Eurocopter AS 332L, G-BWZX

AAIB Bulletin No: 11/99 Ref: EW/C97/12/3 Category: 2.1

Aircraft Type and Registration:	Eurocopter AS 332L, G-BWZX
No & Type of Engines:	2 Turbomeca Makila turboshaft engines
Year of Manufacture:	1984
Date & Time (UTC):	12 December 1997 at 1253 hrs
Location:	10nm East South East of Sovereign Explorer Oil Rig
	(59o 34' N 007o 36' W)
Type of Flight:	Public Transport
Persons on Board:	Crew - 2 - Passengers - 9
Injuries:	Crew - None - Passengers - None
Nature of Damage:	Severe to two main rotor blades, lesser damage to two other blades
Commander's Licence:	Airline Transport Pilot's Licence (Helicopters)
Commander's Age:	54 years
Commander's Flying Experience:	15,485 hours (of which 9,927 hours were on type)
	Last 90 days -162 hours
	Last 28 days 38 hours
Information Source:	AAIB Field Investigation

History of flight

The captain reported that he landed on the Sovereign Explorer in clear weather at 1226 hrs. Whilst the aircraft was being re-fuelled for the next sector, a heavy shower passed over the oil rig and moved away, but there were no indications of lightning activity. The captain further reported that the aircraft took off at 1245 hrs and climbed to 3,000 feet on a south-easterly track. There were none of the usual indications of lightning activity, such as fluctuations of ADF needles or radio interference. It was possible to see the surface intermittently although there was a fair amount of low scud around. At 1253 hrs and without warning, there was a bright flash and a loud bang. The aircraft immediately developed a one-per-rev vibration and a loud one-per-rev noise could be heard. The handling pilot reduced power at once and the crew assessed the situation. It was obvious to them that the aircraft had suffered a lightning strike and that the main rotor blades were damaged.

In his report the commander observed "Control of the aircraft was still good, however, and we considered that, provided nothing else separated, the aircraft could remain airborne."

The handling pilot then executed a 180 degree turn back towards the Sovereign Explorer and the non handling pilot made a PAN call to the Sovereign Explorer's radio operator who was maintaining a flight watch service. He advised the passengers of the situation and instructed them to secure their survival suits in preparation for a landing.

An incident free landing was carried out at 1301 hrs. The one-per-rev vibration and corresponding noise had remained present from the incident until the landing.

Relevant aircraft features

The AS 332 is equipped with composite main and tail rotor blades. Lightning protection of the four main rotor blades utilises a brass conductive strip as part of the electrical path within the blade profile. This strip connects electrically the leading edge anti-erosion shield on each blade to a bolt passing through the blade approximately perpendicular to the chord line, near the blade root. The bolt in turn secures a tag end of a braided earthing strap, which conveys electric current from the blade to the rotor head during lightning strikes.

The brass strip is of identical cross-section to that used in a corresponding position on a previous design of tail rotor blade fitted to the UK registered AS 332 fleet. That model of tail rotor blade was in use at the time of the lightning strike accident to AS 332 helicopter G-TIGK.

Extensive testing work was carried out as part of the AAIB investigation into the loss of that aircraft. Some of this work took the form of applying controlled electrical currents between various points on sample blades and the relevant blade root ends. These simulated the effects of lightning strikes at those locations and took the form of currents having a value varying over the application time in accordance with a waveform defined by AC20 53A. (This is the most demanding *civil* specification currently in widespread use for lightning protection certification of structures and blades)

It has been found that the two parameters most significant in inflicting damage to carbon composite structures are, (1) that termed the Action Integral and (2) that termed the Charge Transfer. The first is the area under the curve of Current (in Amps) squared and time (in seconds), whilst the second is the area under the curve of current and time. Action integral is the parameter which, in the case of the AS332 blade design, affects vaporisation of the brass strip, whilst damage inflicted directly to the carbon fibre composite can also result from the magnitude of charge transfer at the arc root.

