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Aircraft Accident Investigation Bureau AAIB

Final Report No. 1964 by the Aircraft Accident Investigation Bureau

concerning the accident

to the Robinson R44 Raven helicopter, registration HB-ZCU

on 26 July 2003

Selzach, municipality of Grenchen/SO

approx. 25 km north of Berne

Bundeshaus Nord, CH-3003 Berne

Ursache

Der Unfall ist darauf zurückzuführen, dass am Ende einer Autorotation ein Rotorblatt in den Heckausleger des Helikopters schlug. Die Autorotation wurde notwendig, weil der Motor im Reiseflug an Leistung verlor. Die Motorstörung trat auf, weil in einem Zylinder das Auslassventil blockierte und die Ventil-Stösselstange brach.

General information on this report

This report contains the AAIB's conclusions on the circumstances and causes of the accident which is the subject of the investigation.

In accordance with Annex 13 of the Convention on International Civil Aviation of 7 December 1944 and article 24 of the Federal Air Navigation Law, the sole purpose of the investigation of an aircraft accident or serious incident is to prevent future accidents or serious incidents. The legal assessment of accident/incident causes and circumstances is expressly no concern of the accident 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 prevention, due consideration shall be given to this circumstance.

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

Unless otherwise indicated, all times in this report are indicated in Swiss local time (LT), corresponding at the time of the accident to Central European Summer Time (CEST). The relationship between LT, CEST and universal time coordinated (UTC) is as follows: LT = CEST = UTC + 2 hours.

For reasons of protection of privacy, the masculine form is used in this report for all natural persons, regardless of their gender.

Final Report

Owner	Heli Sitterdorf AG, Flugplatz, 8589 Sitterdorf, Switzerland
Operator	Heli Sitterdorf AG, Flugplatz, 8589 Sitterdorf, Switzerland
Aircraft type	Robinson R44 Raven helicopter
Country of registration	Switzerland
Registration	HB-ZCU
Location	Selzach, municipality of Grenchen/SO
Date and time	26 July 2003, 15:08 LT

Summary

Synopsis

The pilot was making a private VFR flight in helicopter HB-ZCU with two passengers on board. When cruising at an altitude of approximately 4500 ft AMSL at a speed of approximately 80 kt, he suddenly sensed vibration, the engine rpm meter swung back and forth and the helicopter oscillated jerkily around its vertical axis. When the rotor speed eventually dropped and the corresponding warnings (horn and warning light) came on, the pilot initiated an autorotation. The emergency landing ended with a hard set-down manoeuvre on an open field; the tail skid made contact with the ground and a main rotor blade struck the tailboom.

The occupants were unharmed. The helicopter was damaged.

There was insignificant crop damage.

Investigation

The accident took place at approximately 15:08 LT. The investigation was opened on 26.08.2003 by the AAIB in cooperation with the Solothurn cantonal police.

The accident is attributable to the fact that at the end of an autorotation a rotor blade struck the helicopter’s tailboom. The autorotation was necessary because the engine lost power while cruising. The engine malfunction occurred because the exhaust valve in one cylinder became stuck and the valve pushrod broke.

1 Factual Information

1.1 Pre-flight history and history of the flight

The following information on the flight history is based on the pilot's statements.

The pilot took off from Sitterdorf aerodrome in the R44 Raven helicopter HB-ZCU with two passengers at approximately 11:50 LT on a flight to Berne. The helicopter was refuelled after landing in Berne. The route of the onward flight was via departure point November to Kernenried BE, where the pilot made a scheduled landing in open country. After the landing, the two passengers disembarked the helicopter and two other passengers embarked. At approximately 14:45 LT the helicopter took off from Kernenried BE. The flight lead over Kirchberg, Koppigen, Niederbipp and Oensingen, from which point the southernmost Jura mountain chain was crossed in a northerly direction. The flight then continued southward over the Jura in the direction of Wiedlisbach. The pilot made contact with the control tower in Grenchen and informed them of his intention to fly in the direction of Biel through the Grenchen control zone.

Cruising at an altitude of approximately 4500 ft AMSL at a speed of approximately 80 kt, the pilot sensed low-frequency vibrations. At the same time the engine speed began to fluctuate wildly. The warning light for the clutch lit up briefly. The pilot reduced power and speed and the vibrations reduced. Despite a further reduction in power and speed, the situation did not improve. Shortly afterwards, the vibrations increased and the helicopter began to oscillate jerkily around its vertical axis.

When the "low rpm" warning light illuminated as the rotor speed dropped and the corresponding audible warning signal sounded, the pilot initiated an autorotation. In the course of the autorotation, the pilot informed Grenchen control tower that he was making an emergency landing.

In the final phase of the autorotation, the rear rotor bumper made contact with the ground. Touchdown took place at virtually no forward velocity but at a considerable rate of descent. In this phase, a main rotor blade struck the tailboom.

Once the helicopter had come to a standstill, the pilot stopped the main rotor using the rotor brake, shut down the engine, which was still running, and switched off the helicopter's systems. The occupants were able to vacate the helicopter, which was standing upright on the landing skid, unharmed. After the emergency landing, the cabin, rotor blades, engine and tailboom were contaminated with oil.

The pilot informed Grenchen control tower of his location.

1.2 Injuries to persons

Injuries	Crew	Passengers	Total number of occupants	Third parties
Fatal	---	---	---	---
Serious	---	---	---	---
Slight	---	---	---	---
None	1	2	3	---
Total	1	2	3	---

1.3 Damage to aircraft

The helicopter was damaged.

1.4 Other damage

There was insignificant crop damage caused by leaking oil. This was bound by the cantonal police using oil binder.

