## ACCIDENT

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| **Aircraft Type and Registration:** | Eurocopter AS350B2 Squirrel, G-CBHL |
| **No & Type of Engines:** | 1 Turbomeca Arriel 1D1 turboshaft engine |
| **Year of Manufacture:** | 1992 |
| **Date & Time (UTC):** | 15 September 2007 at 1505 hrs |
| **Location:** | Lanark, Scotland |
| **Type of Flight:** | Private |
| **Persons on Board:** | Crew - 1 Passengers - 3 |
| **Injuries:** | Crew - 1 (Fatal) Passengers - 3 (Fatal) |
| **Nature of Damage:** | Helicopter destroyed |
| **Commander's Licence:** | See text |
| **Commander's Age:** | 39 years |
| **Commander's Flying Experience:** | 965 hours (of which 490 were on type)<br>Last 90 days - 50 hours estimated<br>Last 28 days - 15 hours estimated |
| **Information Source:** | AAIB Field Investigation |

### Synopsis

The helicopter crashed in a wooded valley while manoeuvring at high speed and low height. It was intact prior to impact, and the available evidence indicated that the engine was delivering power. The cause of the accident was not positively determined. Although no technical reason was found to explain the accident, a technical fault could not be ruled out entirely. However, it is more likely that the pilot attempted a turning manoeuvre at low height, during which the helicopter deviated from his intended flight path. This may have been due to the pilot encountering handling difficulties, misjudgement, spatial disorientation, distraction or a combination of factors. There were indications that the pilot had started a recovery but, with insufficient height in which to complete it, the helicopter struck trees in the valley and crashed, killing all four occupants. Four Safety Recommendations are made.

### History of the flight

The accident occurred towards the end of a short flight, about 150 metres from the point of intended landing. The helicopter crashed at high speed in a wooded valley that ran adjacent to the pilot's home, where a dedicated helicopter pad and hangar were situated.

Earlier in the day, the pilot had arranged to visit a friend at a farm complex near Larkhall, 8 nm from his home in Lanark. The pilot regularly flew G-CBHL for business and domestic purposes, so it was not unusual when he decided to use it for the short return journey.

He had spent the first part of the day at home with two male friends, one of whom accompanied him in the helicopter. Also on board were two children: the pilot's five year old son and a friend, aged six years.

There were no surviving witnesses to the pilot's pre-flight preparations, although the adult passenger had a camcorder on which he recorded part of the pilot's cockpit checks prior to takeoff, along with portions of the two flights (see '*Recorded information*'). When the helicopter took off, at about 1400 hrs, the pilot occupied the front right (pilot's) seat, the adult passenger was in the front left seat and the two children sat in two of the three rear seats. The outbound flight took about six minutes. The helicopter was on the ground at the destination for just less than an hour. The pilot was reported as being his normal self during this period and said nothing relating to the helicopter.

The helicopter took off again at 1500 hrs for the short return flight. Apart from an automotive gearbox, which had been loaded into the rear compartment, the aircraft and passenger configuration was unchanged. A number of witnesses, including several in the Lanark area, saw the helicopter during the flight. It approached Lanark from the west, before turning and descending into the Mouse Water valley, which ran past the north side of the town and the pilot's home. When last seen, the helicopter was generally described as flying faster than expected, in a banked, nose-low attitude. There were no witnesses to the accident itself, which occurred in the valley, and in which all four occupants suffered fatal injuries. There was an extensive post-crash fire that consumed a large part of the aircraft structure.

**Accident site details**

The aircraft had crashed into steeply sloping, heavily wooded ground on the south bank of the Mouse Water valley, approximately 1.5 nm north of Lanark, Figure 1. The initial impact, which was on a track of about 110°(M), had occurred with the upper branches of two substantial trees: the left side of the rotor disc had impacted the trunk of a fir about 30 ft from its top, with the fuselage and the rest of the rotor disc striking an oak tree, dislodging a large bough together with several smaller branches. The damage to the rotor head resulted in a complete main rotor blade being released, which then flew above the tree tops, landing in a field approximately 150 m beyond the initial impact point. The main gearbox was torn from its mountings on impact with the trees and fell to the ground nearby.

The tail boom had separated into two major sections at the initial impact. The remainder of the aircraft, comprising the cabin section and engine struck the rising ground of the valley side among smaller trees and saplings, before nosing over into an inverted attitude about 45 metres from the initial impact point. A severe fire developed, which destroyed most of the cabin structure, interior furnishings and the instruments. The engine lay close to the furthest edge of the burned area and had remained attached to the cabin structure by its control cables.

The aft section of the tail boom, including the tail rotor assembly and horizontal stabiliser, had remained lodged in the upper branches of a tree immediately down track from the fir tree that was struck in the initial impact. Fragments from the windscreen and the transparencies in the lower part of the nose were also found in this area, most probably resulting from the impact of the fuselage with the oak tree.

A closer examination of the fir tree at the initial impact revealed that the trunk bore evidence of a broad, horizontal, scar with a number of small branches that had surrounded

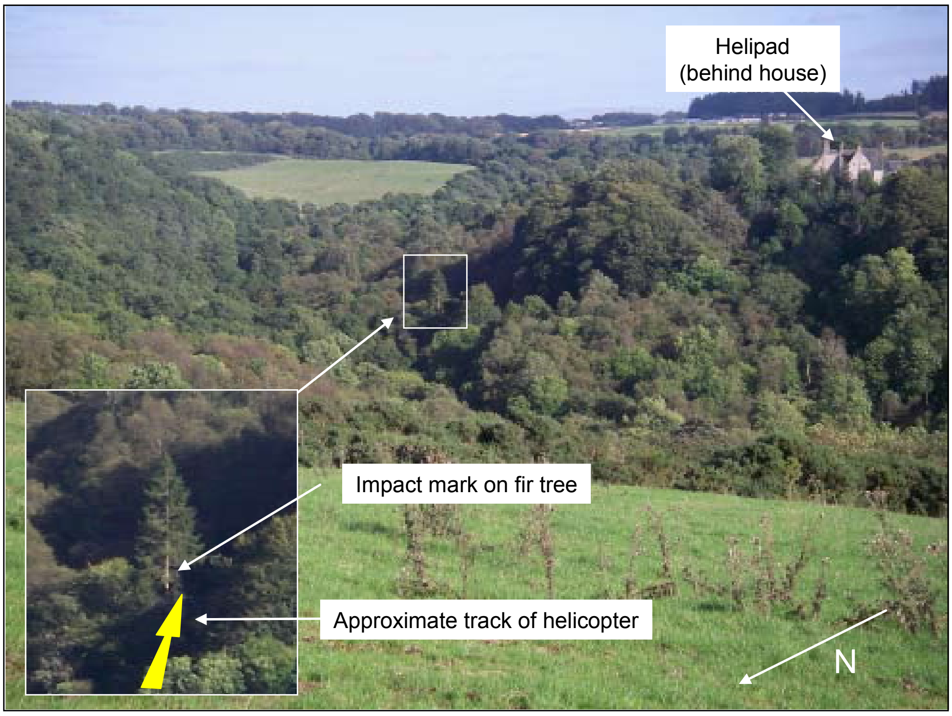


**Figure 1**

Accident location, looking along approximate track at impact

it having been broken off. It was concluded that the scar had been made by a single strike of a main rotor blade, only one of which exhibited any evidence of significant leading edge impact damage. This had resulted in the liberation of the outboard 0.6 m of the blade, which was subsequently located north of the river.

The orientation of the scar on the tree, together with the general disposition of the wreckage, suggested that the helicopter had struck the trees in an upright attitude, with no significant bank angle. The pitch angle was estimated to be nominally level. However, it is possible that the nose was pitched above the horizontal as this would have increased the exposure of the tail boom and horizontal stabiliser to the tree branches and may have resulted in the detachment of the boom. The main impact area was at an elevation of about 550 ft above mean sea level (amsl). This was approximately the same elevation as the initial tree strike, which suggests an almost level trajectory. This, together with the high degree of airframe break-up, indicated a relatively high impact speed. The front portion of the right hand skid was found embedded in the ground before the burned area of wreckage, together with larger pieces of the cabin doors and one of the steps that had been attached to the skid structure. However, there were no significant marks that enabled the aircraft ground impact attitude to be established with any degree of accuracy.

**Witness information**

Twenty witnesses reported seeing G-CBHL during the accident flight. Of these, two had some experience of helicopters in the Army and off-shore oil industry, while several in the Lanark area were familiar with G-CBHL and its normal manoeuvres in the area of the helipad.

The first sighting was about 1 nm from the helicopter's departure point, when it was seen to climb steeply out of a narrow wooded valley, immediately west of Larkhall. Witnesses described it as an unusual manoeuvre, which gave them cause for concern. Witnesses in the Clyde valley described the helicopter flying across the valley from west to east, descending quite low as it did so, before flying a hard right turn and continuing in the direction of Lanark. Other witnesses along the helicopter's route generally described it as flying quite low, but did not describe anything to suggest it was in difficulty.

There were 12 witnesses in and around the town of Lanark, who saw the helicopter for a brief period, only seconds before the accident. No-one saw the accident itself, although several people heard it, and some saw the airborne main rotor blade that was released in the initial impact. The locations of these witnesses are shown at Figure 2, together with an indication of the flight path they described. From their combined accounts, the helicopter approached the area from the west, initially flying across the Mouse Water valley in the general direction of the helipad. It then made a brief right turn before banking steeply to the left and descending into the valley. It adopted a marked nose-low, banked attitude as it descended, and was generally described as flying much faster than normal. The arcs of view shown in Figure 2 are of two witnesses who described seeing the helicopter in the steep left bank when it went out of view.

