crew heard a loud bang followed by an odour. Together with a mechanic they carried out in-depth inspections in open terrain. The parties involved saw the loose power supply unit for the strobelight in a recess next to the main rotor transmission and the singed surface coating of the foam air filter in close proximity to the exhaust as possible explanations for the in-flight experiences.

During the subsequent return flight which took just short of 10 minutes the odour developed again followed by smoke coming from the engine bay. The flight instructor immediately initiated a precautionary landing. In the process, the cooling fan of the air cooling system disintegrated and caused further collateral damage in the engine bay and engine failure. Subsequently, the crew successfully carried out an autorotation.

The following direct causes for the disintegration of the cooling fan were established:

- The fracture of the front disc of the cooling fan is attributed to material fatigue. The fracture surfaces of the circular and of parts of the radial area showed striations typical for a fatigue fracture.
- The structural design of the cooling fan was inadequate for the stress-levels occurring.
- The lateral stiffness of the front disc was too small and it had properties that did not comply with the specifications. The material was brittle as well as inhomogeneous and in certain places the thickness of the disc was up to 25 % less than specified.

The published Service Bulletins by the manufacturer so far are not sufficient to guarantee a safe operation.

4.1.2 Safety recommendation no. 502

The European Aviation Safety Agency (EASA) should ensure that the manufacturer Hélicoptères Guimbal immediately checks the operational safety of the cooling fan of the cooling system in Cabri G2 helicopters across the entire fleet and draws up an inspection programme for continued operation.

4.1.3 Safety recommendation no. 503

The European Aviation Safety Agency (EASA) should ensure that the manufacturer Hélicoptères Guimbal undertakes appropriate measures to prevent the occurrence of a disintegration of the cooling fan of the cooling system in Cabri G2 helicopters.

4.2 Safety advices

None

4.3 Measures taken since the accident

4.3.1 General

In the course of the investigation, several measures were taken by the manufacturer of HB ZLJ. They are described in Chapter 1.7

4.3.2 Redesign of the cooling fan for the cooling system for the helicopter Cabri G2

In a letter dated 25 September 2015 the manufacturer prospects planned measures to be taken and the redesign of the cooling fan for the Cabri G2 as follows:

“Given these data and analysis, HG [Hélicoptères Guimbal] *decided to design a front flange manufactured with carbon composite material. Two prototypes have*

been manufactured, serial production mould was launched and first parts should be available by the end of the year.

In the meantime, in order to mitigate the risk of failure on the fleet, several actions have been taken:

- *Manufacturing of front flange with initial design was ensured to be limited to swaging on solution treated material. This avoids negative impact on material properties and thicknesses.*
- *New intermediate design without flat head screws and double quantity of screws (24) is planned to be installed in production on S/N 1120. Anti-friction shim is maintained.*
- *Life of both aluminium designs will be limited to 2000 flight hours.*
- *Fleet will be monitored for marginal operation with high start-stop cycle rate to ensure adequacy of 50 hours inspection interval.*

→ *First carbon composite design are planned to be available at the beginning of 2016.*

→ *New intermediate design was launched in June 2015 and first items are under quality control. EASA approval is expected by November 2015. It will include limitation section change for maximum life and will account for marginal start-stop cycles."*