It was found during the G-TIGK tests that the brass conducting strip vaporised when the blade was subjected to a lightning discharge having an applied action integral in the region of 1 - $1.2x10^6(A^2S)$.

Although the AC20 53A specification is the widely used standard for civil certification, the German military authorities specify an action integral five times as severe.

Of the two blades which suffered the most severe damage in this incident, one was a low hours component, manufactured approximately 10 years before the event, which had never been repaired by the operator, having been returned once to the manufacturer (in 1989) for overhaul. The other blade had completed 16,000 hours operation since it was manufactured in 1983. It was returned to the manufacturer for overhaul in 1991. Thereafter it had been subjected to numerous small repairs by the operator, mostly to eroded or damaged leading edge sheathing. In this way it was entirely typical of blades in service on AS 332 aircraft operated from the UK and Norway.

Initial examination

It was noted by the operator that major damage had been sustained by all four main rotor blades and it was clear that the aircraft would require removal and replacement of other major components before further flight could be contemplated. Accordingly, preparations were made for the aircraft to be moved by ship to the operator's base at Aberdeen.

Flight recorders

Once the aircraft had been recovered to Aberdeen the Combined Voice and Flight Data Recorder (CVFDR) was removed and sent to the AAIB at Farnborough for replay. The aircraft was fitted with Integrated Health and Usage Monitoring (IHUMS) equipment, which recorded times of flight sector events such as landing, taxi engines on and off as well as automatically recording aircraft vibration data at hourly intervals.

Whilst flying inbound to the Sovereign Explorer the crew commented on the rough weather conditions and in particular a line squall running north east/south west that was visible on their weather radar. The commander also remarked that the weather was causing interference on the VHF radio channels. Several instances of such interference were recorded on the audio channels of the CVFDR. The crew elected to descend to FL45 in order to drop below some cumulo-nimbus cloud that they were flying through at that time.

The commander landed the aircraft at 1226 hrs and the passengers were disembarked. The aircraft took on fuel in both tanks and a new set of passengers embarked. The commander briefed the passengers on the PA before the crew conducted the pre-takeoff checks. The first officer, as the handling pilot for the ensuing sector, briefed the commander stating that he would keep reasonably low initially before climbing to FL75.

The aircraft departed the Sovereign Explorer in a south-easterly direction at 1244 hrs, turned left onto a heading of 171oM and climbed slowly to 3,000 feet. No VHF radio interference was recorded on the CVFDR following the lift from the rig until, at 1250 hrs, the recording terminated with a ten second period of radio interference followed by a burst of static of very short duration being recorded on all three CVFDR audio channels.

Data from the recording system indicates that the strike occurred at approximately 10 nm SE of the Sovereign Explorer at a location of N 59° 34' W 7° 36'.

Analysis of the downloaded IHUMS data by the operator showed that the aircraft had landed back on the Sovereign Explorer at 1301 hrs with aircraft shutdown occurring at 1302 hrs. No aircraft vibration data was acquired, nor was it scheduled to be, during the 11 minute return flight to the rig.

Once the aircraft had been recovered by ship to Aberdeen, it was determined that the G-switch, which was fitted in the power supply to the CVFDR in accordance with CAA specification No 11, had operated at the time of the lightning strike. This had prevented the CVFDR from recording aircraft data and audio pertaining to the handling of the damaged aircraft as it returned to the rig.

The CVFDR was undamaged by the electrical discharge and operated satisfactorily when tested after the event.

Helicopter flight recorders to CAA specification No 11 derive their power from the DC essential/emergency busbar to assure the availability of electrical power as long as battery power is present. In the event of an accident where battery power remains connected, thus allowing continued operation of the CVFDR and eventual erasure of aircraft audio from the time of the accident through over-recording, CAA Specification No 11 requires a means of interrupting the power supply to the recorder. It further states that an acceptable means of compliance is a G-switch.