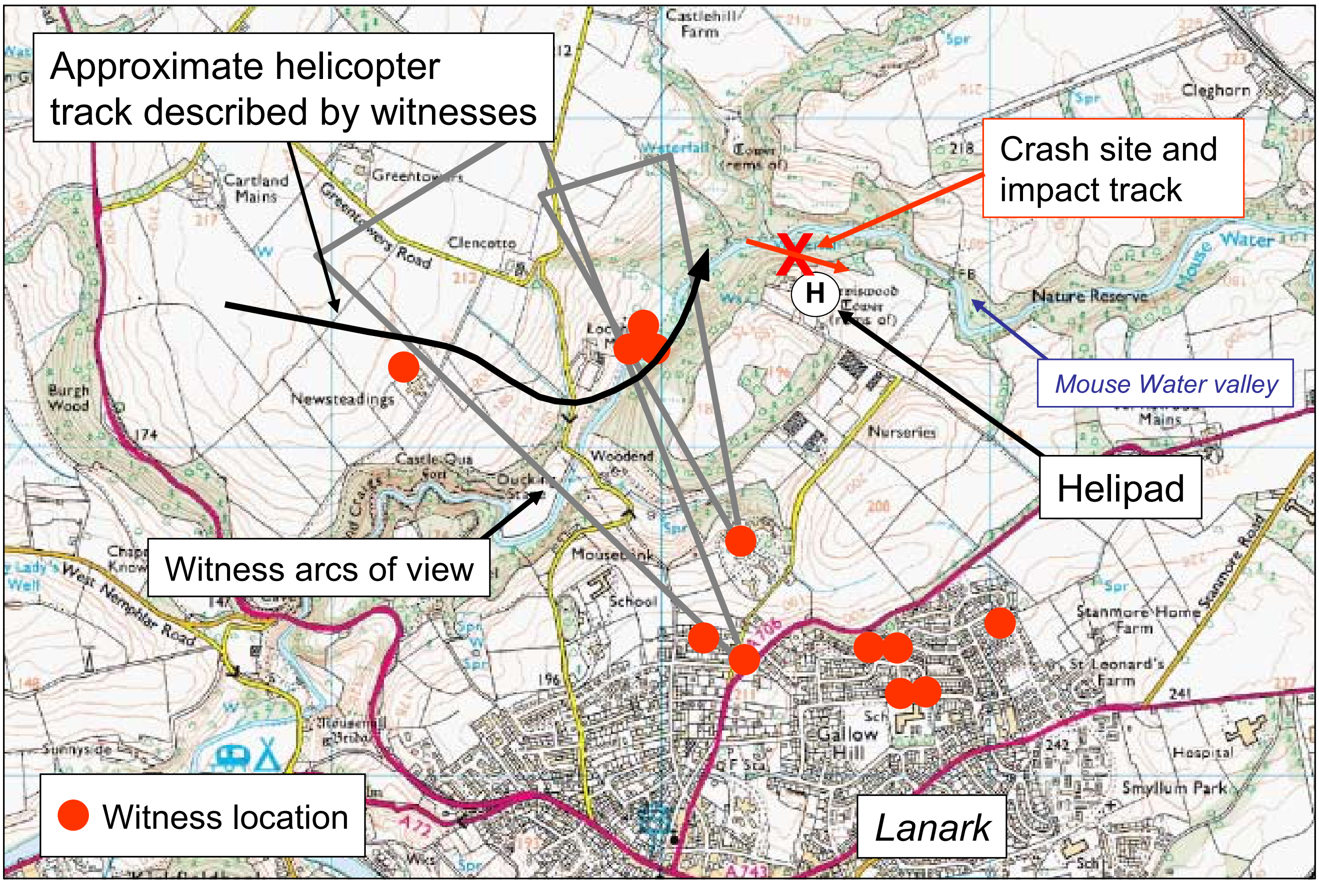


**Figure 2**

Witness information

The helicopter was a common sight locally, so most witnesses could compare what they saw with its normal flight path and manoeuvres. The helicopter's final flight path and speed was generally described as unusual and even alarming, as it normally flew to the east of the helipad before making a slow, controlled descent to land. However, two witnesses described seeing the helicopter perform a similar manoeuvre before, and therefore were not concerned on this occasion. The helicopter was not described as being in obvious difficulty, other than may have been suggested by its descending flight path and unusually high speed. No-one reported smoke or flames from the helicopter and nothing was seen to fall from it, or to strike it.

Of the witnesses who described the sound of the helicopter, the majority reported it as normal or unremarkable. These included two of the closest witnesses: the first was serving in the Army and very familiar with helicopter operations; the second was a local farmer, who was directly under the flight path, and regularly saw and heard the helicopter flying close to his farm. Although there were some reports of the helicopter making an unusual noise, or sounding 'high revving', some who described this attributed it to the helicopter's high speed.

None of the witnesses who saw the helicopter descend into the valley saw it emerge again, although two of them did see the airborne rotor blade, and several saw smoke rising from the site soon afterwards.

**Meteorological information**

According to the Met Office, a warm front would have been about 35 nm west of the area. This would have produced dry, cloudy weather until about the time of the accident, with light or moderate rain after. Visibility would have been between 15 and 30 km outside any showers. An automated weather station 4 nm south of the accident site reported a scattered cloud base at 3,200 ft amsl, which was considered representative of conditions at the accident site.

Satellite imagery showed some evidence of mountain wave activity. Detailed analysis of the data produced an estimated vertical wind velocity of about 200 ft min, which was below the 500 ft/min threshold that would warrant inclusion as a caution note on aviation forecast charts. Winds at the accident site were estimated using an isobaric analysis and the reported wind from the nearby weather station. The wind at 500 ft above the accident site (ie about 1,000 ft amsl) was estimated as between 23 kt and 28 kt from 240º, increasing at 1,000 ft to between 25 kt and 30 kt from 250º. Mean sea level pressure was 1017 HPa and the 500 ft temperature was 13ºC.

Witness and video evidence supported the assessment of generally good flying conditions. The wind was universally reported as the main feature of the weather, described as brisk to strong by ground observers. Pilots of the emergency service helicopters - on scene 25 minutes after the accident - reported a gusty wind in the valley area with some turbulence, though it was not excessive or severe.

**Recorded information**

*Radar data*

The majority of the flight was captured by the Lowther Hill radar (19 nm south of the accident site), but the track was lost shortly before the helicopter reached the accident site. This was probably due to terrain obscuring the line of sight between the radar facility and the helicopter as it descended. The transponder on the helicopter was not set to Mode C (altitude reporting), so the recorded track did not provide altitude data. Although the helicopter's groundspeed was derived from the radar data, such radar-derived ground speeds are not very accurate when calculated between data points a short time apart. This is due to limitations of radar positioning and the possibility that the track may not be a straight line between the data points. Radar-derived ground speeds are more accurate when averaged over longer periods in straight and level flight.

Figure 3 shows an overview of the outbound flight (white track) and the inbound accident flight (yellow track). It also shows the last six recorded radar points, together with a graph of the derived speed data of the whole accident flight. The coverage from Lowther Hill radar was good, and recorded positional data for the whole flight until less than 20 seconds before the accident.

The radar track of the accident flight started at 1500:29 hrs and ended at 1504:32 hrs. The average ground speed at the start of the track was between 90 kt and 100 kt, subsequently increasing to between 120 kt and 130 kt. In the second half of the flight, the average ground speed fluctuated between 100 kt and 120 kt, with the average speed over the last 30 seconds of data having increased to 122 kt.

*Video recording*

The only form of flight recording recovered from the helicopter was the video recording taken during the two flights; the helicopter was not fitted with, and was not required to be fitted with, an accident data or cockpit voice recorder.

The adult passenger's camcorder had recorded a total of 5.3 minutes of video and sound track from the two flights. The video was all taken from his seat within the cabin, and ended about 55 seconds before the accident. Cabin noise levels prevented the microphone from recording normal conversation, although louder comments and exclamations were audible.

A short segment, recorded before takeoff from the helipad, showed what appeared to be a normal pre-flight process. The pilot appeared relaxed as he went about his pre-takeoff checks and the mood in the aircraft was jovial, with the adult passenger providing some commentary. Fuel contents were 50%, sufficient for about 1 hour 40 minutes flying. All engine and system indications were normal, and flight instruments appeared serviceable. Based on later observations, the altimeter pressure setting was not changed before or during flight, so an approximate 100 ft error before takeoff was assumed to exist throughout the recording period. In this report, height calculations based on observed altimeter indications have been adjusted accordingly.

Airborne cockpit indications were normal throughout the recorded period, with the exception of the chronometer, which was not running. Indicated Air Speed (IAS) generally varied between 110 and 115 kt, which would be a typical cruise speed. The main radio was tuned to 119.875 MHz, which was an appropriate Scottish Area Control Centre frequency. However, there was no requirement for the pilot to contact Air Traffic Control during either flight, and no such contact was made. The pilot remained in full control of the helicopter, and the manner in which he flew the aircraft suggested that he had no concerns about its serviceability or continued airworthiness.

The helicopter's autopilot remained in its normal flight mode, although the yaw channel was disengaged throughout. The autopilot was equipped with a self-monitoring function.

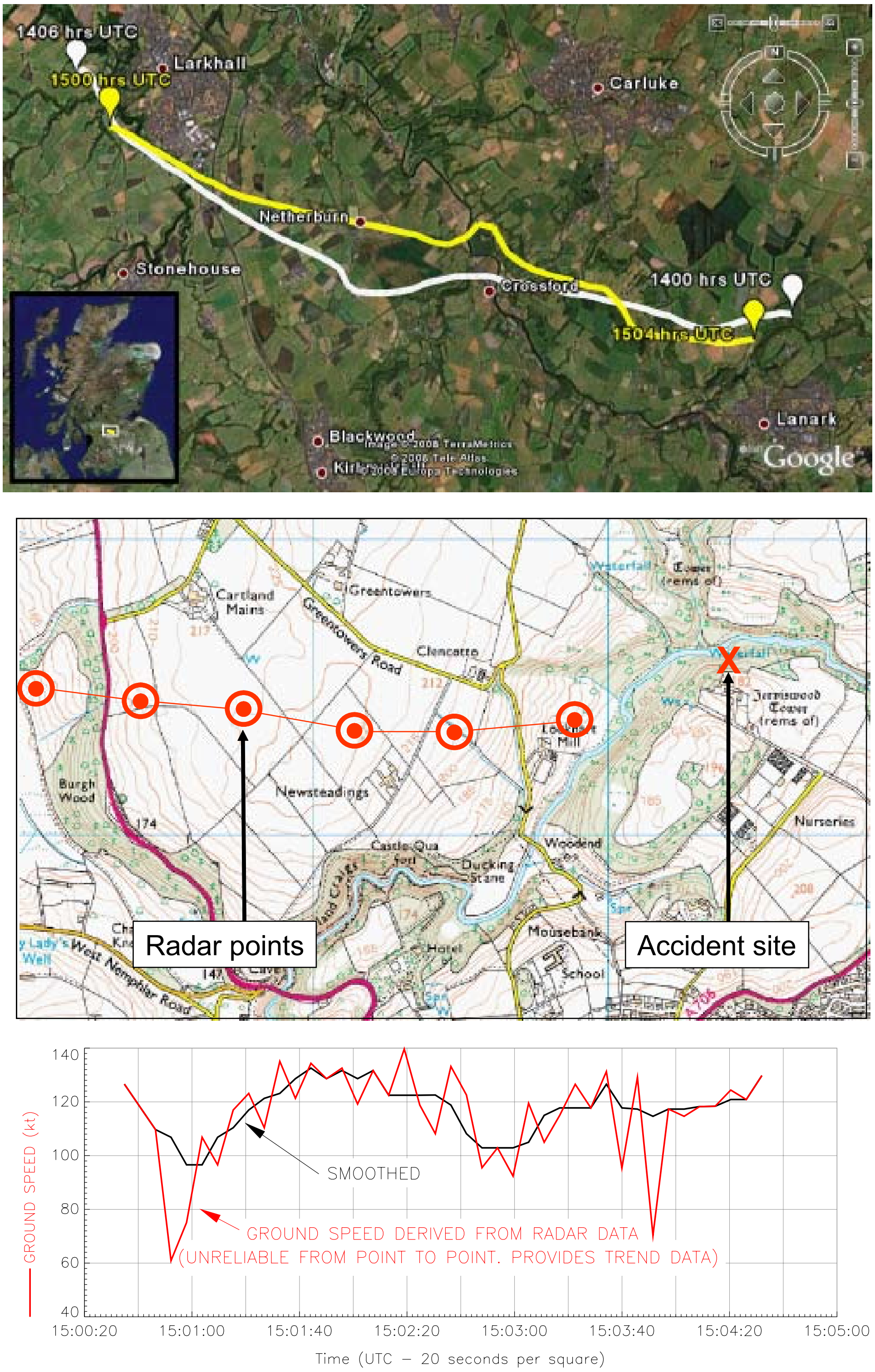


**Figure 3**

Radar derived parameters

*Google Earth ™ mapping service / Image © 2008 TerraMetrics / © 2008 Tele Atlas / © 2008 Europa Technologies*

Dual flight controls were fitted, but the recording showed that the adult passenger, although of large stature, was able to sit without interfering with them. A flight guide booklet on a map shelf was the only observable loose article, assuming that the passenger retained adequate restraint of the camcorder. During much of the recording, and particularly whilst the helicopter was manoeuvring, the passengers were vocal in expressing apparent enjoyment of the experience.