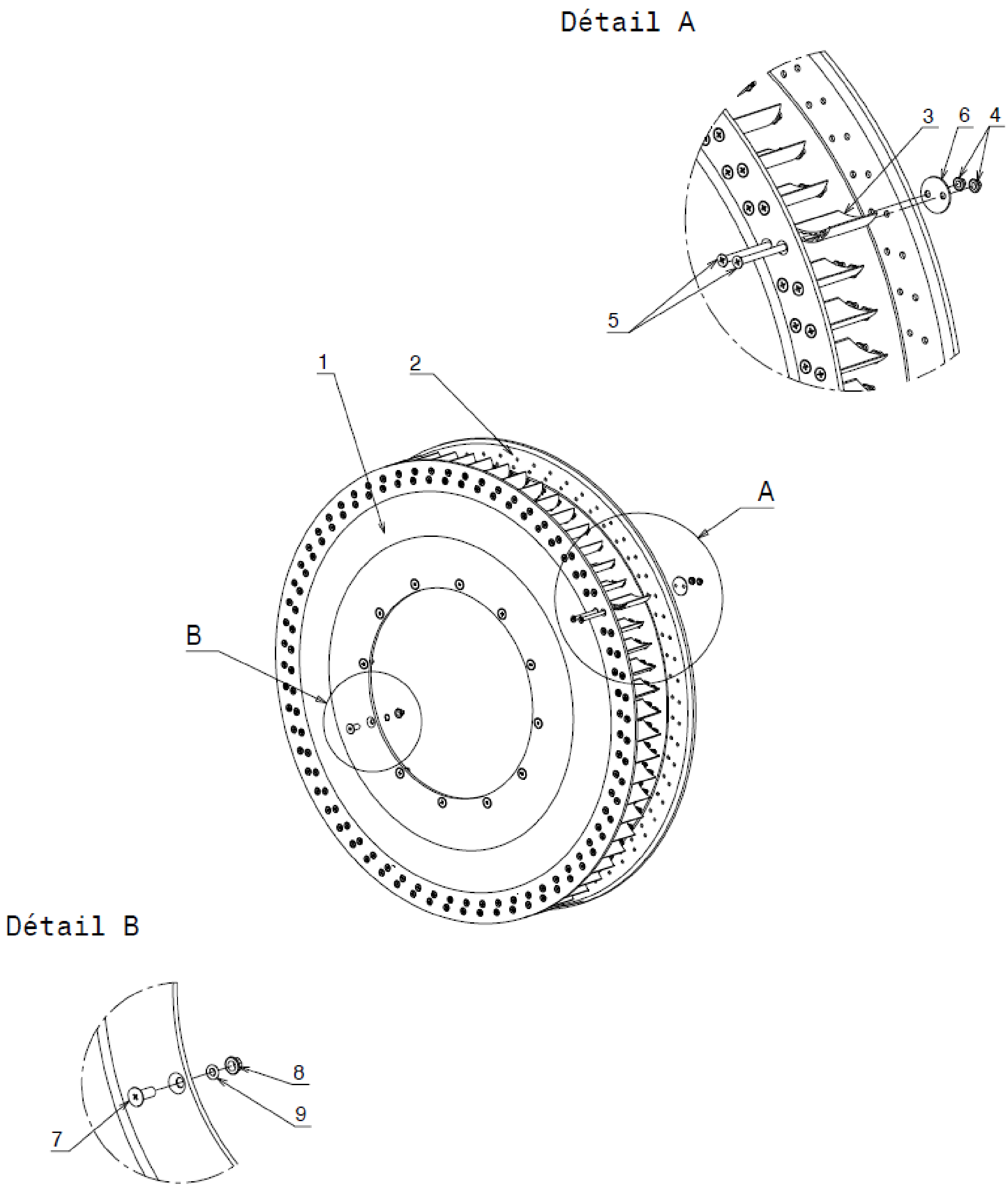
Payerne, 18 October 2016 Investigation Bureau STSB