1.5 Personnel information

1.5.1 Pilot

Person	Swiss citizen, born 1973
Licence	Commercial Pilot Certificate for Rotorcraft-Helicopter, issued on 27.10.2001 by the Federal Aviation Administration, USA
	Private Pilot's Licence (cat. helicopter) PPL (H), issued on 21.07.2003 by the Federal Office for Civil Aviation, issued on the basis of the US CPL (H), valid till 20.11.2004
Ratings	R22
	R44
	RTI (VFR)
Instrument flying rating	None
Last proficiency check	09.07.2003 PPL (H) examination
Medical fitness certificate	Class 1, with IR, without restrictions
	Commencement of validity: 23.11.2002
	End of validity: 23.11.2003
Last medical examination	20.11.2002

1.5.1.1 Flying experience

Total	183 hours
on the accident type	22 hours
during the last 90 days	14 hours
of which on the accident type	14 hours
during the last 24 hours	01:30 hours
of which on the accident type	01:30 hours
Landings, total	1471
Landings during the last 90 days	126
Total landings on the accident type	205
Landings during the last 90 days on the accident type	126

1.5.2 Passengers

Person A	Swiss citizen, born 1971
Person B	Swiss citizen, born 1977

1.6 Aircraft information

Registration	HB-ZCU
Aircraft type	Robinson R44 Raven
Characteristics	Helicopter with semi-rigid two-blade main rotor and piston engine propulsion
Manufacturer	Robinson Helicopter, Torrance CA, USA
Year of construction	2001
Serial number	0986
Owner	Heli Sitterdorf AG, Flugplatz, 8589 Sitterdorf, Switzerland
Operator	Heli Sitterdorf AG, Flugplatz, 8589 Sitterdorf, Switzerland
Engine:	
Manufacturer	Textron Lycoming Engines, Williamsport, PA , USA
Type	O-540-F1B5
Year of construction	2000
Serial number	L-25840-40A
Construction	Six-cylinder 4-stroke petrol engine, boxer configuration, direct drive, air-cooled Naturally aspirated engine with carburettor Dual ignition with two magnetos Two valves per cylinder Sodium-cooled exhaust valves

	Valve control by a central camshaft via pushrods and rocker arms, hydraulic valve clearance adjustment
Cooling system	Direct-drive radial fan
Cubic capacity	541.5 cubic inches - 8874 cm³
Rated power	194 kW (260 bhp) (brake horse power) at 2800 rpm
Maximum continuous power installed in R44	153 kW (205 bhp) at 2692 rpm (102% on the tachometer)
Take-off power for 5 minutes, installed in R44	168 kW (225 bhp) at 2692 rpm
Operating hours aircraft and engine	774:06 h
Maintenance	See 1.6.3 Since the last 50-hour check there were no remarks concerning technical problems noted in the engine and flight logbook.
Technical limitations	None
Fuel grade	AVGAS 100LL aviation gasoline
Fuel remaining	According to the pilot’s statement, the total fuel on take-off from Sitterdorf was sufficient for 2:30 hours flying time. Flying time to Berne was 1:20 hours. Refuelling with 90 litres of AVGAS 100LL was performed in Berne. Given an assumed flying time of 0:15 hours for the flight from Berne to Kernenried and 0:23 hours up to the accident and a consumption of 60 l/h, the flying time reserve at the time of the accident was approximately 2 hours. When the helicopter was examined, it was found that there was fuel in the entire combustion system, up to and including the carburettors.
Registration certificate	Issued by the FOCA on 28.02.2001, valid till removal from the aircraft register
Airworthiness certificate	Issued by the FOCA on 12.03.2001, valid till revoked
Certification	VFR day / VFR night In commercial use VFR day

1.6.1 Mass and centre of gravity

At take-off, the maximum permitted mass is 2400 lbs.

The mass and centre of gravity were within the permitted range during the flight involved in the accident.

1.6.2 Power calculations

The power calculations using the graphs in the pilot's operating handbook (POH) for the values and environmental conditions at the time of the accident show that at an elevation of 1600 ft AMSL, hovering flight would have been possible both within and without the ground effect.

1.6.3 Maintenance

On 19.01.2002, at an operating time (time since new – TSN) of 304.5 hours, a 100-hour check was carried out by Valair Maintenance AG, on both the airframe and engine, and the Lycoming mandatory service-bulletin SB 388B (exhaust valve inspection) was carried out.

The measured valve stem clearances were documented in the engine log and amounted to:

Cylinder No.	1	2	3	4	5	6
Clearance [inches]	0.022"	0.021"	0.019"	0.019"	0.020"	0.018"
Clearance [mm]	0.559mm	0.533mm	0.483mm	0.483mm	0.508mm	0.457mm

On 21.01.2003, at an operating time of 601:48 hours, a 100-hour check was carried out by Ben Air Helicopter-Service AG on the airframe and engine, and the Lycoming mandatory service-bulletin SB 388B (exhaust valve inspection) was carried out.

Item 16 from SB 388B reads:

"Enter the inspection results and any corrective action accomplished in the engine log."

Implementation of the mandatory Service Bulletin SB 388B was noted in the engine and flight logbook; the valve stem clearances were not documented by the maintenance company.

The last annual inspection was carried out in conjunction with a 100-hour check on the airframe and engine at 697:12 hours on 15.05.2003 by Valair Maintenance AG.

The last 50-hour check on the airframe and engine was performed at 740:30 hours on 24.06.2003 by Valair Maintenance AG.

1.6.4 Examination of the fuel

A sample of fuel from the helicopter's tank was examined in the laboratory. The following findings were made:

Appearance: clear, free from undissolved water, contains small solid particles.

Evaporation residue: measured: 9 mg/100 ml.