During the periods of flight captured on the video recording, the helicopter did not fly above 500 ft agl, and it was considerably lower for most of the time. Other aspects of the pilot's handling of the aircraft were noteworthy: these included instances of very low flying, valley flying and other manoeuvres, as described below.

On the outbound flight the helicopter flew as low as 155 ft over open farmland, as indicated by the altimeter and, at one point, it flew over farm buildings at a height estimated from the video to be 275 ft. The pilot then rolled the helicopter rapidly into a brief but steeply banked right turn, before reversing the turn to the left, at which point a true indicated height of 335 ft was recorded.[1]

When the helicopter departed from the farm on the accident fight, the pilot flew a 'zoom' climb[2], before descending into a narrow, steep-sided valley, next to the town of Larkhall. The valley is about 250 ft deep, and densely packed with trees along its length. This section of the recording showed the helicopter flying over trees at the valley's edge at speed, with a separation from the trees estimated from the video footage at between 20 ft and 30 ft. It then pitched nose-down and descended into the valley, coming into similar proximity to trees on each side and below. The pilot then flew a further zoom climb out of the valley, which was seen by witnesses on the ground. The passengers appeared to enjoy the manoeuvre, with laughs and shouts audible on the video. Figures 4a and 4b show full screen images from the video, of the helicopter approaching the valley, and in the valley just prior to the zoom climb.

The next recorded segment showed the helicopter in a steep right turn, at low level, over the Clyde valley. The helicopter then stabilised at a moderate height, flying towards its destination, about 2.8 nm away.

The final recorded segment lasted 8 seconds, the first frame of which is shown at Figure 4c. The helicopter was flying at 110 kt in a steep (about 60º angle of bank) turn to the right, at about 440 ft above a shallow valley floor. It appears to have just started a climb, with a pitch attitude at 10º and greater than normal cruise power applied. The helicopter then rolled left, reaching an approximately upright attitude as the recording ended. Again, the video and accompanying audio appeared to show that the passengers were enjoying the experience.

**History of the aircraft**

The helicopter was initially delivered to Japan; subsequently it operated in Canada. It was first registered in the UK in January 2002 and appeared in the subject pilot's log book in November 2003.

The current Technical Log (covering 28 May 2007 onwards), which recorded each flight together with any defects, was not recovered and was presumed lost in the post-impact fire. Consequently the exact number

**Footnote**

1 Rule 5 of the *Rules of the Air Regulations 2007* prohibits any aircraft from being flown closer than 500 ft to any person, vessel, vehicle or structure.

2 A steep climb, in which aircraft speed is exchanged for height.


**Figure 4**
Still images from the recorded video

of flight hours at the time of the accident is not known. The maintenance company provided documentation, including the engine and airframe log books and work-packs, which listed the maintenance activity carried out on the helicopter. The most recent work was an Annual Inspection carried out on 7 June 2007 at 4,158.8 flight hours. The previous Annual Inspection was on 1 June 2006 at 4,084.5 hours and the 12 Year Inspection was signed off on 25 April 2005 at 3,939.5 hours.

The documentation included a European Aviation Safety Agency (EASA) Standard Certificate of Airworthiness, which was valid to 1 May 2008.

**Detailed examination of the wreckage**

*General*

The recovery of the wreckage included a fingertip search of the site, which was conducted by the police. In addition, the top layer of earth in the main wreckage area, which contained significant quantities of ash and burned debris, was also taken away for subsequent sifting. All the wreckage was recovered to the AAIB facility at Farnborough, where the detailed examination was assisted by representatives from the engine and airframe manufacturers, and from the Bureau d'Enquêtes et d'Analyses pour la sécurité de l'Aviation Civile, the French air accident investigation authority.

*Structure*

All the extremities of the aircraft were accounted for and there was no evidence of any pre-impact failure or detachment. All the failures in the structure, the rotor head and the main rotor blade attachments were consistent with violent impacts with the trees and/or the ground.

*Engine*

The engine had been extensively damaged in the accident, with the rotating components having seized as a result of distortion of the engine casing. In the case of the free turbine, the blades had broken at their approximate mid-span points due to tip contact with the shroud. Evidence of rotation of the gas generator part of the engine was provided by rotational score marks on the intake 'bullet' on the first stage of the compressor.

Disassembly of the free turbine module revealed that the drive nut had slipped rotationally relative to the turbine shaft. The direction of slippage indicated that the shaft was being driven, i.e. the engine was delivering power at the time of the impact.

Elsewhere on the engine, the magnetic plugs were clear of metallic particles and the oil filter clogging indicator was in its normal, recessed position.

*Hydraulic system*

This aircraft type is equipped with a hydraulic system, which comprised a pump, filter, pressure regulator and a reservoir. Its function is to provide hydraulic power for the flying control servos. The pump is mounted on a housing attached to the rear of the main rotor gearbox and is driven via a Kevlar belt from the tail rotor drive shaft.

The pump was found separated from its mounting on the drive shaft housing. However, it had remained intact and the pump mechanism still functioned when the input wheel was rotated. The drive belt was also recovered and was found to have snapped cleanly, with no evidence of fraying or other signs of in-service deterioration. It was concluded that the belt had failed in overload when the tail rotor drive shaft parted from the main gearbox during the impact sequence. The hydraulic reservoir had remained attached to its mounting on the main gearbox and although it had been holed during the impact, approximately 50% of the fluid contents remained when examined on the accident site. The pressure regulator was tested at Eurocopter's hydraulic test facility in Marignane, France; this was witnessed by the AAIB. It was found that a full production test could not be conducted due to the pressure inlet fitting having been torn out during the accident but it was possible to test the regulatory function. It was noted that a seal fitted to the unit at manufacture was still intact, indicating that it had never been adjusted. Under test, at a representative flow rate of 6 lt/min, the regulated pressure was found to be between 44 and 45 bar, which compared favourably with the specified figure of 43 ± 1 bar. At the end of the test, an internal filter was removed and was found to be free from contamination. The regulator was fitted with an electrically operated valve, which, when operated by the Hydraulic Test button on the cockpit pedestal, depressurises the system. This valve was also tested and found to operate correctly.

*Flying controls*

The flight controls on this type of helicopter are conventional in that the cyclic and collective levers are connected to the main rotor swashplate by push-pull rods and bellcranks, with the yaw pedals connected to the tail rotor servo by similar means. It is usual in most aircraft for the rods and bellcranks to be connected together using nuts and bolts, and secured with split-pins. However, in the AS350 model series, aluminium alloy rivets, secured by deformable collars, were used in place of steel nuts and bolts on all aircraft built up to the year 2000, when a problem on the assembly line resulted in a change to nuts and bolts being used on all subsequent aircraft. This process was covered by Modification No 07-3103, which was approved by the manufacturer in October 2001.

Any maintenance activity on an in-service aircraft requiring disconnection of the flying controls would necessarily involve drilling out the rivet. Since few, if any, maintenance organisations would possess the specialised riveting tool, the subsequent reconnection would be achieved using a nut, bolt and split pin. There would be no need to record which specific control rod connections had been changed, unless all the rivets had been replaced with nuts and bolts, in which case the aircraft would be deemed to have complied with Modification 07-3103. This had not been accomplished on G-CBHL, although it was clear from the wreckage that some of the flying controls were connected by nuts and bolts.

Although most of the flying controls components located under the floor of the forward cabin area had remained connected, much of the remainder had been severely affected by the post-impact fire. Most of the push-pull rods had been fabricated from aluminium alloy tubes with steel end fittings and as a result, the tubes had largely been consumed in the fire, leaving just the end fittings. It was not possible to identify the specific airframe locations of many of these items. Where rivets had been used in component connections, these generally appeared as solidified molten beads, although the joints had remained intact. The one exception was the lower end of the forward servo operating rod, where it had been attached to a bellcrank mounted on the transmission deck immediately in front of the main rotor gearbox. The bellcrank had been constructed from sheet alloy and was not recovered and identified. The rod, which had remained attached at its upper end to the forward servo on the gearbox, had not been exposed to the fire and the lower eye end was in near pristine condition, as can be seen in Figure 5. Figure 6 shows the bellcrank installation in an intact aircraft; this happened to have a steel nut and bolt assembly connecting it to the servo operating rod, with a rivet attaching it to the control linkage at the opposite end.

Any mechanical linkage that has been subjected to a violent impact would be expected to display evidence of overloading at the component connections. In the case of forks or eye ends, this could take the form of elongation of the bolt/rivet holes, or the components could separate as a result of the bolt or rivet pulling through the material surrounding the holes. Thus an apparently undamaged eye end, such as that seen on the servo operating rod, might suggest that the bolt or rivet was missing at the time of the impact. However, a steel bolt is inherently stronger than an aluminium alloy rivet, with the attendant possibility that a rivet could fail without causing significant damage to the eye end.

As noted earlier, the main rotor gearbox had been torn from its mountings on the initial impact with the trees. Thus, as the airframe continued on its trajectory, the servo operating rods would have been exposed to predominantly tensile loads, which had led to failures in two of the three rods. Both these rods had been attached to bellcranks located beneath the transmission deck and there was evidence to suggest that the failures had occurred partly as a result of a guillotining effect at the point where they emerged from their respective apertures in the transmission deck. The third rod, with the undamaged eye end, had remained attached to the servo input linkage on the gearbox and was in good condition, apart from a slight bend. This was probably caused as a result of the rod becoming trapped beneath the gearbox as it rolled along the ground.

In view of the apparent lack of damage to the servo rod eye end, additional investigation was conducted on this component in order to determine whether a bolt or rivet had been present at the time of the impact.