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, 22 September 2016

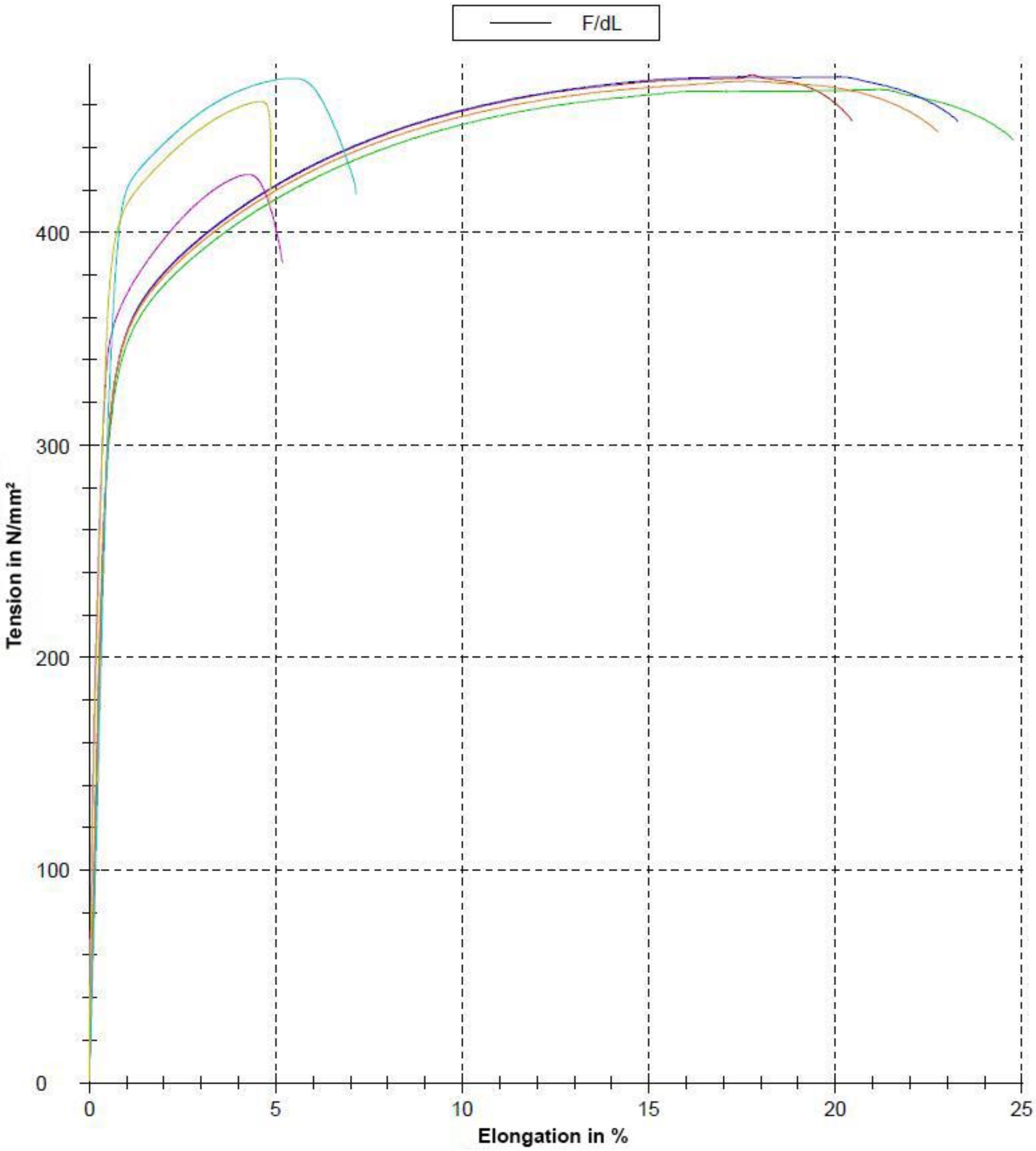
Annexe 1: Assembly of the cooling fan according to the flight manual

5.7.1 VENTILATEUR / COOLING FAN



Index	Qty	Reference	Désignation	Designation
1	1	G52-02-200	Flasque avant du ventilateur	Cooling fan front flange
2	1	G52-01-200	Flasque arriere du ventilateur	Cooling fan rear flange
3	64	G52-00-200	Aube de ventilateur	Cooling fan vane
4	128	HG12-0332	Ecrou	Nut
5	128	G52-04-200	Vis	Bolt
6	AR	G52-03-200	Masse d'equilibrage	Balancing mass
7	12	HG17-0523	Vis	Bolt
8	12	HG12-0328	Ecrou	Nut
9	12	HG17-0551	Rondelle	Washer