More recent generations of flight recorder, including all such equipment using solid state memory,

are required to be able to terminate recording within 10 minutes of the aircraft being unable to move under its own power. This applies even if the power supply to the recorder is not removed. Typical means of compliance used in the past to determine 'End of Flight' have been interlocks with low oil pressure warning(s) and rotor brake application. Using such a method of preventing over-recording of information would not require the installation to be fitted with a G-switch. The latest minimum operational performance specification governing the design of cockpit voice recorder systems, ED-56A states that 'the use of negative acceleration sensors (G-switches) is not considered to be a reliable practice'.

A number of previous accidents where the operation of the G-switch has curtailed recorder operation before the aircraft has landed or ditched successfully have prevented accident investigators from obtaining a complete picture of events subsequent to the onset of an accident or serious incident. As a result of the investigation and report into the accident to another AS332L Super Puma (G-TIGK) on 19 January 1995 the AAIB recommended to the CAA that the CVFDR G-switch was rendered inoperative (Safety Recommendation 97-32). The CAA did not accept the recommendation on the grounds that some recorders may continue running after an accident resulting in a crash impact, thus erasing the recorded data.

As stated in the G-TIGK report (Aircraft Accident Report 2/97) the AAIB was, and continues to be, unaware of any accidents where recorders would have continued to run after crash impact had no G-switch been fitted, but has encountered several (including this accident) where premature operation of the G-switch has impeded the accident investigation. In the absence of recorded aircraft data and audio, it was fortunate in this instance that crew statements were available to determine the sequence of events following the lightning strike.

The prime reason for the fitting of accident recorders to aircraft is to allow accident investigators the most comprehensive set of information available, following an accident or serious incident, to assess the circumstances and help prevent recurrence. It is considered that the premature operation of the G-switch may preclude a more detailed investigation and hence hinder improvements in aircraft safety that might otherwise be made. For this reason the following Safety Recommendation is made:

> The CAA reassess the response made to part 1 of Safety Recommendation 97-32 with a view to rendering the CVFDR G-switch inoperative. (Safety Recommendation 99-24).

Detailed aircraft examination

Examination of the main rotor blades revealed that all four had suffered extensive damage and two diametrically opposite blade tips were badly damaged, each losing about 40% of their area. The brass earth-path strips of both these blades were found to have completely vaporised. The rotor head exhibited evidence of arcing where the bonding straps had failed and residual current had passed directly from the blades to the head. Considerable heat damage and some de-lamination was evident in the regions between the inboard ends of the anti-erosion shields and the roots of all four blades. Numerous regions of local damage were evident along the blade lengths including areas of blistering and de-lamination, together with peeling back of the root end of the anti-erosion shield on one blade and arcing/erosion damage at joints in the erosion shields.

The blades were initially subjected to a standard series of deflection tests by the operator. These are used to detect gross internal damage to the blade material and are generally carried out when any blades become damaged, as part of a process of defining the extent of damage not immediately visible. The blades were found to fall within the acceptable deflection range. The operator commented, however, that no damaged blades subjected by them to this test had so far fallen outside the range.

The blades were then transported to the AAIB facility at Farnborough and examined by a specialist (from AEA technology, Culham, Oxon) in lightning testing for aircraft type certification. He concluded that the characteristics seen on the two most severely damaged main blades from G-BWZX represented a strike considerably above the level at which vaporisation of similar brass strips had occurred during tests on sample tail-rotor blades as part of the G-TIGK investigation. He considered that the level was probably in the region of the AC 23-53A certification standard ie an action integral figure of $2x10_6(A^2S)$, with a peak current of 200 kA.

Although this is the currently accepted civil certification standard, applicable to new types, the AS 332 was certificated to the earlier TSS 8.6 standard having an action integral of under one third of this figure, but with the same peak current.