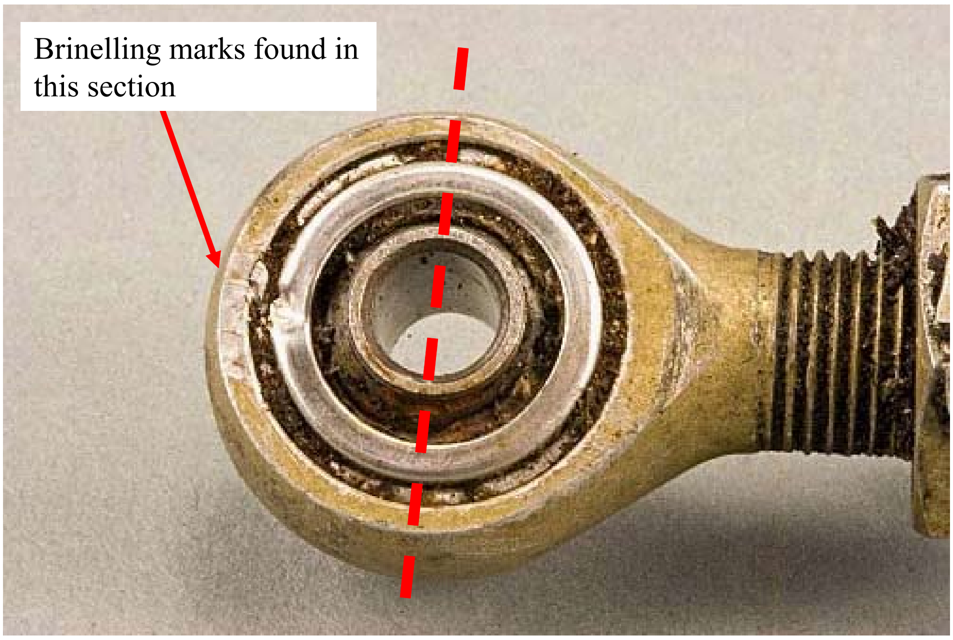


**Figure 5**

Forward servo rod eye end from G-CBHL

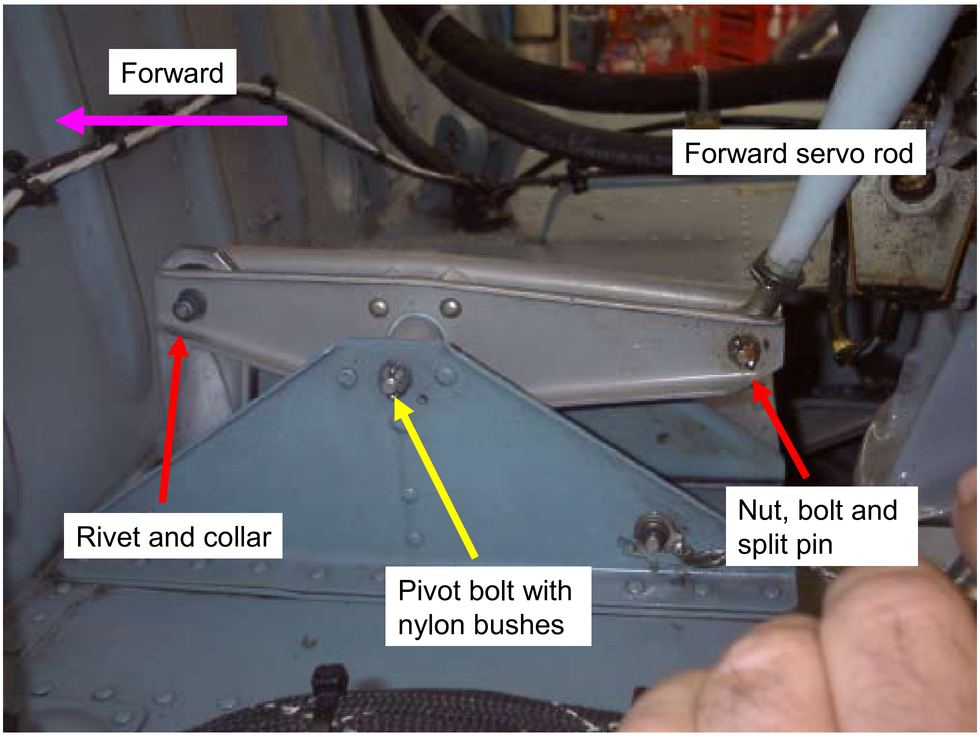


**Figure 6**

The bellcrank on the transmission deck of an intact aircraft, showing bolted and riveted connections

*Investigation of servo operating rod eye end*

It was not apparent, from the maintenance documentation, whether the original aluminium rivet had been changed to a steel nut and bolt at some point in the life of the aircraft. However, it was noted that a nut and bolt was installed at the upper end of the rod where it attached to the servo input linkage. This was not considered surprising, in view of the periodic requirement to remove and replace the servo and/or gearbox.

The documentation indicated that the flying controls in the area of interest were last disturbed in April 2005 during the 12 year inspection. An Additional Worksheet item raised the requirement to: *'replace fore/aft servo input bellcrank bushes on transmission deck'*. The worksheet bore the signature of the technician who carried out the work, together with the stamps of the licensed engineers who conducted the subsequent dual inspection. Also listed was the Part and Batch Numbers of the replacement bushes. There was no record of what components were disturbed in order to access the bellcrank bushes and in fact it was not clear, from a visual inspection of the area on an intact aircraft, whether it was even necessary to disconnect any of the adjacent linkages. Furthermore, the Maintenance Manual did not provide a procedure for performing the task.

The technician who replaced the bushes still worked for the maintenance organisation that conducted the inspection and he stated that he recalled carrying out the task. At the time of the work, the main rotor gearbox had been removed from the airframe, with the upper end of the servo rod having been disconnected from the servo. This greatly facilitated access to the push-fit nylon bushes which was accomplished simply by removing the bellcrank pivot bolt (arrowed in Figure 6) and lifting the bellcrank clear of its mounting. This meant that it was thus not necessary to disconnect additional flying control components. However, the technician could not recall whether there was a bolt or a rivet in the attachment to the servo rod, which was understandable given the elapsed time between carrying out the work and the accident.

The servo input eye end shown in Figure 5 comprised a central bearing that was able to swivel, by means of a double row of ball bearings, within an outer eye. The latter was cut open along the axis indicated which allowed inspection of the bearing outer race. Brinelling[3] marks were evident around that portion of the circumference that would have been loaded as a result of a tensile interaction between the servo input rod and the attaching bellcrank. These marks are shown in Figure 7 and it can be seen that they are elongated in nature, as opposed to circular dimples that might be expected from the individual balls.

In parallel with this examination, the aircraft manufacturer conducted a tensile test using representative rod end and bellcrank components which were attached with a rivet. Whilst the test machine could not replicate the dynamic nature of the accident, it did provide an indication of the failure load and mode of the rivet. The eye end, both in the test and on the helicopter, is located in the fork formed by the two sides of the bellcrank so that the rivet is loaded in double shear. The results of the test are shown in Figure 8, where it can be seen that the rivet failed in two positions along its shank, either side of the eye end. The fracture faces did not exhibit any significant burrs, so that the central portion of the rivet was not retained within the hole in the eye end. The failures,

**Footnote**

[3] Brinelling is a form of mechanical damage typified by permanent deformation of the bearing surfaces where the rollers (or balls) contact the races; it is generally the result of excessive load or impact.

**Figure 7**

Brinelling marks on the forward servo input rod lower eye end

which were actually the result of a combination of bending and shear, were not exactly simultaneous; this had led to the central portion of the eye end twisting on its ball bearings during the failure process, which in turn had caused the balls to mark the outer race surface in a similar manner to that seen on the accident aircraft. The bore of the central, eye, in which the rivet had been located, was undamaged.

**Figure 8**

Results of eye end test conducted by the manufacturer. Note failed rivet and undamaged eye

The actual failure load in the test was 1,680 daN. The manufacturer conducted a stress analysis of the subject area of the flying controls and concluded that approximately similar loads could result in the failure of the bellcrank mounting to the transmission deck. Thus, if a steel bolt had been used in place of the rivet, its superior strength would have resulted in it remaining intact, with failure most probably occurring in the bellcrank mounting.

The test, in conjunction with the examination of the servo input rod end from the accident aircraft, provided conclusive proof that this area of the flying control linkage was intact at the time of the accident. The rivet represented the weakest link in this part of the system and failed as a result of forces generated during the impact, evidence of which was provided in the form of brinelling marks on the eye end outer race.

*Flying control servos*

Each of the four flying control servos was fitted with a pneumatically charged fluid reservoir, which is designed to provide a period of hydraulic power in the event of a failure of, for example, the hydraulic pump or its drive belt. The inflation valve on the right cyclic servo had been torn out during the impact, thus exhausting the pressure. The front and left servos were found to be pressurised to 10 and 12 bar respectively, with the Maintenance Manual figure being 15 bar at 20°C. The tail rotor servo reservoir pressure was found to be 22 bar which, although high, was not considered likely to have affected the operation of the servo, and was most probably a reflection of the relative difficulty of access for charging, due to its location in the tail boom.

The servos were taken to the manufacturer's facility in Coventry, where they were tested under AAIB supervision.

The tail rotor servo had been retained within the tail boom, which had protected it during the accident to the extent that it bore no evidence of external damage. When installed on a test rig it performed satisfactorily.

All three cyclic servos had suffered varying degrees of damage as a result of their exposed position on the main rotor gearbox. The right unit had suffered severe damage to part of the actuator body and the ram was bent; this resulted in the ram failing to move when it was placed on the rig. It was decided to remove the valve body and install it on the body of an intact example, when it functioned normally.

The left servo was found to be slow in operation, especially on the retraction part of the cycle. As with the right hand unit, it was decided to install it on another actuator body but there was little improvement. Upon disassembly of the servo valve input linkage, it was noted that it was contaminated with dirt, most probably from the accident site. After cleaning and reassembly, the servo functioned satisfactorily. During disassembly, the bypass valve, which allows passage of fluid from one side of the actuator piston to the other during manual mode (ie, in the absence of hydraulic pressure), could not physically be extracted from the valve body. It was considered that this was a result of minor distortions caused during the accident. However, operation of the valve was confirmed by manually moving the actuator ram.

The forward cyclic servo was of a slightly different design to the others in that it featured a locking device in the valve input mechanism which, in the absence of hydraulic pressure, eliminated the free play arising from movement of the spool within the valve body. When the unit was placed on the test rig, no actuator movement initially occurred, possibly due to a reluctance of the spring-loaded locking device to move under the application of hydraulic pressure. Tapping the valve body elicited some movement, albeit at a very slow rate. It was decided to strip the valve body; however it was noted that the servo valve was almost seized and was difficult to remove. The components were then examined for evidence of scoring caused, for example, by a trapped piece of swarf, none was found. When the components were cleaned prior to reassembly, a slight discoloration was noted in the fluid wiped from the spool stem. The servo manufacturer pointed out that the spool valve components were machined to extremely close tolerances, with the result that a relatively small amount of distortion, together with almost microscopically small pieces of debris, could impede operation. Whilst all the cyclic actuators were equipped with plastic dust covers over the valve blocks, which were designed to minimise the ingress of contaminant particles in service, these had been largely destroyed in the impact and in any case would have been ineffective in preventing dirt from the accident site entering the valve mechanism. When the servo was retested after cleaning it operated satisfactorily.

At the completion of the examination and testing of the flying control servos it was concluded that there had been no failure of the internal components. Although the operation was often less than satisfactory, it was considered that this was consistent with damage sustained in the impact, together with the likelihood of contamination of the valve components with dirt from the accident site. However, it was not possible, in the case of the forward cyclic actuator, to entirely discount the possibility of a pre-impact seizure of the valve.

*Autopilot system*

The aircraft had been equipped with a three-axis autopilot system, capable of controlling the helicopter in pitch, roll and yaw. The yaw axis was an optional addition to a basic two-axis system. Autopilot control is achieved via a computer that sends electrical outputs to three 'series' actuators, which are interposed in the control linkages in all three axes. These actuators are fast acting, but have a small extension/retraction from their mid-position (± 2 mm for roll, ± 3 mm in pitch and ± 5.5 mm in yaw), thus limiting their authority to approximately 10% of the control range of movement. Integral to the system are two trim actuators which operate on the pitch and roll linkages connected to the cyclic stick. These actuators incorporate springs that provide basic artificial feel to the pilot. They have full control authority (ie they can move the controls over their full range of movement), albeit at a slow rate: 2°/sec in pitch and 4°/sec in roll. In the event of a mechanical jam within the trim actuators, a weak link within each mechanism will fail under the action of the pilot's input forces, ensuring that normal control inputs may be made.

A pitch/roll monitor automatically monitors the pitch and roll channels for faults. It receives its attitude reference from a dedicated source, for comparative purposes. The monitor has the authority to automatically deselect a pitch or roll channel if certain failure conditions are detected.

The pitch and roll autopilot actuators had escaped the worst of the fire, with visible damage appearing to be limited, in the case of the roll actuator, to the output shaft, which had broken off the end of the housing. The actuators were in turn connected to a suitable power supply. It was found that the actuating shafts would extend and retract normally; by noting the amount of shaft movement, it was established that the as-found positions were at the approximate mid-points. The yaw actuator had been severely fire-damaged and was not capable of being tested.

Two feedback potentiometers within each actuator provide inputs to the autopilot computer. A resistance check was conducted on these at the limits of shaft travel. Whilst the roll channel actuator was satisfactory, it was found that by tapping the body of the pitch actuator an open circuit condition could be provoked on both potentiometers.