According to the specification, a maximum of 3 mg/100ml evaporation residue was allowed to remain. In the laboratory analysis, however, it was especially noted that the specification with which the laboratory analysis was compared had not been amended for more than 10 years. In newer ASTM specifications, the evaporation residue is no longer listed.

The measured result of 9 mg/100 ml is not extraordinarily high. In addition, there is the possibility that the result of the measurement was affected by solid particles (see Appearance).

1.7 Meteorological information

1.7.1 General

The information in sections 1.7.2 to 1.7.4 was provided by MeteoSwiss.

1.7.2 General weather situation

Translated from German:
A low-pressure area centred over the British Isles was moving towards central Europe. Switzerland was still in the area affected by a ridge of high pressure which was slowly weakening and drawing away to the east.

1.7.3 Weather at the time and location of the accident

The following information on the weather at the time and location of the accident is based on a spatial and chronological interpolation of the observations of different weather stations.

Weather/cloud	*2-3/8 cumulus, base approx. 6000 ft AMSL, 4-5/8 altocumulus, base approx. 14 000 ft AMSL*
Visibility	*about 25 km*
Wind	*West-south-west (approx. 250 degrees) at approx. 15 kt, gusting to 23 kt*
Temperature/dewpoint	*29 °C/14 °C*
Atmospheric pressure	*1014 hPa QNH (LSGS), 1014 hPa QNH (LSZH)*
Hazards	*Turbulence due to west wind and high temperatures*

1.7.4 Astronomical information

Position of the sun	Azimuth: 222°	Elevation: 57°
Lighting conditions	Daylight	

1.8 Aids to navigation

Not applicable.

1.9 Communications

Radiocommunication between the pilot and Grenchen control tower took place according to the rules and without difficulties up to the time of the accident. After the emergency landing, the pilot informed Grenchen control tower of his location, at which time the rescue services were informed.

1.10 Aerodrome information

Not applicable.

1.11 Flight recorders

Not prescribed and not installed.

1.12 Wreckage and impact information

1.12.1 The wreck

The following findings were made on the helicopter:

The helicopter was upright on the landing skid in a stubble field. The nose was pointing to the west. The helicopter had damage to the main rotor and tailboom, i.e. a main rotor blade had struck the tailboom. The rotor blades, cabin, engine housing and tailboom were contaminated with oil.

Tailboom with damage due to impact of a main rotor blade

1.12.2 Impact

According to the pilot's statement, the landing was vertical from a height of approximately one metre and was a hard landing.

1.12.3 Site of the accident

Accident location	Selzach Moos, municipality of Grenchen/SO
Swiss coordinates	600 407 / 228 535
Geographical latitude	N 47° 12' 28"
Geographical longitude	E 007° 26' 38"

Elevation	485 m AMSL
	1591 ft AMSL
National map of Switzerland	Sheet No. 1126, Büren a.A., scale 1:25 000

1.13 Medical and pathological information

There is no indication that at the time of the accident the pilot was affected in terms of his mental or physical capabilities.

1.14 Fire

Fire did not break out.

1.15 Survival aspects

1.15.1 Possibilities of surviving the accident

In the course of the autorotation respectively the emergency landing, the pilot was able to reduce both the vertical and horizontal components of the helicopter's velocity to such an extent that the occupants did not suffer any physical injury.

1.15.2 Alarm and rescue

The aerodrome traffic controller at Grenchen regional airport raised the alarm with the Solothurn cantonal police. The latter proceeded to the site of the accident and arrived there a few minutes after the emergency landing.

1.15.3 Emergency transmitter

The helicopter was equipped with an emergency transmitter (emergency location beacon aircraft – ELBA). The permanently installed device was not triggered by the hard landing.

1.16 Tests and research

1.16.1 Forensic investigations

The main rotor blades, tailboom, tail skid, the grey paint on the securing wires and screws on the valve covers, as well as the panel with the engine monitoring instruments were examined forensically.

1.16.2 Results of the forensic investigations

1.16.2.1 Main rotor blades

The results of the investigations show that one of the two main rotor blades struck the tailboom.

1.16.2.2 Tail skid

The samples removed from the tail skid, using adhesive tape, contain blue metallic paint particles, oil residue and plant material, large quantities of soil and stone particles. The trace material found therefore indicates that the tail skid made contact with the ground.

1.16.2.3 Engine monitoring instruments

Pointer marks could not be found on any of the instruments. The absence of pointer marks on all the instruments examined can be explained by the fact that the impact (touchdown) on the ground was not sufficiently violent to leave corresponding traces. The panel concerned was fitted in the helicopter in an approximately horizontal location. Given the impact direction in question, favourable conditions should have existed with regard to leaving pointer traces.