It was established from the manufacturers that two of the blades were damaged beyond repair and the remaining two blades were worth a more detailed examination with a view to carrying out a factory repair scheme. Accordingly, these less damaged blades were returned to the factory whilst the two more damaged blades were subjected to a full (destructive) examination by the AAIB and the DERA, Farnborough.

The general conclusion of the examination was that, other than the visible tip damage, most of the damage on both blades was restricted to the surface laminates. Although this was quite severe near the root and slightly reduced the structural strength in that area, blade designs used in this size and class of helicopter generally have a considerable strength margin close to the root. Blade stiffness in flap is normally the governing parameter which in turn is generally defined by the need to limit blade sailing during shutdown in conditions of strong wind. The damage in this area seems to have been limited to the outer two or three plies.

The mass loss and aerodynamic effects of the tip damage appeared fortuitously to have been in almost perfect balance on these two diametrically opposite blades. This served to minimise any damage to the rotor-head and aircraft structure which might otherwise have resulted from stresses caused by vibration arising from imbalance.

Meteorological data.

An assessment of the recorded weather conditions at the time of the strike was carried out. The UK Meteorological Office supplied archived data from their Arrival Time Differential Thunderstorm Location System, (known amongst meteorologists as SFERICS*)* for the area and period from 1230 hrs UTC until 1330 hrs UTC.

The Significant Weather (NW) forecast data issued at 0303 hrs that day with chart valid at 1200 hrs showed the relevant area to be between two occlusions with a freezing level of 5,000 feet. The conditions were, visibility 18 km, weather NIL/SHRA, cloud 6/8 CU/SC 020/060, with OCNL visibility 8KM, weather RA/SHRA cloud 6/8 CUSC 012/080, 7/8 LYR 080/XXX ISOL visibility 5000M, weather +RA/TS/SHRA, cloud 6/8 LYR 010/XXX + EMBDCB 020/XXX This is presumed to have been available to the crew before departure from Aberdeen some hours earlier.

A later forecast issued at 1035 hrs, valid from 1200 hrs to 2200 hrs, with chart valid at 1800 hrs, shows little change to conditions at the area in question except that the freezing level descends to 3,000 feet after the occluded front passes through.

Although the Meteorological Office continuously supplied data on recent lightning activity to the briefing room at Aberdeen, there is a processing delay between detection of discharges and presentation of relevant data in the briefing room. Since the departure from the Sovereign Explorer took place more than 2 hours after the crew would have left the briefing room, the displayed lightning strike information would have been of little use in avoiding lightning conditions at the time the strike on the aircraft occurred.

The only Meteorological observation recorded that day at the Sovereign Explorer and made available after the strike was taken at 0830 hrs. It included the fact that no lightning was sighted and the temperature was 9 Deg C.

Subsequent assessment of archived SFERIC data recorded between 1230 hrs and 1330 hrs UTC in the general area showed strikes at the following times and locations.

1250 hrs UTC 59.48N 007.50W

1251 hrs UTC 58.39N 009.26W

1256 hrs UTC 58.39N 009.17W

1259 hrs UTC 58.42N 009.17W

1259 hrs UTC 58.39N 009.13W

The 1250 hrs strike agrees *closely* in the timing at which the recording system in the aircraft registered a loud event and ceased to function. The SFERIC recorded location is approximately 17 nm from the aircraft position The strikes recorded over the next 10 minutes are all grouped at locations more than 80 nm from the aircraft position.

It is understood that the guaranteed accuracy of the SFERIC system is not closer than 10 km at this location so it would appear that the actual strike has been successfully detected and no other strikes have been detected in the area of the aircraft within a short period before or after it was damaged.