The two trim actuators were recovered from the wreckage and it was found that their output arms could be rotated by hand, without being opposed by spring pressure. This indicated that the weak links had failed. It is probable that this was the result of rapid and violent control linkage movement that probably occurred during the impact.

Both units were subjected to electrical tests which confirmed the satisfactory operation of the clutches and effort switches. The motor in the pitch actuator operated satisfactorily, although no response could initially be obtained from the roll actuator. An internal inspection revealed a degree of corrosion around the motor, which most probably occurred after the accident. Manually turning the mechanism resulted in the motor subsequently operating.

The electronic components in the system, together with the associated wiring, had all been consumed in the fire and therefore could not be examined.

**Mass and balance**

The helicopter's maximum permitted mass for takeoff and landing was 2,250 kg. A post-accident mass and balance computation was performed which produced a mass at the time of the accident of 1,836 kg. The longitudinal centre of gravity was at 3.25 m from the datum, which represented a mid to forward centre of gravity position, within the allowable envelope of 3.17 to 3.42 m.

**Pathology and survivability**

Autopsy findings were reviewed by a specialist aviation pathologist, who produced a report for the AAIB. Although there was an extensive post-crash fire, all four occupants had suffered severe multiple injuries in the initial impact, which were immediately fatal. The two adults sustained the most severe injuries, which suggested that they had been exposed to peak decelerations in excess of 100 g. The crash forces were outside the range of human tolerance, and alternative or additional safety equipment is unlikely to have altered the fatal outcome. The injuries to the rear seat occupants were of a slightly lesser extent and severity than those of the two adults. Whilst this could have been due to their age and size, it would also be consistent with the fuselage impacting the ground nose first, thus absorbing some of the crash forces.

An autopsy identified no significant natural disease in the pilot that could have caused or contributed to the accident, and toxicology revealed no drugs in the pilot's blood. Alcohol was present in some of the samples subjected to toxicological analysis but there was considerable medical evidence that some degree of post-mortem production of alcohol had taken place in the pilot's body. Consequently, the values of alcohol measured in the samples could not be taken as an accurate reflection of the alcohol concentration at the time of death. There was no evidence that the pilot had consumed alcohol on the day of the accident.

The report concluded that the four occupants had died in a non-survivable helicopter crash. No recommendations arose from the medical investigation.

**Pilot information**

*Flying history*

The pilot gained a Private Pilot's Licence (Helicopters) (PPL(H)) in early 2000, after training on Robinson R22 helicopters. Between March and August that year, he owned and operated an Enstrom 280FX, which he replaced with a turbine powered Eurocopter EC120B. He qualified to fly the EC120B in September 2000 and flew it as his main type between that date and November 2003, when he acquired G-CBHL. He started training for an AS350B2 type rating on 12 November 2003, and passed the qualifying flight test on 17 November 2003. The pilot also undertook additional training in instrument and night flying techniques, and was issued a night rating to his PPL(H) in March 2004.

Under existing regulations,[4] the pilot was required to maintain details of each of his flights in a personal flying logbook, which he did until March 2004. Although he continued to fly regularly, individual entries ceased after this date, being replaced with block entries of flying time (presumably transferred from the helicopter's technical records) and entries out of sequence. There was only one entry for 2005, a Licence Proficiency Check (LPC) on 3 May 2005, which was to renew his AS350B2 type rating; after this, the pilot closed the logbook. No other logbooks, either hard copy or electronic, were found. Archived pages from G-CBHL's technical log provided a record of the pilot's flying hours in the helicopter until 27 May 2007, at which time the pilot had a total of about 900 flying hours, including 440 hours in G-CBHL.

**Footnote**

[4] Air Navigation Order 2000 (as amended).

Technical log records from 28 May 2007 onwards are believed to have been destroyed in the accident. Based on historical flying patterns, it was estimated that the pilot had accrued a total flying time of 965 hours, with 490 hours in G-CBHL.

The same examiner who conducted the pilot's initial AS350B2 check flight for the issue of the type rating also conducted the pilot's next two LPCs, which were for the purpose of renewing the rating. He described the pilot as very competent, achieving a high standard during the check flights.

*Pilot's flying licence*

At the time of the accident, the pilot did not hold a valid flying licence, or a valid AS350B2 type rating. He had been issued with a UK PPL(H), which was valid for five years but which expired on 14 February 2005. No other flying licence was found, or is believed to have existed, and there were no records with the Civil Aviation Authority (CAA) of the pilot having applied to renew his licence. The validity period of the type rating was one year; this had expired on 21 March 2007. In order to revalidate it, the pilot was required to pass an LPC (which the CAA defined as *'a demonstration of continuing knowledge and skill to revalidate or renew ratings')* in the same helicopter type. Again, there was no record of an application to renew it; enquiries with examiners qualified to conduct LPCs on the AS350B2 revealed that none had conducted such a check on the pilot, or been approached to do so.

Further scrutiny revealed the pilot had allowed his AS350B2 type rating to expire on each occasion before renewing it; yet he continued to fly the helicopter during these periods of invalidity, as evidenced by entries in the aircraft's technical log. During the first period, of 106 days between November 2004 and March 2005, the pilot made 42 entries, totalling over 20 hours of flight time. During the second period, of 18 days in March 2006, the pilot recorded nearly six hours of flight time. There were a further 18 entries made between the pilot's type rating expiry on 21 March 2007 and 27 May 2007, which was the last surviving technical log entry.

The pilot's last two LPCs in the AS350B2 were flown on 3 March 2005 and 21 March 2006, both after the expiry of his flying licence. The CAA Authorised Examiner who conducted the LPCs did not check the pilot's licence on either occasion, and did not consider it his responsibility to do so. However, he did recall on one occasion mentioning to the pilot that his type rating had expired. The examiner had known the pilot for a number of years and was under the impression that the pilot's licence had been issued with a lifetime validity.

For the LPC in March 2006, the pilot had flown G-CBHL from his home in Scotland to an airfield in the London area where the LPC was to be flown. The examiner thought that the pilot had made this flight with a properly licensed pilot, although the airfield's records showed that G-CBHL arrived there the previous evening with only the pilot on board.

The pilot held a Joint Aviation Authorities (JAA) Class Two medical certificate (validity period two years), which was valid at the time of the accident. However, there were two separate periods between November 2003 and March 2006, totalling 110 days, during which the pilot did not hold a valid medical certificate, his current one having expired: the pilot continued to fly G-CBHL during these periods.

For a 13 day period in March 2006, the pilot's flying licence, AS350B2 type rating and medical certificate had all expired yet, during this time, he recorded two entries as captain in G-CBHL's technical log.

**Flight control system malfunctions**

The AS350B2 can be flown without hydraulic servo assistance, but the control forces are high. If the single hydraulic system loses pressure, the main rotor servo accumulators will provide about 30 seconds of power, enabling the pilot to land the helicopter (if in a hover), or establish it in the recommended safety speed range of 40 kt to 60 kt, which minimises the control forces in forward flight.

The hydraulic system is controlled from the cockpit by a guarded cut-off switch on the pilot's collective lever and a test pushbutton on the centre console. Selecting the cut-off switch to OFF depressurises both the main system and the main rotor servo accumulators. Operating the test pushbutton also depressurises the main system, but only the tail rotor servo accumulator, leaving the main rotor servo actuators to be powered by their respective accumulators. This allows correct functioning of the accumulators to be tested before flight and is also used to simulate hydraulic failures during flight training.

A hydraulic system failure is indicated by a red warning light and a warning horn. The correct pilot response in forward flight is to fly the aircraft into the recommended speed range and then to select the cut-off switch to OFF. This last action prevents possible asymmetric accumulator exhaustion, which could cause transient control difficulties. The pilot should plan to make a shallow approach over a clear area and land with a low forward speed, typically 15 kt to 20 kt. Hydraulic failures and 'hydraulics out' approaches and landings are mandatory training for the AS350B2 type rating.

The manufacturer also provided a procedure in the Flight Manual for a main servo actuator valve seizure. This involved depressurising the hydraulic system by means of the cut-out switch on the collective lever, thus reverting to manual control. However, the manufacturer stated that, by the end of 2007, the AS350 model series had accumulated more than 14.5 million flight hours which, since there are four flying control servos per helicopter, equates to 58 million servo operating hours. The manufacturer was unaware of any stuck valve incidents having occurred during this time.

**Flight control servo transparency phenomenon**

*General*

The purpose of the main rotor servo actuators is to reduce the force required to control the aircraft by isolating the pilot from aerodynamic forces acting upon the main rotor blades. These forces are constantly changing, and increase as a function of speed, helicopter mass, density altitude, collective pitch input and normal g loading. Under normal flight conditions within the approved flight envelope, hydraulic system pressure enables the servo actuators to overcome the aerodynamic loads, and the helicopter's controls remain light and responsive.

*Servo transparency*

If the helicopter is manoeuvred in such a way that the airspeed and/or rotor disc loading (commonly known as g-loading) become excessive, aerodynamic forces on the rotor blades can exceed the maximum force that can be produced by the servo actuators (which is limited to a value that exceeds the requirements of the approved flight envelope, whilst protecting the airframe against overstress). If this occurs, the aerodynamic forces will be progressively fed back to the flying controls, which become heavy to operate. If unrestrained, this will cause uncommanded movement of the pilot's controls: the cyclic control moves rearwards and to the right, whilst the collective pitch control moves down (reduced blade pitch). The helicopter will thus roll to the right and may pitch up. Although the controls remain fully operable, increased pilot force will be required to overcome these effects. This phenomenon is commonly known as 'jack stall', but is termed 'servo transparency' or 'control reversibility' by Eurocopter.

*Manufacturer's published advice*

In a Service Letter,[5] Eurocopter advised owners of all AS350 series helicopters about the servo transparency phenomenon, stating that it:

> *'can be encountered during excessive manoeuvring of any single hydraulic system equipped helicopter, if operated beyond its approved flight envelope.'*

Concerning the uncommanded control movements, the Service Letter stated:

> *'The cyclic and collective control inputs required to counter these motions may give a pilot who is not aware of this phenomenon an impression that the controls are jammed. If the severity of the manoeuvre is not reduced, the aircraft will roll right and may pitch up. The amplitude of the induced control feedback loads is proportional to the severity of the manoeuvre, but the phenomenon normally lasts less than 2 seconds since the resultant aircraft reaction helps to reduce the factors that contribute to the severity of the manoeuvre and of the Servo Transparency.'*

**Footnote**

[5] Service Letter SL 1648-29-03, 4 December 2003.

The Service Letter also detailed the pilot's recovery actions for a servo transparency encounter:

> *'The pilot's reaction to the first indication of control forces feedback should be to IMMEDIATELY reduce the severity of the manoeuvre.'*

Subsequent actions were detailed, which included allowing the collective pitch to decrease to reduce the overall load on the rotor system, and smoothly counteracting the right cyclic tendency. The Service Letter concluded with:

> *'Pilots should understand that Servo Transparency is a natural phenomenon for a perfectly flyable helicopter. Basic airmanship should prevent encountering this phenomenon by avoiding combinations of high speed, high gross weight, high density altitude and aggressive manoeuvres which exceed the aircraft's approved flight envelope. It is a basic rule (that) tells you that it is particularly inappropriate to perform manoeuvres which reach and exceed several aircraft limitations simultaneously.'*

In response to the Service Letter, some National Aviation Authorities, including the Federal Aviation Administration (FAA) in the USA, issued airworthiness bulletins which reproduced the content of the Service Letter.