Annexe 2: Tensile tests with source material and material from HB-ZLJ



Test results

Legende	Nr	a_0 mm	b_0 mm	S_0 mm²	m_E GPa	$R_{p0.2}$ MPa	R_m MPa	A %	Material Type
(red)	1	3.88	9.18	35.62	71.3	326	474	19.8	1E **(Source Material)**
(green)	2	3.92	9.19	36.02	63.7	326	467	24.1	1F **(Source Material)**
(blue)	3	3.9	9.19	35.84	69.7	327	473	22.6	2E **(Source Material)**
(orange)	4	3.89	9.25	35.98	77.7	321	471	22.2	2F **(Source Material)**
(magenta)	5	3.38	9.16	30.96	217	292	427	5.0	A (aus HB-ZLJ)
(cyan)	6	3.78	9.18	34.70	56.7	416	473	6.4	B (aus HB-ZLJ)
(yellow)	7	3.8	9.17	34.85	167	314	462	4.6	C (aus HB-ZLJ)

Annexe 3: Service Bulletin SB 13-021A – Cooling fan inspection

GUIMBAL

SERVICE BULLETIN

SB 13-021 A

	OPTIONAL		RECOMMENDED
	REPAIR	X	MANDATORY

SUBJECT **Cooling fan inspection**

DATE OF EFFECTIVITY	18 / 07 / 2013
DEADLINE (if applicable)	- First inspection : Applicable immediately – mandatory within the next 5 flight hours. - Periodicity : 50 hours
Associated AIRWORTHINESS DIRECTIVE	NA
Associated MODIFICATION / REPAIR	NA
HG CONTACT	Helicopteres Guimbal – Support Aerodrome d'Aix-en-Provence - 1070 rue Lieutenant Parayre - 13290 LES MILLES - FRANCE Tel : +33 (0)4 42 39 10 88 - Fax : +33 (0)4 42 39 10 82 email : support@guimbal.com

REVISION	SUBJECT	DATE
A	Creation	18 / 07 / 2013

APPLICABILITY

All Cabri G2.

Evolution : This SB will be superseded by the application of a new damage tolerant design (MOD13-050 - SB13-022).

SITUATION

One serious incident concluded by a forced landing was caused by the failure of the cooling fan for undetermined reasons that could involve corrosion or damage on the ring.
This mandatory SB prescribes an inspection of the ring in order to detect any crack or damage.

REQUIRED ACTIONS

- Remove the upper right and left engine baffles.
- Remove the four upper sparkplugs to allow easy rotation of the fan by hand.
- Mark the position of the fan with a felt pen or identify the position numbers (64 blades).
- For each visible sector of approx.. three blades, proceed as follows :
    - Clean ring surface with petrol,
    - Inspect for cracks, damage or corrosion.