1.16.2.4 Paint on the securing wires of the valve cover bolts

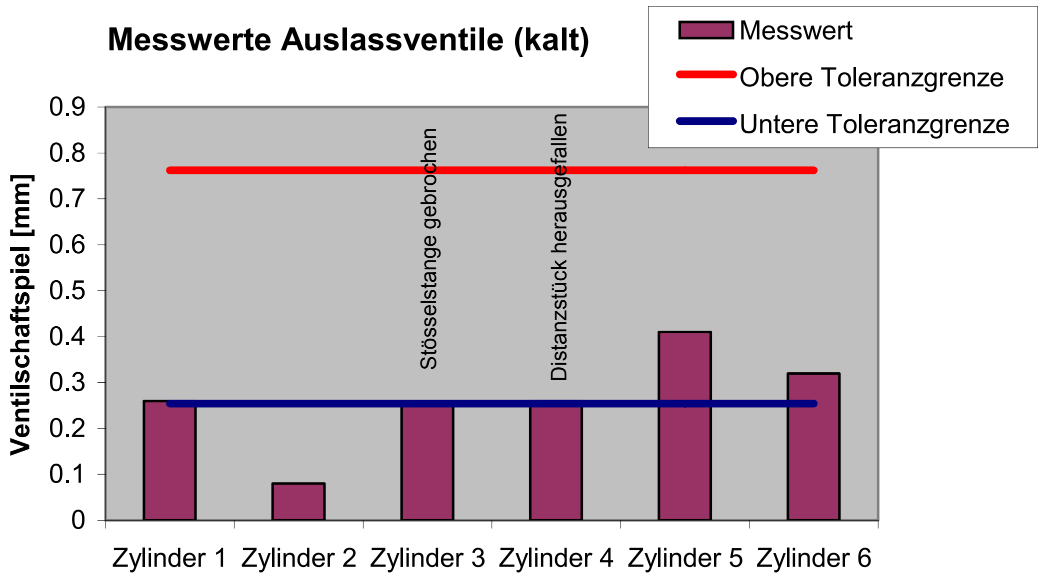
The microscopic and analytical investigations of the grey paint from the securing wire of the centre valve cover on the left and from the can and glass of the maintenance company showed that with regard to condition and colour the compared samples appeared similar, contained the same organic components and therefore cannot be distinguished either from the viewpoint of material composition.

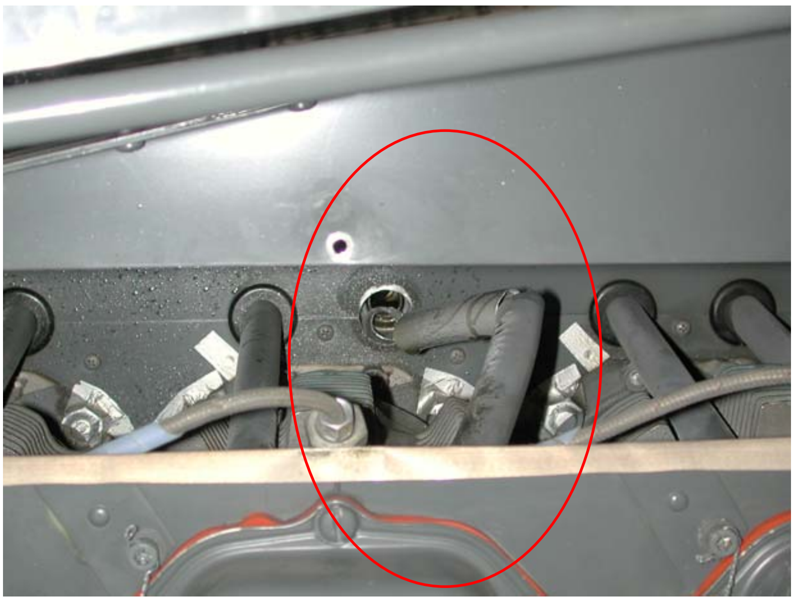
1.16.3 Technical examinations of the engine

General findings	On cylinder No. 3, the pushrod of the exhaust valve and the corresponding protective tube were kinked and broken. An oil leak had occurred through the fractured pushrod tube.
Engine oil level	4 qt. The required minimum quantity is 7 qt.
Ignition	Both magnetos within tolerance.
Fuel	Fuel was present up to and including the carburettor.
Valves	All valves were examined for the following points: • Damage • Loss of compression • Valve clearance • Valve stem clearance (measurement method according to SB 388B) Rated value: Minimum: 0.254 mm Maximum: 0.762 mm

Cylinder No.	Valve stem clearance Exhaust valve	Tolerance situation	Comments
1	0.260 mm	within	
2	0.080 mm	outside	The valve may possibly have become blocked within a short time as a result of the low valve stem clearance.
3	0.250 mm	outside	
4	0.260 mm	within	The valve spacer was found loose in the valve cover.

5	0.410 mm	within
6	0.320 mm	within





Cylinder No. 3 and the corresponding valves were examined.

This examination produced the following results:

Exhaust valve stem guide, inside:

- Deposits of lead residue, predominantly in the lower half of the valve guide
- Aluminium and iron particles present on the surface
- No indications of sticking

Exhaust valve stem guide, inside. The dark deposits on the lower half of the valve guide (on the right in the photo) are predominantly lead residue.

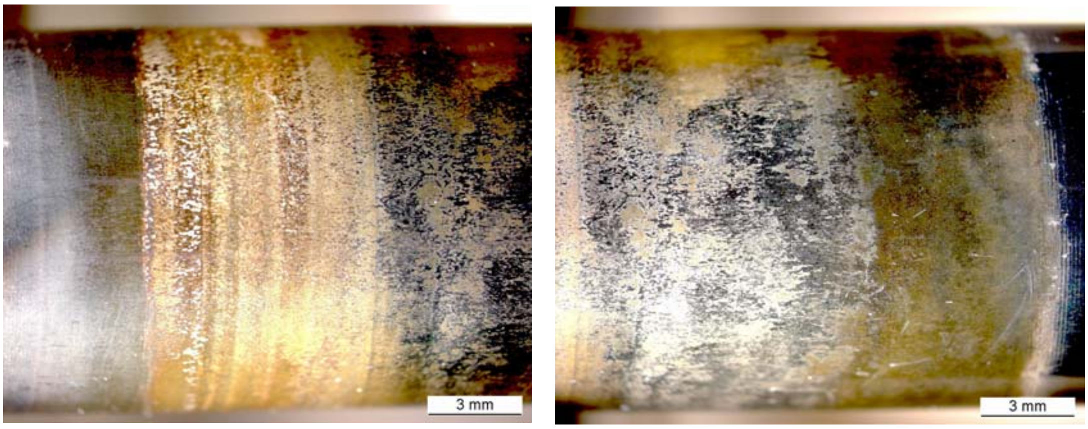
Exhaust valve:

- Small scratches on the valve stem
- Lower half of the valve stem covered with paint-type carbon deposits
- Underneath, the layer of chrome on the valve stem is damaged in places; completely removed over a 3 mm wide area
- Large quantities of lead and bromine deposited on the surface of the valve stem
- Valve fit area predominantly covered with carbon residue

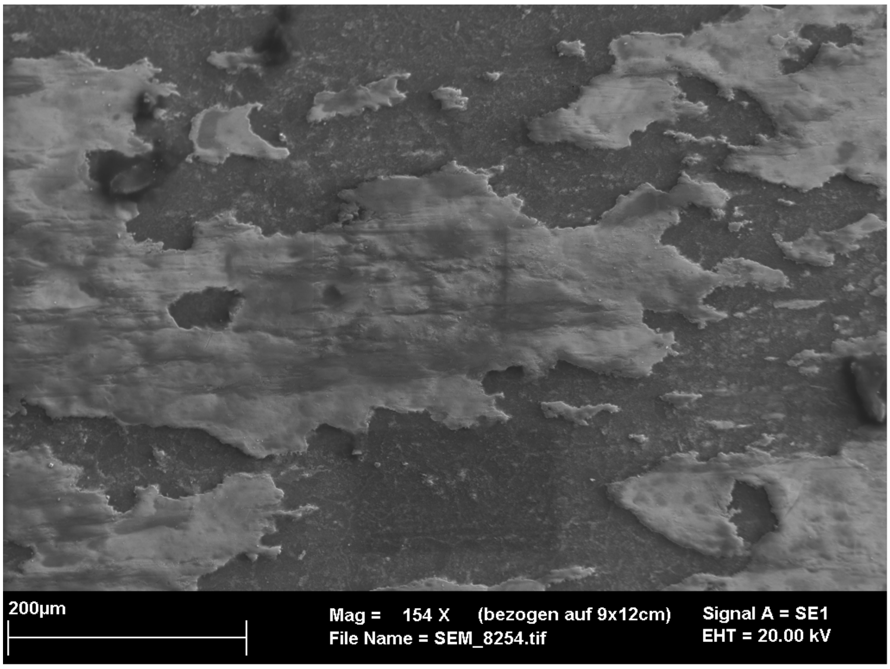
Comment: Bromine is normally mixed into leaded petrol as a scavenger[1].

[1] Scavengers are included in the lead additives which are added to fuel. They are halogenated hydro-carbons which are intended to prevent lead deposits inside the engine and resulting malfunctions in operation.

Cylinder No. 3 exhaust valve with deposits on the lower part of the valve stem



Microscopic photograph of deposits on the stem of cylinder no. 3 exhaust valve



REM (Raster Electron Microscope) photograph of lead deposits on the surface of the valve stem of cylinder No. 3 exhaust valve

Carbon residue on the fit of cylinder No. 3 exhaust valve

Inlet valve:

- No deposits found
- Approx. 3 mm wide trace of sticking on the lowest part of the valve stem

Valve fits in the cylinder head:

- Poor condition, i.e. the valve fits on both the inlet and exhaust valves were found to have rough surfaces; they were no longer capable of providing a complete seal.

Cylinder No. 3 combustion chamber. Rough surfaces of the valve fits clearly visible in the cylinder head, exhaust valve above, inlet valve below.

1.16.4 Examination of the lubricant

A sample of the lubricating oil of the engine was subjected to spectrometric analysis.

The analysis produced the following result:

- Iron (Fe) 35.4 ppm
- Aluminium (Al) 14.0 ppm
- Silicon (Si) 11.0 ppm

These values are distinctly higher than usual.

The engine oil used was an "aviation grade, ashless dispersant" multi-viscosity oil with the viscosity designation SAE20W50 and corresponded to specification SAEJ1899 and MIL-L-22851 respectively.

In the pilot's operating handbook (POH) and also in the Lycoming Service Instruction SI-1014 there are matching tables with recommended oil viscosities for various average ambient temperatures. The oil used is there listed twice, once for the temperature range from 0 °F to 90 °F (-17.8 °C to 32.2 °C) and once for "all temperatures".

1.17 Organizational and management information

Not applicable.

1.18 Additional information

1.18.1 Information on engine operation

1.18.1.1 Comment by the engine manufacturer

Lycoming, the engine's manufacturer, was provided with a description of the accident and the results of the engine investigation. The Field/Technical Support department made the following comments:

1. *The cooling system and specific operational recommendations regarding cooling are the responsibility of the airframe manufacturer. They do the certification testing and hold the approved data in this regard.*
2. *Lycoming does have a recommendation in the Operator's manual, no. 60297-10, page 3-18, to idle until there is a decided decrease in the Cylinder Head Temperature. The airframe manufacturer may provide expanded, specific recommendations appropriate to their installation.*
3. *The inspections called out in Service Bulletin 388B are considered adequate for normal conditions. The inspection intervals carry the note A or earlier if valve sticking is suspected***.** *Individuals or fleet operators flying in extreme conditions may elect to perform a more frequent inspection based on their operational experience. You may note that Supplement 1 to SB 388B details an optional inspection method that may be easier for some to perform accurately. Also applicable are Service Instruction 1425, which describes a procedure to proactively prevent valve sticking and suggests operational procedures to avoid them.*

   If all applicable Service Bulletins, Service Instructions and Service Letters are consulted and adhered to, valve sticking can be largely eliminated."

1.18.1.2 Manufacturer's procedures

In the pilot's operating handbook Section 4 Normal Procedures SHUTDOWN PROCEDURES, the following sequence is specified.