Success in receipt of lightning strike signals is affected by a variety of factors. At the time of this incident the SFERIC system could detect both airborne and cloud to surface strikes but was more likely to detect the latter because on the whole they are stronger. Unfortunately, the SFERIC system records strikes over a large proportion of the earth's surface and, at the time of this incident, had a total capacity which was believed to be insufficient to record all strikes which may occur in a short time frame. The absence of detected discharges near the aircraft in the period before the damaging strike is thus not conclusive evidence that this was the first lightning event in the area. The crew reports, however, make the point that no radio interference or movement of ADF needles was noted in the period up to the strike, rather suggesting that this was an isolated occurrence.

(Although radio interference was noted by the crew and recorded on the audio channel of the CVFDR during the leg from Aberdeen to the Sovereign Explorer, it occurred some considerable time before the lightning strike, whilst the aircraft was not close to the position of the final incident. It is believed that winter thunder storms over the sea are of much shorter duration than summer thunder storms over land)

The data on the nearest strike supplied using the detection and mapping system operated by EA Technology, a specialist lightning detection company, suggests that an isolated positive cloud to surface strike occurred close to this time at a position which was approximately 24 nautical miles NW of the actual position of the aircraft. (The system in question is designed to detect only cloud to surface strikes, but can also establish their polarity).

The SFERIC times quoted are based on reports received every minute whilst the timing system used to produce the EA Technology data is referenced to National standard time on the Rugby radio clock and should be accurate to within 10 milliseconds. The clock system used to establish the time base of the aircraft's on-board recording equipment is set on an opportunity basis and is thus of unknown accuracy. Accurate time correlation between the three systems is therefore not possible.

The positional accuracy of the EA Technology detection system at this location is assumed to be within 1.5 km, based on close correlation of a number of independent station recordings of this particular strike. Although the timing and polarity of this detected strike, together with the absence of other activity detected in the locality within the relevant time frame, suggested initially that this was the same event, the difference in location from that established using the aircraft on-board recording equipment and that of the strike recorded by SFERIC indicate that the strike recorded by the EA Technology system was not the same event. The absence of other strikes recorded by the EA Technology system, at the relevant location, indicate that the strike which damaged the aircraft was not successfully recorded on that equipment.

From all the available data, the aircraft appears to have been damaged by an isolated strike rather than by one which followed from a developing storm having less powerful preceding discharges. Major lightning strike incidents in the North-Sea area, where most large transport helicopter offshore activity has been concentrated, are divided between two types. These are as follows:

1. Those occurring after a period of detected lightning activity in the area and

2. Those for which no preceding activity has been observed and no recorded lightning discharges in the vicinity and during the immediately preceding period have been found in archived data.

It appears that the OAT at the time of the strike would have been of the order of +2 to +4°C. Until recently it has been held that a feature common to most over-water lightning strikes is the proximity of the OAT to 0°C. It has, however, been pointed that a high proportion of all North Sea and Eastern Atlantic operating hours during winter months (the lightning 'season') take place in OAT conditions close to freezing. The most recent significant strike reported on a large transport helicopter occurred close to the coast at a reported temperature of -6°C.

Conclusions

The aircraft suffered a lightning strike of a severity well above the level to which the aircraft was originally certificated and in the region of the more demanding present-day certification requirements. The rotor blades suffered substantial damage although this was insufficient to reduce their strength to an immediately dangerous degree. However, the blade damage reduced the stiffness to an extent that their susceptibility to blade sail on shutdown may have been increased.

Fortuitously, the major damage/mass loss was symmetrically disposed between two blades situated on opposite sides of the rotor head. Had this not been the case, the vibration level would probably have inflicted rapid damage in the rotor head and structure. The crew would have been faced with a difficult decision as to whether they should remain airborne or carry out a controlled ditching. The situation was greatly helped by their close proximity to the heli-deck from which they had just departed.

The damage appears to have been inflicted by an isolated strike which was not preceded by any other observed or detected activity in the immediate area.

The forecast available at the time included isolated thunder storms and embedded cumulo-nimbus clouds, though no lightning was observed nor was CB activity detected close to the aircraft in the period immediately preceding the strike.