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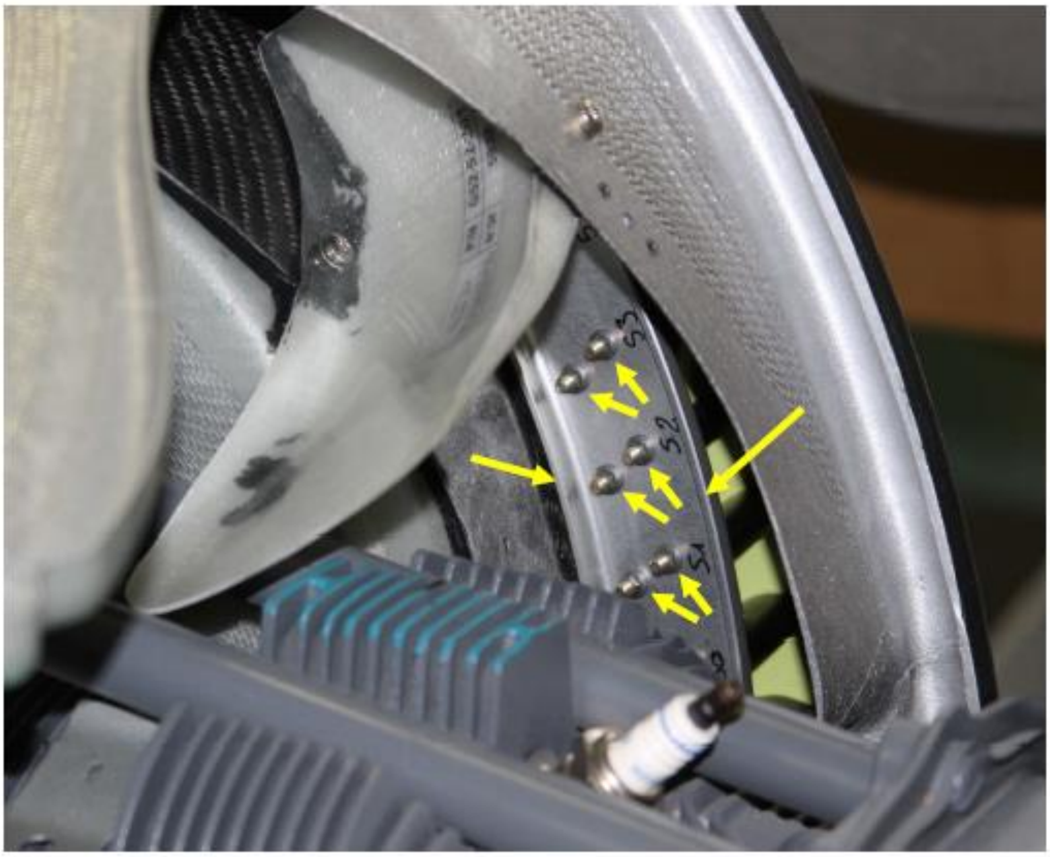
Specifically check :
- Around each bolt,
- Along the inner and outer rims of the ring.

- Proceed to the next sector until reaching the initial mark again : Total 64 blades.



Starting the engine and subsequent flight is not permitted if any damage is found. Proceed to the replacement of the ring.

- Report initial application of this SB.

Annexe 4: Service Bulletin SB 13-022A – Cooling fan upgrade

GUIMBAL	SERVICE BULLETIN				SB 13-022 B
		OPTIONAL		RECOMMENDED	
		REPAIR	X	MANDATORY	

SUBJECT	Cooling fan upgrade
DATE OF EFFECTIVITY	10 / 09 / 2013
DEADLINE (if applicable)	200 flight hours - February 2014 for parts refund
Associated AIRWORTHINESS DIRECTIVE	N/A
Associated MODIFICATION / REPAIR	MOD 13-050
HG CONTACT	Helicopteres Guimbal – Support Aérodrome d'Aix-en-Provence - 1070 rue Lieutenant Parayre - 13290 LES MILLES - FRANCE Tel : +33 (0)4 42 39 10 88 - Fax : +33 (0)4 42 39 10 82 email : support@guimbal.com

REVISION	SUBJECT	DATE
A	Creation	09 / 09 / 2013
B	Addition of Assembly P/N marking change	12 / 09 / 2013

APPLICABILITY

All Cabri G2 not equipped with MOD 13-050 Cooling fan. S/N 1003 to 1054 except S/N 1053. Later S/N include MOD 13-050.

SITUATION

Following an incident involving the engine cooling fan, the mandatory inspection SB13-021 was issued to ensure fleet safety.
In order to reduce the customer workload, HG decided to design a fail safe cooling fan ring that is intended to remove the mandatory inspection.
This SB prescribes the installation of this new ring.

REQUIRED ACTIONS

Note : This SB requires to remove the engine, but does not include many operations included in scheduled maintenance. This SB could thus be applied at any time, though a small amount of work is saved if applied during a 100 hrs inspection.
In any case, one should consider to take the opportunity of this SB to do some scheduled or unscheduled maintenance requiring or facilitated by engine removal, e.g. transmission belt replacement, front engine bearing regreasing, exhaust inspection etc.

Engine removal

a) Remove the engine per operation 50-A-10 of the Maintenance Manual.