Idle at 70 to 80%	*CHT drop*
Throttle	*Closed*
Clutch switch	*Disengaged*
Wait 30 sec	*Pull idle cut-off*

1.18.1.3 Information on the checklist

The operator's internal checklist described the following procedure under SHUTDOWN:

Reduce RPM for cooling *75% (within 3min 30sec).*

1.18.2 Origin of deposits on engine parts

In several documents, such as, for example, Service Instruction 1425, Lycoming, the engine manufacturer, explains the mechanism which may lead to the build-up of coke and other layers on engine parts, in particular on the valve guide and valve stem of exhaust valves. This is summarised below.

In the case of operation with AVGAS 100LL fuel with its high lead content, lead salts and other combustion residues find their way into the engine oil as contaminants. This contamination occurs for the most part in engine oil either as very fine particles (dispersion) or they remain in solution and are therefore not trapped by the oil filter. During operation, the concentration of lead and other contaminants in the engine oil continuously increases until the contamination is removed from the engine with the old oil when the oil is changed.

The mode of operation of the engine affects the quantity of lead which finds its way into the oil. A correct mixture setting at cruising power (a lean mixture) leads to full combustion of the fuel. As a result, less lead residue and other contaminants get into the engine oil. More residue is formed if the mixture setting is too rich.

This contamination tends to separate out favourably on hot surfaces with which the engine oil comes into contact, especially the valve guides and valve stems, causing layers to build up. The higher the concentration of contamination in the oil, the faster these layers build up.

Temperature is a second important factor. Carbon deposits are caused by thermal dissociation (decomposition) and oxidation of the oil at high temperatures. In several publications, the engine manufacturer refers to the fact that carbon or contaminant deposits are favoured by operation at a high ambient temperature or if cooling is reduced.

Particularly when a hot engine is shut down before it has cooled down sufficiently, this may lead to accelerated formation of layers which can cause the valves to stick. When the engine is shut down, the lubricant circulation also comes to a stop. If at this point in time, for example, the valve stems are still hot, the oil which adheres to them heats up since it is no longer flushed away. As a result, thermal decomposition and oxidation, i.e. coke formation, is started and contaminants which are present, e.g. lead residue, are deposited.

Quotations from Lycoming Service Instruction No. 1425A dated 19 January 1988:

"Field experience has shown that engine oil contamination increases the possibility of sticking and/or stuck valves. This situation occurs when the contaminants in the engine lubrication oil become deposited on the valve stems, restricting the valve movement, and resulting in intermittent engine hesitation or miss. If corrective action is not taken to remove the deposits, a valve could become stuck causing engine damage.

"Since the rate of oil contaminant accumulation is increased by high ambient temperatures, slow flight with reduced cooling, and high lead content of fuel, ..."

".... , or shutting the engine down before it has sufficiently cooled down can also induce valve sticking."

"The prime cause of valve sticking is the accumulation of harmful contaminants in the oil and oil filter."

"Investigations have shown that exhaust valve sticking occurs more frequently during hot ambient conditions. The lead salts that accumulate in the lubricating oil from the use of leaded fuels contribute to the deposit build up in the valve guides. …

…. Operating with any of the following conditions present can promote deposit build-up reducing valve guide clearance and result in valve sticking.

a. High ambient temperatures

b. Slow flight with reduced cooling

c. High lead content of fuel"

In a further article, "Operational and Maintenance Procedures To Avoid Sticking Valves", Lycoming writes, among other things:

"Ground running also involves a slightly rich mixture which contributes to the formation of lead sludge in the oil. During flight, the deposit of lead sludge in the oil can be minimized by proper leaning.

Although some excess fuel is required for engine cooling during high power operation, proper leaning at cruise power settings will promote complete burning of the fuel and, therefore, a minimum of lead sludge deposited in the oil. This is important since lead sludge is not filtered out, but is removed by changing the oil."

"*… lack of effective cooling air may cause some areas of the engine to be excessively hot, and therefore have an effect on any contaminants that are in the oil. The formation of deposits is promoted with the exhaust valve guide area the most likely to be affected. The result of these deposits may be a stuck or sticking valve.*"

The type of engine oil used is also significant. Multi-grade oils usually contain synthetic additives to make viscosity less dependent on temperature. As a result, these oils remain thinner at low temperatures than customary single-grade oils, allowing them to be used in a much wider temperature range. However, it is a disadvantage of some of these additives that they tend to cause increased carbon deposits in the uppermost temperature range of their spectrum of use.

In this context, Lycoming writes in an article entitled "More About Oils":

"...*Unfortunately the additives that make these oils capable of operation at all temperatures also tend to form carbon products during hot weather operation when the oil usually runs at the high end of the temperature spectrum. These products may settle out in the valve guides and contribute to sticking valves."*

1.18.3 Maintenance instructions for the Lycoming O-540 engine

The problem of sticking exhaust valves in Lycoming engines has been known for decades, since 1988 at least, and the manufacturer reacted to it with mandatory Service Bulletin No. 338 and Service Instruction 1425. These two documents contain detailed information on checking the clearance of the exhaust valve stems as well as instructions on how the necessary clearance can be re-established. At the time of the accident, SB388B, dated 13 May 1992, applied.

Quotation from the introduction to Lycoming Service Bulletin SB388B:

"TIME OF COMPLIANCE:

Helicopter engines should be inspected at 300 hour intervals; all other engines should be inspected at 400 hour intervals, or earlier if valve sticking suspected.