*AS350B2 Flight Manual*

As originally issued, the *'Limitations'* section of the aircraft's Flight Manual contained the following, under *'Manoeuvring limitations'*:

> *'Do not exceed the load factor corresponding to the servocontrol reversibility limit,'*

In the '*Normal Operating Procedures*' section of the manual was stated:

> *'Maximum load factor in turns is felt in the form of servo-control "transparency"; this phenomenon is smooth, and presents no danger. In maximum power configuration, it is advisable to decrease collective pitch slightly before initiating a turn, as in this manoeuvre power requirement is increased.'*

In 2003, as well as producing Service Letter SL 1648-29-03, Eurocopter initiated Rush Revision 3A to the AS350B2 Flight Manual. This provided more information to owners and operators about servo transparency, including the following:

> *'The maximum load factor is determined by the servo-control transparency limit. Maximum load factor is a combination of TAS, density altitude, gross weight. Avoid such combination at high values associated with high collective pitch. The transparency may be reached during manoeuvres such as steep turns, hard pull-up or when manoeuvring near $V_{ne}$[6]. Self correcting, the phenomenon will induce an uncommanded right cyclic force and an associated down collective reaction. The transparency feedback forces are fully controllable, however immediate action is required to relieve the feedback forces: decrease manoeuvre's severity, follow aircraft natural reaction, let the collective pitch naturally*

**Footnote**

[6] The 'never exceed' speed, which was 155 kt, less 3 kt per 1,000 ft altitude.

*go down (avoid low pitch) and counteract smoothly the right cyclic motion. Transparency will disappear as soon as excessive loads are relieved.'*

Eurocopter's agent in the UK sent Rush Revision 3A to its customers on 29 October 2004. In the case of G-CBHL, this was sent to the contracted maintenance company, which acknowledged receipt of the revision.

The Flight Manual revision standard at the time of the accident was Revision 2 (2002) and Rush Revision 3B (2004). The Flight Manual for G-CBHL was recovered from the accident site, although it was damaged and some pages had become detached. The leading pages indicated that the manual was revised only to Revision 1 (1990) and incorporated up to Rush Revision 2P (2000). There was no indication that any later revisions had ever been incorporated. The revisions, and other pertinent information, were also available directly from Eurocopter via their internet site. Owners and operators could register on the site without charge, and be notified of material affecting their aircraft; however, there was no record of the pilot having registered. It could not be established with any certainty whether the pilot, who as aircraft owner was responsible for ensuring the Flight Manual was revised to the latest standard, had seen the most recent advice from Eurocopter concerning servo transparency.

*Servo transparency onset conditions*

As part of the investigation, Eurocopter were asked to predict at what point G-CBHL would have encountered servo transparency, given the helicopter's known mass and the atmospheric conditions. The predictions, in terms of airspeed and load factor, are shown in graphical form at Figure 9. They assume that maximum continuous power is applied; flight tests have shown that servo transparency does not occur under any circumstances with the collective pitch lever less than 50% raised. At 130 kt, the onset of servo transparency was predicted to occur at a load factor of 2.1 g.

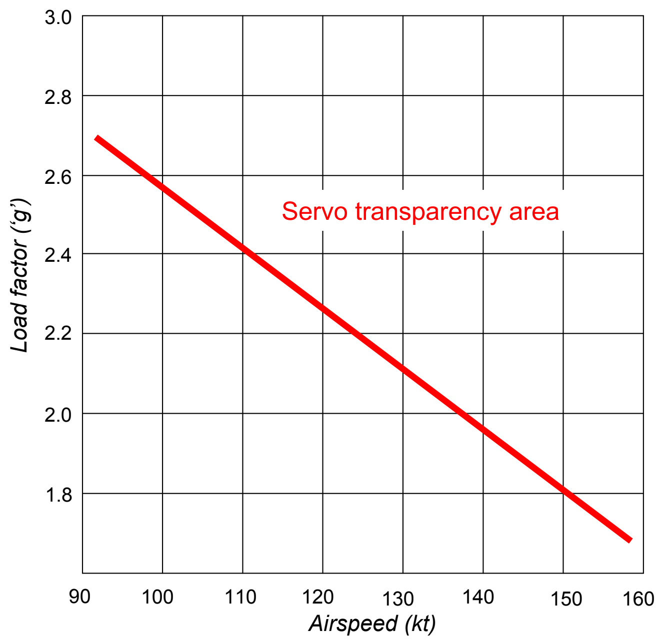


**Figure 9**

Predicted conditions for the onset of servo transparency

*Previous occurrences*

On 11 October 1994, an AS350B was involved in a fatal accident in New Zealand. The pilot, who survived the accident, reported[7] that he was in a descending right turn about a point of interest when the flight controls 'locked up'. The helicopter struck the sea at high-speed in a nose-low attitude with about 90° of right bank. An examination of the flight control system found no evidence of any pre-impact failure. It was calculated that the helicopter had descended at about 1,000 ft/min during its turn.

**Footnote**

[7] Transport Accident Investigation Commission, report number 94-022, 19 April 1995.

There was a 25 kt to 30 kt wind at the time, which gave rise to significant turbulence and downdraughts. The accident report considered that the wind probably caused the pilot to 'tighten' the turn to maintain a desired turn radius. The pilot stated that his attention was fixed on the ground feature (it was a sight-seeing trip for the passengers), and not the horizon. The control lock up had been a surprise to the pilot, who may have interpreted a sudden increase in control effort as a control system failure. The report found that the pilot probably encountered servo transparency, or its incipient stages, with insufficient height to recognise the problem and effect a recovery.

On 19 October 2001, an AS350B2 crashed in the USA during an informal demonstration of the helicopter's approach and landing capabilities in the air ambulance role[8]. The pilot initiated a low level right turn towards his landing site at between 115 kt and 120 kt, reaching what he thought was about a 2 g loading. He then realised that the turn had become too steep, but as he tried to reduce the bank angle he found that the cyclic control would not move to the left. The helicopter crashed, killing two of its three passengers. The accident occurred at a density altitude of 6,107 ft. The subsequent investigation found no technical reason for the accident. Although servo transparency was considered, the probable cause was reported as a seizure of the cyclic control for an undetermined reason.

*Pilot training*

Each Type Rating Training Organisation (TRTO) is required to submit training syllabi to its National Aviation Authority for approval. The servo transparency phenomenon was not mandated by Eurocopter as a flight training item, since it would have entailed operation at, or possibly beyond, published limits. Therefore, servo transparency was not the subject of specific study or training for the aircraft type rating. However, as an aircraft limitation, a student undergoing type rating training would be required to know of it, and to demonstrate such knowledge during training. Servo transparency is covered as a ground training item at the manufacturer's training subsidiary, Eurocopter Training Services.

Enquiries with staff pilots at the UK Defence Helicopter Flying School (DHFS), which operates the AS350BB[9], revealed that jack stall (as servo transparency is commonly referred to in the UK), was the subject of a flight demonstration on the SA341 Gazelle helicopter when that type was in military service. The Gazelle was susceptible to jack stall under certain conditions of military flying, to the extent that it was considered desirable to include the demonstration in the pilot training course. Such demonstrations were limited to the minimum number necessary and airframe fatigue was carefully monitored. Although the AS350BB is used in a similar role to that of the Gazelle, the type's susceptibility to jack stall is not considered such as to warrant an airborne demonstration.

**Flight trials**

Profiles were flown in AS350B2 helicopters to determine the most probable maximum IAS and rate of descent achieved by G-CBHL during its descent into the Mouse Water valley. Parameters for the profiles were set according to radar and witness information, known helicopter mass, limitations of the known terrain, and the position of the accident site. The profiles were flown by three pilots, and consistently achieved an IAS of 130 to 135 kt, with rates of descent in the range 1,500 ft/min to 2,000 ft/min.

**Footnote**

[8] National Transportation Safety Board, report FTW02FA017, 2003.

[9] The AS350BB is a military variant of the AS350B2.

A helicopter flight was made over the route taken by G-CBHL, to provide an airborne perspective of the terrain and to help explore theoretical scenarios. The helicopter was flown by the CAA's Staff Flight Examiner (Helicopters) with an AAIB operations inspector on board, both type rated on the AS350B2. Weather conditions were good, with a south-westerly wind at 10 kt to 15 kt in the accident area.

In order to match witness descriptions of a steeply banked, descending manoeuvre, it was found that a relatively late left turn into the Mouse Water valley was required. Flying this profile would have necessitated a subsequent right turn in the valley through about 90° in order to fly along the river valley past the accident site. A noticeably high rate of descent was required to descend into the valley, even at the slower speed used during the trial and with less tail wind than affected G-CBHL.

For an aircraft at low height in the valley and turning steeply to the right, an accurate assessment of the true horizon would have been difficult, as attention would primarily be focussed on the valley itself. There were several isolated trees in the immediate vicinity of the impact site, of which the fir tree that G-CBHL struck was not the most obvious. It was considered possible that shadow on the south side of the valley at the time of the accident could have further hindered an accurate assessment of flight path and hence separation from the trees.

**Helicopter low flying**

Aviation is a complex and often unforgiving activity that demands not only skill and knowledge, but also discipline and sound judgement. Low level flying is inherently high risk, increasing the aircraft's exposure to hazards and reducing the pilot's options in the event of an aircraft malfunction. An engine failure at low height in a wooded valley would leave the pilot of a single-engined helicopter like G-CBHL with little or no chance of landing safely. The risks associated with low level operations are well known by agencies like the military, who are required to operate there. To address and minimise the risks, military pilots are subject to rigorous selection, and extensive training in low level flying techniques, and are required to maintain flying currency in the environment.

There are also sensitive environmental issues concerning helicopter operations, particularly as helicopters often operate closer to the general public than many other aircraft types. Military and commercial operators place great emphasis on lessening the environmental impact of low level helicopter operations. The CAA produced a leaflet in their '*Safety Sense*' series which covered many aspects of helicopter airmanship, including environmental considerations. Readers of the leaflet are urged to read the 'Codes of conduct', produced by the British Helicopter Advisory Board (BHAB) and available on its website.

The BHAB's main objective is to promote the use of helicopters throughout the country and to bring to the attention of potential users the advantages of using or owning a helicopter. It is also concerned that helicopter operations are conducted safely and responsibly, and that proper attention is paid to environmental issues. The first point on the BHAB's Codes of conduct is:

> *'ALWAYS FLY AS HIGH AS POSSIBLE consistent with the weather and other factors. This will reduce your projected noise at ground level, and also give you more scope to find a suitable landing site in the event of an emergency.'*

**Licensing regulations and procedures**

The CAA issued the pilot's PPL(H) under the licensing provisions of the United Kingdom Air Navigation Order (ANO) 1995 (as amended), which stated that there was no maximum period of validity for such a licence. However, the licensing provisions of the Joint Aviation Requirements[10] were implemented in the UK on 1 January 2000. Changes made to the ANO, and which were notified by Aeronautical Information Circular (AIC)[11], allowed for the transition between the previous national licensing requirements and the new requirements applicable under JAR-FCL. This also allowed for both UK national licences and JAR licences to co-exist, although it was CAA policy to align the licensing requirements and validity dates of national licences with those of JAR-FCL. Thus, when the pilot's UK national PPL(H) was issued on 15 February 2000 it bore a five year validity period (printed on the title page), although a similar licence issued a short while beforehand would have been issued with a validity for the lifetime of the holder. The initial issuing of the UK national PPL(H) ceased on 1 January 2001.

As part of the LPC administration process, the examiner was required to forward completed documentation to the CAA's Personnel Licensing Department (PLD), which maintained appropriate records.