Cooling fan removal

b) Remove the manifold pressure line from the scroll if it came with the engine,
c) Remove the 10 small screws clamping the two halves of the composite scroll,
d) Using a new cutter blade and some light oil to lubricate, cut precisely the compound bead all around the scroll. This might have been done already before. Keep the cut bead in good shape so that it does not need to be redone for reassembly,

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(Extract)

Annexe 5: Airworthiness directive AD 2014-0038

EASA	AIRWORTHINESS DIRECTIVE
	AD No.: 2014-0038 **Date: 14 February 2014** Note: This Airworthiness Directive (AD) is issued by EASA, acting in accordance with Regulation (EC) No 216/2008 on behalf of the European Community, its Member States and of the European third countries that participate in the activities of EASA under Article 66 of that Regulation.

This AD is issued in accordance with EU 748/2012, Part 21.A.3B. In accordance with EC 2042/2003 Annex I, Part M.A.301, the continuing airworthiness of an aircraft shall be ensured by accomplishing any applicable ADs. Consequently, no person may operate an aircraft to which an AD applies, except in accordance with the requirements of that AD, unless otherwise specified by the Agency [EC 2042/2003 Annex I, Part M.A.303] or agreed with the Authority of the State of Registry [EC 216/2008, Article 14(4) exemption].

Design Approval Holder's Name:	Type/Model designation(s):
HELICOPTERES GUIMBAL	CABRI G2 helicopters

TCDS Number:	EASA.R.145
Foreign AD:	Not applicable
Supersedure:	None

ATA 71	**Powerplant – Engine Cooling Fan – Inspection / Modification**
Manufacturer(s):	Hélicoptères Guimbal
Applicability:	Cabri G2 G00-00-000 helicopters, all manufacturer serial numbers (S/N).
Reason:	An in-flight engine shutdown was reported on a Cabri G2 helicopter, leading the pilot to a forced landing. Subsequent investigation revealed that the engine cooling fan had failed, which led to power shutdown as the fan damaged the scroll and pulled the mixture control cable. The suspected cause of the cooling fan failure is a crack which had developed in the fan external ring. Although the origin of that crack has not yet been determined, contributing factors could be corrosion, a manufacturing defect or local damage caused by maintenance or foreign object impact. This condition, if not detected and corrected, could lead to other events of cooling fan failure and subsequent in-flight engine shutdown or damage to the engine installation, possibly resulting in reduced control of the helicopter. To address this potential unsafe condition, Hélicoptères Guimbal (HG) issued Service Bulletin (SB) 13-021, providing instructions for inspection of the fan external ring to detect damage or cracking. HG also designed a new external ring with improved mechanical characteristics and a fail-safe feature (glass fiber winding). HG SB 13-022 was issued to provide instructions for installation of this new external ring on in-service helicopters. Helicopters S/N 1053 and from S/N 1055 onwards will be equipped with the new external ring design in production (MOD 13-050). For the reasons described above, this AD requires repetitive inspections of the engine cooling fan external ring part number (P/N) G52-01-200 or P/N G52-01-201and replacement of the ring with a new design part P/N G52-00-101.