To insure positive and trouble free valve train operation, the inspection procedure described in this publication should be accomplished as recommended in the Time of Compliance section of this publication. Failure to comply with the provisions of this publication could result in engine failure due to excessive carbon build up between the valve guide and valve stem resulting in sticking exhaust valves or; broken exhaust valves which result from excessive wear (bell-mouthing) of exhaust valve guide."

Lycoming Service Instruction SI1485A, dated 2 July 2003, provides information to the effect that since March 1998 the engine manufacturer has replaced the exhaust valve stem guide material with a material with a higher chrome content. On engines which are equipped with these valve stem guides featuring material with a higher chrome content, apart from those which are fitted to helicopters, the valve stem clearance measurement according to SB 388 must be carried out less frequently, that is to say only every 1000 hours (or half the TBO, whichever occurs first).

For engines fitted to helicopters, however, the 300 hours inspection intervals continue to apply, even if, like the engine in the helicopter involved in the accident, they were manufactured after March 1988 and therefore have valve stem guides made from the material with a higher chrome content.

On 22 November 2004, i.e. 16 months after the accident, SB388C was published. The essential changes from SB338B consist of the following points:

1. The inspection intervals for engines which are fitted with valve stem guides with a higher chrome content and which are not fitted to helicopters were increased according to SI1485A, i.e. to 1000 hours or half TBO.
2. As an option, a different method for checking the correct valve stem clearances, i.e. using a cylindrical limit gauge (GO/NO-GO gauge), was added. This measurement method provides substantially clearer results and in addition makes it a very simple matter, if necessary, to re-work the valve stem guide to the specified diameter using a reamer, with very little additional effort.

On 09 March 2006, airworthiness directive (LTA) HB-2006-151 was published by the FOCA, with entry into force set for 14 March 2006. This is based on airworthiness directive AD 2005-0023R2 of the European Aviation Safety Agency (EASA)[2]. For helicopters with Lycoming engines, this LTA prescribes the mandatory implementation of Lycoming SB 388C. This must be implemented within the first 100 hours of operation after its entry into force and at subsequent intervals of max. 330 hours of operation.

[2] European Aviation Safety Agency, the European Union aviation authority

On 21 June 2006, LTA HB-2006-330 was published by the FOCA, with entry into force set for 28 June 2006. This replaced HB-2006-151 and is based on EASA AD 2005-0023R3. For helicopters, nothing changed as a result of the new version of the airworthiness directive.

1.19 Useful or effective investigation techniques

Not applicable.

2 Analysis

2.1 Technical aspects

2.1.1 Loss of power and engine damage

The broken valve pushrod and the corresponding tappet sleeve on the cylinder No. 3 exhaust valve which was also broken clearly indicate that this valve must have stuck completely during operation. As a result, the pushrod buckled and failed. From this moment, cylinder No. 3 was no longer able to supply power.

The fracture of the cylinder No. 3 pushrod sleeve caused a major oil loss; this explains the low engine oil level.

The spacer which fell out of the valve train of the cylinder No. 4 exhaust valve means that during operation this valve must have stuck in the open position at least temporarily. As a result, the load on the spacer was relieved and the clearance became such that it was able to fall out. Even if at the time of the accident the valve was moving again, without the spacer both the valve stroke and the timing were altered, leading to loss of power in cylinder No. 4. The hydraulic clearance adjustment system of the valve train was, however, able to partly compensate for this adverse effect.

It is possible that the cylinder No. 4 exhaust valve was stuck in the open position at the time of the accident and that as a result this cylinder was no longer providing power. However, it is more probable that the valve was moving for part of the time then sticking, then moving again, etc. In this case, abrupt fluctuations in power would have occurred. This would explain the fluctuations in engine speed observed by the pilot and the jerky oscillations of the helicopter around its vertical axis.

The valve stem clearance on the cylinder No. 2 exhaust valve was also too small.

On cylinder No. 1 the exhaust valve stem clearance was only just within tolerance (by 0.006 mm).

Therefore, of the six cylinders, two exhaust valves were demonstrably sticking in operation, another had a markedly insufficient valve stem clearance and a fourth was only just within tolerance. The valve stem clearance was obviously within the tolerance limits on only two of the six exhaust valves.

The materials analysis of the valve stem and the valve guide on the cylinder No. 3 exhaust valve shows that deposits of carbon, lead and bromine are responsible for the low valve stem clearances.

2.1.2 Maintenance aspects and measurement methods

In the case of helicopters, the valve stem inspections prescribed in Service Bulletin SB-388B must be carried out after every 300 hours of operation.

The question as to why the valve stem clearance on the valves of cylinders Nos. 2 and 3 was out of tolerance some 170 operating hours after implementing SB-388B must remain open.

Since the measured values were not documented on the occasion of the last inspection of the valve stem clearances according to SB-388B, it is impossible to assess how much the values changed in the approximately 170 hours of operation.

The measurement method for valve stem clearance according to SB388B (a 'wiggling' test) does not provide very reliable results with regard to sticking of the valve stems. This is shown by the results of the clearance measurement after the accident (cf. section 1.16.2). The measurement results for cylinders 3 and 4 were borderline in terms of tolerance. However, both valves demonstrably stuck during operation.

On the other hand, the cylinder No. 2 exhaust valve exhibited a clearance which was considerably below the tolerance. However, no indications of sticking in operation could be found on this valve.

In revision C of Service Bulletin 388 dated 22.11.2004 (cf. section 1.18.3), the manufacturer proposes an alternative measurement method using a cylindrical limit gauge (a GO/NO-GO gauge). This is distinctly more reliable with reference to measurement of valve stem clearances and is therefore to be preferred.