A rating or other qualification issued by the CAA for inclusion in a flying licence was deemed to form part of that licence. The Air Navigation Order 2005[12] (being in force at the time of the accident) stated the following:

> *'… a person shall not act as a member of the flight crew of an aircraft registered in the United Kingdom unless he is the holder of an appropriate licence granted or rendered valid under this order.'*

In relation to the aircraft type rating, Article 29 of the ANO stated:

> *'The holder of a pilot's licence to which this article applies shall not be entitled to exercise the privileges of an aircraft rating contained in the licence on a flight unless – the licence bears a valid certificate of revalidation in respect of the rating.'*

The ANO thus placed the responsibility on the licence holder for ensuring ongoing validity of their flying licence, aircraft type rating and medical certificate, if the intention was to exercise any of the privileges conferred by them.

A number of licences issued during the transition period subsequently expired because their holders were unaware of the revised validity periods, although appropriate notification of the changes had taken place and the licences were issued bearing the correct expiry date. To assist licence holders, the CAA began notifying them when their licences were approaching expiry date. This process began in late 2006 but, as it was not applied retrospectively, the pilot of G-CBHL would not have received such notification.

*CAA Authorised Examiners*

The CAA authorises suitably experienced and qualified pilots as examiners, whose authority to conduct tests and checks is derived from the ANO and JAR-FCL. Guidance notes for helicopter examiners are contained

**Footnote**

10 Joint Aviation Requirements – Flight Crew Licensing 2 (JAR-FCL 2), applicable to helicopter licences.

11 AIC 92/1999 (White 363).

12 ANO Part 4 '*Aircraft Crew and Licensing*', Article 26.

in Standards Document 28.[13] The immediate reference for helicopter examiners was the Flight Examiners' Handbook (Helicopters) (FEH(H)), which drew upon material contained in both JAR-FCL and a JAA Flight Examiners' Manual. Neither of these contained a specific requirement for an examiner to check the licence of a pilot presenting himself for an LPC.

The FEH(H) stated only that an examiner should *'inspect documents as appropriate',* before listing a number of examples, of which *'licence'* was one. However, an earlier CAA *Notice to Flight Examiners* (NOTEX 1/2001) listed an internal CAA requirement that examiners check licences. It stated:

> *'Examiners are reminded that, as an essential part of each skill test or proficiency check, they are required to check the applicant's licence and medical certificate for currency. Where an applicant's licence or ratings are expired, or approaching expiry the examiner must advise the licence holder of the situation and must remind him that he cannot exercise the privileges of any expired rating.'*

It was intended that the requirement of NOTEX 1/2001 be incorporated into subsequent versions of Standards Document 28 and the FEH(H). However, the versions current at the time of the accident (and still current at the time of writing) did not contain it, and NOTEX 1/2001 had since been withdrawn. The CAA's Staff Flight Examiner (Helicopters) stated that a check of an applicant's licence was included as a requirement in the current training and testing of examiners.

**Footnote**

13 Standards Document 28 Version 01, 8 March 2004, available from the CAA's website at www.caa.co.uk.

**Analysis**

*Engineering investigation*

The examination of the accident site indicated that the helicopter had struck the trees on the south side of the river valley at a high speed and in a nominally upright attitude. Although the post-impact fire destroyed much of the helicopter, it was possible to confirm that there had been no pre-impact structural failure, with the available evidence indicating that the engine was delivering power. Although some aircraft documentation was lost in the fire, it was established that maintenance had been conducted in accordance with the Maintenance Schedule.

The nature of the impact was such that it could conceivably have been the result of a flying control system malfunction; considerable effort was therefore expended in the examination of the system components. This task was compounded by the unusual use of aluminium alloy rivets in joining together many of the control rods and bellcranks. This led, in one instance, to the possibility that there may have been a pre-impact disconnect of a rod and its attaching bellcrank. However, detailed examination of the components, in conjunction with tests conducted by the helicopter manufacturer, confirmed that they had been correctly attached at impact. No other evidence was found that indicated the possibility of a pre-impact control disconnect.

The flying control servos, with the exception of the one that controlled the tail rotor, had sustained varying degrees of damage in the impact and the deficiencies, on test, of these units could all be explained by this damage. The seized valve on the forward cyclic servo, in the absence of any internal debris such as a piece of swarf, was probably the result of contaminant particles from the accident site, although there was no hard evidence in support of this supposition. A seized servo valve, in flight, especially at low level, would be a serious event and would likely come to the attention of the helicopter and servo manufacturers and/or the airworthiness authorities. However, no such occurrence has been reported in some 58 million servo operating hours. Thus the probability of a flying control servo valve seizure occurring at a critical point when the helicopter was flying low in the river valley, and which resulted in the accident a matter of seconds later, must be considered extremely remote. Moreover, it might reasonably be expected that any such seizure would be preceded by a stiffness resulting in a resistance or 'notchy' feeling in the cyclic controls.

The aircraft was fitted with a relatively sophisticated autopilot system, of which it was possible to conduct meaningful examinations only on the trim and series actuators. The results indicated that these components were probably functioning normally, with the anomalies such as the (initially) non-operating roll trim actuator motor most likely being a consequence of the accident. Since the associated avionic components and the wiring looms were not available for examination, it was not possible to confirm that the entire system was functional.

The video evidence showed that the autopilot yaw channel remained disengaged, although it could not be established whether this was due to a fault or simply that the pilot had chosen not to engage it. There were correct cockpit indications for the pitch and roll channels and the monitoring function was selected on. As the yaw channel was an optional addition to the basic two-axis autopilot, and there was no evidence to indicate a directional control problem, the engagement status of the yaw channel was not thought to have played a part in the accident.

Whilst the incomplete examination of the autopilot system raises the theoretical possibility of a fault developing during the final minute of flight, the limited authority in terms of its effect on the range of movement and force on the flying controls would be minimal. So even in the event of a major fault, the pilot could have retained control simply by moving the cyclic stick as required, if necessary opposing the feel springs and breaking the weak links in the trim actuators.

No existing unrectified defects affected the helicopter, and the video showed no cockpit malfunctions or control difficulties in flight. The majority of witnesses described no unusual noises, smoke, flames, obvious control problems or other visible signs of distress. If a system failure or other emergency had occurred before, or during, descent into the valley, the pilot's reaction would have been to attempt to establish a safe (ie level or climbing) flight path and speed, or to set up a controlled steady descent to a clear area if level flight was not achievable. It is unlikely that he would have deliberately flown the aircraft into the valley if he was experiencing problems with the flight controls, or indeed any system that could affect the safety of the aircraft. It must follow, therefore, that there was only a very narrow window of opportunity, in terms of time, in which a technical problem could have occurred leading to a loss of control: the engineering examination found no such evidence.

*Flight path analysis*

For the purposes of this analysis, the aircraft's known or estimated flight path has been divided into three sections: the initial descent into the valley, the final seconds of the flight immediately prior to impact, and the manoeuvre that must have joined the two.

*Initial turn and descent*

The helicopter was apparently in normal flight as it approached the Mouse Water valley from the west. Its probable initial track is shown at Figure 10, based on radar data and witness information, the latter indicating that the flight path was not a direct line between radar points. Although this was an uncommon route for the helicopter to take, two witnesses had seen something similar on previous occasions. The track shown is consistent with an initial right turn, followed by a brisk left roll to a high bank angle, as described by witnesses. The helicopter maintained the left bank as it descended, until it went out of view. At this point it would have been approximately along the line marked '*witness limit of view*'. Although the helicopter was banked left as it descended, it would not have actually turned a great deal or it would have flown out of the valley to the north.

Although deliberate flight into the valley would have entailed an increased risk, it would be consistent with earlier manoeuvres seen on the video recording. If he so chose, the valley would have presented an opportunity for the pilot to link together the manoeuvres previously flown, and which were apparently enjoyed by his passengers. If this were the case, the pilot's likely intention would have been to descend into the valley before flying a steep right turn to follow its route, possibly with a further zoom climb before approaching the helipad to land. A planned zoom climb would account for the helicopter's relatively high speed, which would be required for such a manoeuvre.

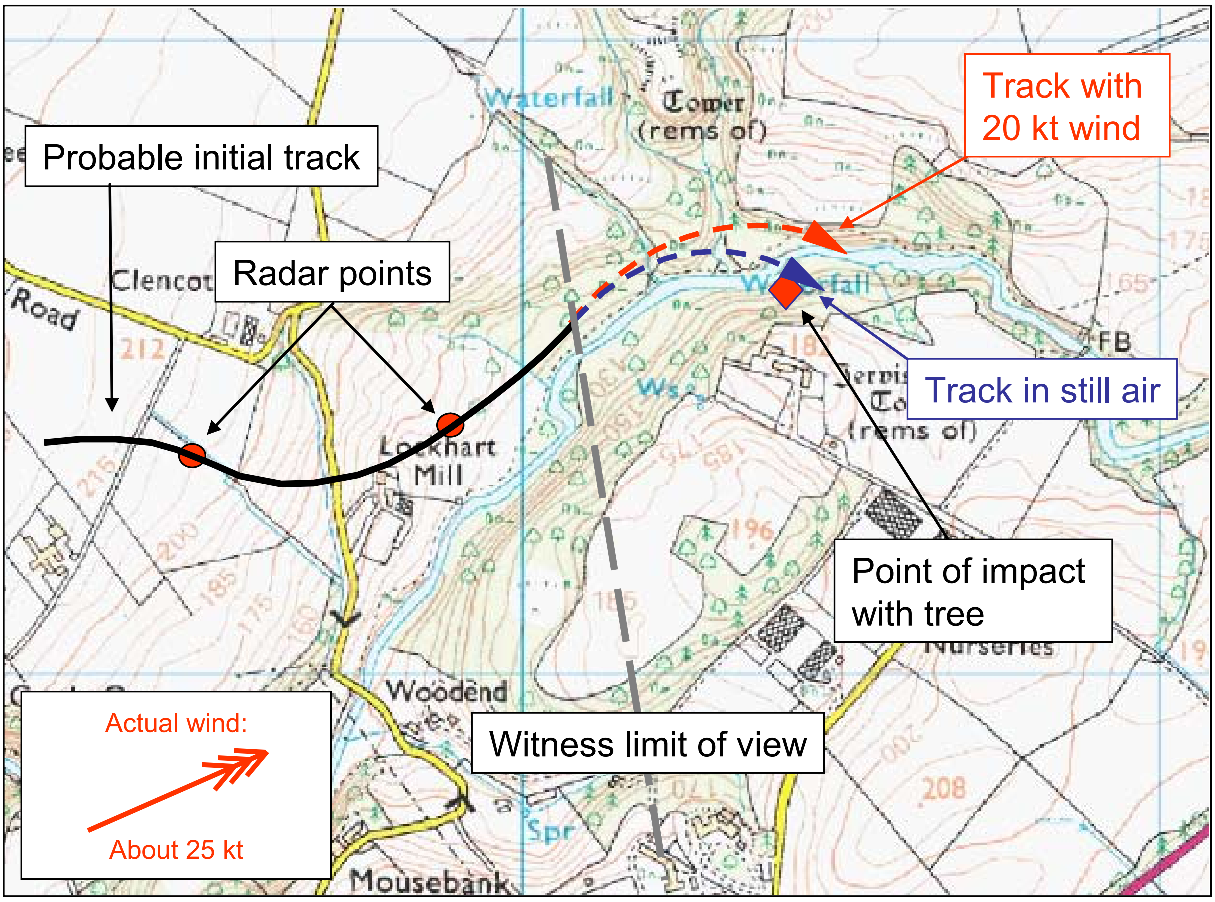


**Figure 10**

Probable initial flight path, shown with turns at 130 kt IAS and 60º bank angle

*Final seconds of the flight*

The helicopter's main rotor disc struck the fir tree about 30 ft below its top; a considerable distance, which was not suggestive of a simple misjudgement of height by the pilot, such as may have caused the helicopter to 'clip' the tree. The impact track would have taken the aircraft across the line of the valley towards rising wooded ground, which is unlikely to have been the pilot's desired or intended track. The helicopter's attitude and trajectory when it struck the trees suggests a dynamic situation rather than a steady flight path; that the pilot may have been attempting to arrest a rate of descent and was therefore trying to avoid the rising terrain.