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Effective Date:	28 February 2014
Required Action(s) and Compliance Time(s):	Required as indicated, unless accomplished previously: (1) Within 5 flight hours (FH) after the effective date of this AD, identify the engine cooling fan P/N, and, if P/N G52-00-000 is installed, before next flight, inspect the cooling fan external ring in accordance with the instructions of HG SB 13-021. (2) Within 50 FH after the initial inspection as required by paragraph (1) of this AD, and, thereafter, at intervals not to exceed 50 FH, inspect the external ring of engine cooling fan P/N G52-00-000 in accordance with the instructions of HG SB 13-021. Note: A non-cumulative tolerance of 5 FH may be applied to the inspection interval specified in paragraph (2) of this AD. (3) If, during any inspection as required by paragraph (1) or (2) of this AD, any crack or damage is found on the external ring, before next flight, modify engine cooling fan P/N G52-00-000 by replacing the ring with a new design external ring P/N G52-00-101and by marking the cooling fan with new P/N G52-00-001 in accordance with the instructions of HG SB 13-022 issue B. (4) Within 200 FH or 3 months, whichever occurs first after the effective date of this AD, unless already accomplished as required by paragraph (3) of this AD, modify engine cooling fan P/N G52-00-000 by installing a new design external ring P/N G52-00-101and by marking the cooling fan with new P/N G52-00-001 in accordance with the instructions of HG SB 13-022 issue B. (5) Installation of a new design external ring P/N G52-00-101 and marking of the cooling fan with new P/N G52-00-001 as required by paragraph (3) or (4) of this AD, as applicable, constitutes terminating action for the repetitive inspections required by paragraph (2) of this AD. (6) From the effective date of this AD, do not install a cooling fan P/N G52-00-000 and do not install on an engine cooling fan a plain external ring P/N G52-01-200 or P/N G52-01-201.
Ref. Publications:	HGSB 13-021 original issue, dated 18 July 2013. HGSB 13-022 issue B, dated 10 September 2013. The use of later approved revisions of these documents is acceptable for compliance with the requirements of this AD.
Remarks:	1. If requested and appropriately substantiated, EASA can approve Alternative Methods of Compliance for this AD. 2. Based on the required actions and the compliance time, EASA have decided to issue a Final AD with Request for Comments, postponing the public consultation process until after publication. 3. Enquiries regarding this AD should be referred to the Safety Information Section, Executive Directorate, EASA. E-mail: ADs@easa.europa.eu 4. For any question concerning the technical content of the requirements in this AD, please contact: Helicoptères Guimbal – Support Aérodrome d'Aix-en-Provence, 1070 rue du Lieutenant Parayre, 13290 LES MILLES, FRANCE Tel : +33 (0)4 42 39 10 88 E-mail: support@guimbal.com.

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Annexe 6: Service Bulletin SB 14-018A – Cooling fan inspection

GUIMBAL

SERVICE BULLETIN

☒ MANDATORY	☐ RECOMMENDED	SB 14-018 A
☐ OPTIONAL	☐ REPAIR	

SUBJECT :	**Cooling fan inspection**
DATE OF ENTRY INTO FORCE	27 Aug 2014
DEADLINE	First inspection : Applicable immediately Mandatory within the 5 flight hours after effective date.
Associated AIRWORTHINESS DIRECTIVE	To be issued
Associated MODIFICATION / REPAIR	N/A
HG CONTACT	Helicopteres Guimbal – Support Aérodrome d'Aix-en-Provence - 1070 rue Lieutenant Parayre - 13290 LES MILLES - FRANCE Tel : +33 (0)4 42 39 10 88 - email : support@guimbal.com

REVISION	SUBJECT	DATE
A	Creation	27 Aug 2014

APPLICABILITY

All Cabri G2.

- First inspection..... Applicable immediately – mandatory within the 5 flight hours after effective date.

- Periodicity............ 50 hours (5-hour non cumulative tolerance)

Evolution : This SB will be superseded by the application of a new front flange design. (MOD14-050 - SB14-019).

SITUATION

A crack was found on a high-time cooling fan front flange. This crack developed radially from the starter ring-gear.
Despite the SB 13-022 / AD 2014-0038 which greatly reduces the hazard, development of such crack bears a risk.

REQUIRED ACTIONS

- Open the cowlings,
Note : The inspection is easier if the engine cowlings are removed (which is the case for 100-hour inspections).

- Remove the scroll inlet screen with the two Camlocs,
- Closely inspect the fan front flange :
  - Clean the visible portion with a cloth dampened with petrol,
  - Using a torchlight, look for any crack, specifically around the starter ring gear,
  - Turn the crankshaft approximately 90° and reiterate until the complete flange is inspected.

Note : If the sparkplugs are removed, the crankshaft is easy to turn by hand. If they are not removed, short pulses on the starter may be used to turn the crankshaft. Turn slowly by hand to turn against the compression if needed.

Warning : strictly prohibit using any tool on the starter ring gear to turn the crankshaft.

- If a crack is found, proceed to fan replacement before any further flight.
- Send the cracked front flange to HG when ordering the new one.

SB 14-018 A Approved under DOA EASA21J.211 2 / 2