2.1.3 Engine operation

Sufficient cooling of a hot engine before shutdown is a key factor in relation to the formation of deposits on hot engine parts. In this context, in the case of helicopters, less favourable conditions apply in comparison with fixed-wing aircraft, as a helicopter engine is generally operated at high power before landing and is accordingly at high temperatures after landing. The POH therefore prescribes that the engine should continue to be operated at an rpm of 70-80% until the cylinder head temperature drops before it is shut down.

The flying school which operated the helicopter had included the following instruction in its checklist: "*reduce RPM for cooling … 75% (within 3 min. 30 sec.)*". The manufacturer's instruction to wait for a reduction in the cylinder head temperature was applied in this manner.

It must remain open whether these procedures were always and fully complied with by pilots. The findings on the helicopter indicate that the engine had not cooled down sufficiently before shutdown for an extended period.

2.1.4 Influence of the type of oil

The type of oil has a significant effect on the formation of deposits on hot engine parts. In fact, the engine manufacturer points out on the one hand in SI 1425 that the additives in multi-grade oils favour the formation of carbon deposits and hence exhaust valve sticking, and on the other hand it lists multi-grade oil types SAE15W50 and SAE20W50 in SI 1014 "Lubricating Oil Recommendations" as a recommendation for "all" temperatures and also for temperatures from 0 °F to 90 °F (-17.8 °C to +32.2 °C).

The specification for engine oils (SAEJ1899) does not state which additives can be included in multi-grade oils. It is therefore up to the oil manufacturers to decide which additives they use and the concentration in which they add them to the oil, as long as the specification is complied with. However, since these additives have an effect on coking behaviour, it is obvious that engine oils from different oil producers may exhibit distinctly different behaviour in terms of the formation of layers and deposits, even though they all meet the same standard.

It would be useful to check whether the use of single-grade oils (e.g. SAE50 or SAE60) might contribute to improving the situation in hot summertime ambient temperatures.

2.1.5 Fuel

The fuel in the helicopter's tank was AVGAS 100LL. The measured evaporation residue (gum) of 9 mg/100 ml is three times higher than would be permitted by the specification and is also considerably higher than is for example specified for automobile petrol (max. 5 mg/100 ml). The test result may have been affected by solid particles which were in the sample.

Excessively high values for evaporation residues typically occur as a result of overlong storage of fuel and possible consequences include deposits in carburettors, injection systems and the intake tract.

The quality of the fuel is unrelated to the loss of power and the engine damage.

2.2 Human and operational aspects

The indications of loss of engine power were interpreted correctly by the pilot. The immediate initiation of an autorotation was correct. The engine power would very probably no longer have been sufficient for a normal landing. The terrain chosen by the pilot was suitable for an emergency landing.

In July 2001 the pilot concluded a one-week "awareness training" course on an R22B in the United States. This course also included ample flight training in the event of the occurrence of malfunctions and emergencies. In particular, autorotations were practised. It is obvious that this training had a positive effect on the pilot's flying capability in the present emergency situation.

The impact of a main rotor blade with the tailboom occurred either when the tail skid contacted the ground or during the hard landing after the autorotation.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects

- The helicopter was certified for VFR transport by day.
- The helicopter's mass and centre of gravity were within the permitted limits throughout the flight involved in the accident.
- A distinct loss of engine power occurred whilst cruising.
- The engine exhaust valve of cylinder No. 3 had stuck completely, causing the pushrod to buckle and break.
- The cylinder No. 4 exhaust valve was also very probably stuck in the open position at the time of the accident, or at least had been temporarily stuck at some time, allowing the valve train spacer to fall out.
- The stem clearances of two other exhaust valves were also reduced.
- The reduced stem clearances and the consequent sticking of the exhaust valves were caused by deposits of carbon, lead and bromine on the valve stem and valve guide.
- Multi-grade oils contain synthetic additives which tend to cause coking at high temperatures, i.e. at the upper limit of the recommended temperature range.
- The helicopter's engine was also being operated using a multi-grade oil in high summer.
- The engine oil used complied with the engine manufacturer's specification and recommendation.
- At the time of the accident, the helicopter, S/N 986, and also the engine, S/N L-25840-40A, had an operating time since manufacture of 774:06 hours.
- In the helicopter's technical documentation, implementation of mandatory Service Bulletin SB-388B (exhaust valve inspection) is confirmed at an operating time of 601:48 hours on 21.01.2003. The valve stem clearances were not documented by the maintenance company.
- In SB-388B the manufacturer prescribed the so-called 'wiggle' test to measure valve stem clearances.
- The manufacturer issued Revision C of SB-388 on 22.11.2004. In it, it proposed an optional measurement procedure using a cylindrical limit gauge (a GO/NO-GO gauge) to determine the valve stem clearances. Experts are of the opinion that this procedure provides more reliable measurements.

3.1.2 Crew

- The pilot was in possession of the necessary licences and ratings.
- There are no indications of the pilot suffering any health problems during the flight involved in the accident.

3.1.3 History

- The pilot initiated an autorotation.
- On landing (flare), the tail skid came into contact with the ground.
- The helicopter touched down at a low forward velocity and a considerable rate of descent.
- A main rotor blade struck the tailboom.

3.1.4 General conditions

- In the POH, the manufacturer prescribes that before shutting down the engine it is necessary to wait at an engine speed of 70-80% for the cylinder head temperature to drop.
- This instruction is applied in the helicopter operator's checklist as follows: *"reduce RPM for cooling … 75% (within 3 min. 30 sec.)"*.

3.2 Cause

The accident is attributable to the fact that at the end of an autorotation a rotor blade struck the helicopter's tailboom. The autorotation was necessary because the engine lost power while cruising. The engine malfunction occurred because the exhaust valve in one cylinder became stuck and the valve pushrod broke.

Berne, 19 September 2007 Aircraft Accident Investigation Bureau