*The manoeuvre in the valley*

Witness arcs of view indicate that the helicopter remained in a steep left bank until quite close to the point where the valley changed course eastwards, placing the start of the turn after the line shown at Figure 10. As the valley sides were tree covered and poorly defined, the pilot probably intended to fly along the line of the river, it being the lowest part of the valley. Before the pilot started a right turn, the obvious escape option, in case of a problem would have been to climb straight ahead out of the valley, which did not happen.

The helicopter probably reached 130 kt to 135 kt IAS as it descended into the valley and its groundspeed would have been about 150 kt due to the brisk tailwind. This speed would have necessitated a high rate of descent, in comparison with the same flight path flown at a lower groundspeed.

Figure 10 also shows two turn scenarios, illustrating turn performance and wind effect. Each turn is through a heading change of 90º, commencing from the witness limit of view line. Each of the paths is for a helicopter flying at 130 kt IAS with a 60º bank angle. One shows a turn in still air, the other with a 20 kt wind blowing along the initial line of travel. In the latter case, the helicopter would drift just over 200 ft downwind during the turn. Flown under ideal conditions, in calm air and in level flight, the turns would require a steady loading of 2g. Figure 10 shows that such a turn would not have been sufficient to keep the helicopter within the narrowest part of the valley in the prevailing wind conditions.

In attempting to fly in the valley at relatively low height and high speed, the pilot was undertaking a demanding manoeuvre. With the aircraft initially banked steeply in the opposite direction of the intended turn, descending at relatively high speed and rate of descent, and with a strong tailwind, accurate judgement of the required turn point would have been very difficult. The risk was that the pilot would start to turn late, come into unexpectedly close proximity of the terrain immediately ahead, and need to fly a harsh manoeuvre to avoid it. Even had the turn started in the correct place, it would have been difficult to judge, given the helicopter's speed, the nature of the valley, the lack of a good horizon reference, and the effect of the wind.

*Possible contributory factors*

In attempting to manoeuvre low in the valley, the pilot placed his helicopter in a situation in which there was a greatly reduced margin for error, or opportunity to deal with an unexpected event. From the foregoing analysis and the location of the accident site on the south side of the valley, it is probable that, at some stage, the pilot manoeuvred the helicopter at maximum performance, whether to ensure terrain avoidance and/or to arrest the descent, or for some other reason. This would have made a servo transparency encounter more likely, as well as increasing the risk of an unintentional deviation from the intended flight path due to spatial disorientation, misjudgement, or some other factor.

A sudden, harsh manoeuvre could have had other implications which, singularly or in combination with the above, could have contributed to the accident. Such a manoeuvre would have increased the potential for an involuntary of inadvertent interference with the flight controls by the front seat passenger. Dual flight controls can easily be removed. Whilst their fitment was not prohibited, it is inadvisable to have them fitted when carrying unqualified or inexperienced front seat passengers. As they had not been removed, interference by the passenger, for whatever reason, cannot be ruled out.

The camcorder was the only known potential loose article in the cabin, apart from paper documents. Had it been dropped, it could feasibly have interfered with the controls or presented a distraction at a critical time. Even a temporary control restriction at low height would be a serious event and therefore is also a possible contributory factor.

Birds are a common hazard at low level: they could have affected the flight path by forcing an avoiding manoeuvre by the pilot or, if they had struck the helicopter, by creating a distraction or restricting forward visibility. No evidence for a bird strike was found at the accident site, although it could have been lost in the post-crash fire, so the influence of birds cannot be ruled out as a possible contributory factor.

*The servo transparency phenomenon*

The servo transparency phenomenon is not unique to this helicopter type. It should not be encountered in normal service. Its onset marks the manoeuvre limit, and it would normally only be encountered through fairly aggressive manoeuvring. However, inadvertent encounters could occur, for which the manufacturer developed pilot procedures. According to Eurocopter, servo transparency is a transitory phenomenon which, because of the helicopter's natural response, tends to be self-correcting. However, this may not be so for a helicopter in a turn to the right. In this case, the helicopter's natural reaction will cause the angle of bank to increase which, together with a possible pitch-up, will cause an increased rate of turn. The effect, if any, on airspeed would be much less.

Although the helicopter will recover from the servo transparency of its own accord, the potential exists for a significant flight path deviation. The onset of this could be rapid and could conceivably lead to a helicopter in a right turn exceeding 90º of bank before the pilot was able to recognise what was happening and react accordingly. The associated transition from light and responsive controls to heavy controls that require considerable force to counter the uncommanded manoeuvre, could cause an unsuspecting pilot to believe that he was experiencing a malfunction, rather than a known characteristic of the helicopter when manoeuvred at the published limits. As Eurocopter have advised, a servo transparency encounter '*may give a pilot who is not aware of this phenomenon an impression that the controls are jammed*'.

A further consideration for a helicopter that encounters incipient servo transparency whilst manoeuvring in a turn to the right, is the possible delay in recognising an increasing bank angle. This is particularly so if already at a high bank angle and without a good horizontal reference, when the pilot's attention would probably be focussed on ground features ahead.

Although the helicopter's natural tendency in servo transparency is to reduce collective pitch, this will only assist recovery if the pilot does not oppose the associated movement of the collective lever. If a pilot were to be faced with an unexpected situation requiring additional power, this would not necessarily be an option. Indeed, the application of collective at a critical stage could be the factor that induces the servo transparency, rather than cyclic manoeuvring alone.

With the onset of servo transparency in this case predicted to have been at 2.1 g (with maximum continuous power set), even a modest increase in turn rate over that shown at Figure 10, if accompanied by a power increase, would have caused the helicopter to encounter the phenomenon. Any turbulence in the valley could have caused transient additional loading of the rotor disc, which would further increase the likelihood of an encounter. At the height the pilot chose to fly, there would have been very little time to recognise and deal with such an encounter, and the helicopter could rapidly have adopted an attitude from which recovery was not possible.

*Pilot training*

Among many other things, good airmanship dictates that a pilot knows his aircraft's limitations and does not place it in a situation in which they are, or could be, exceeded. Similarly, recovery manoeuvres need to be thoroughly understood. Operations at minimum height are demanding and are subject to specialised and regular training, such as undertaken by military pilots. Such operations incur greater risk of encountering hazards which, in other flight regimes, may present a lesser threat to the aircraft's safety.

Although flight training, or demonstration, of potentially hazardous characteristics or phenomena may appear desirable, any training which takes an aircraft to the limits of its flight envelope incurs risk and is likely to expose man and machine to additional stresses. There may also be difficulties with achieving standard, repeatable demonstrations. There are hazards specific to rotary flight that continue to cause accidents and incidents, yet cannot be experienced by a pilot in a safe and controlled way. An awareness of these hazards, including avoidance and recovery actions, is therefore confined to ground study. It follows that the information on which such study is based must be as complete as possible.

Servo transparency may have been a factor in this accident, although only because the helicopter's low level manoeuvring may have delayed recognition and made recovery from the encounter difficult. The factual information about servo transparency, distributed by Eurocopter through Service Letter and Flight Manual revision, was accurate: pilot recovery actions were unambiguous and applicable to all situations. However, although the aircraft's well-documented response can readily be applied by an informed reader to any flight scenario, a servo transparency encounter must present a potential hazard to an aircraft already manoeuvring in a right turn, particularly at low level. It is therefore arguable whether it can be correctly stated that servo transparency '*presents no danger*' or that it is always '*self-correcting*'. Indeed, such language could cause an unwary pilot to consider the phenomenon as unimportant.

The following Safety Recommendation is therefore made:

**Safety Recommendation 2008-067**

It is recommended that Eurocopter review current operational information and advice about the servo transparency phenomenon. This should be with a view to including a warning in applicable Flight Manuals that the associated uncommanded right roll and possible pitch-up, if encountered by an aircraft manoeuvring in a right turn, have the potential to cause a significant deviation from the intended flight path which, if encountered in close proximity to terrain or obstacles, could be hazardous.

Eurocopter's Service Letter describing servo transparency was effectively reissued in the USA by the FAA as a Special Airworthiness Information Bulletin. There was no comparative action in the UK, although the Service Letter would have been sent to all registered owners/operators of the applicable helicopter models by the manufacturer. In the light of this accident, the following two Safety Recommendations are made:

**Safety Recommendation 2008-068**

It is recommended that the Civil Aviation Authority should circulate, by the most appropriate means, the content of Eurocopter's Service Letter SL-1648-29-03 to owners and operators of applicable helicopter models, with a view to reminding them of the causes, symptoms, hazards and recovery actions relating to 'servo transparency' or 'jack stall' encounters.

**Safety Recommendation 2008-069**

It is recommended that the Civil Aviation Authority, in conjunction with the European Aviation Safety Agency, require an awareness of the causes, symptoms, hazards and recovery actions relating to 'servo transparency' or 'jack stall' encounters to be covered as a ground study item as part of the mandatory training for aircraft type ratings for those helicopter types likely to be affected.

*Licensing matters*

The pilot did not hold a valid flying licence or a valid type rating for G-CBHL (or indeed for any type of helicopter), and had not done so for a considerable time, in contravention of Articles 26 and 29 of the Air Navigation Order. The type rating could only be renewed by passing an LPC on the helicopter type. The LPC was a check of the pilot's continuing competence and fitness to hold the type rating, and included handling of simulated emergency scenarios such as engine failures and hydraulic system malfunctions. Therefore, the lack of a current type rating was relevant to the continued safe operation of the helicopter.

The investigation into the pilot's licensing history revealed several cases, between 2004 and the time of the accident, of non-compliance with existing regulations. When the pilot flew from Scotland to London in March 2006, he would have known that his type rating had expired, since the purpose of the flight was to meet with an examiner to renew it. Therefore, whilst the flying licence lapse could possibly be explained by confusion over validity periods, and may be seen as an administrative oversight by the pilot, the same is unlikely to be true of the type rating.

The responsibility to monitor validity periods of licences and ratings rests with the licence holder, not the CAA. However, there is no requirement for a person to renew a licence or rating, provided they do not intend to use it. Therefore, a considerable number of lapsed licences and ratings would ordinarily exist on the CAA's database. Although the CAA would have received notification of the pilot's two most recent LPCs during the period when his licence was invalid, this would not have been raised as an anomaly. A similar situation would legitimately exist if, for example, a pilot was intending to renew a licence, for which he would require a valid LPC.

There were some variations in the CAA's advice to its Authorised Examiners about checking the licences of pilots presenting themselves for proficiency check flights. Licence checks were required in guidance given to fixed wing examiners but were not explicitly required of rotary wing examiners. The examiner who conducted the pilot's last two LPCs did not believe it was his responsibility, with the result that he conducted both LPCs on a person who was not the holder of a valid flying licence, without being aware of the fact.

Whilst the CAA does not have a responsibility for the validity of individuals' licences, it does attempt to assist licence holders by alerting them to approaching expiry dates, so that they may take appropriate action. Similarly, a licence check as part of a skills test or proficiency check may serve as a timely reminder to the holder about expiry, and in cases were the licence is found to have expired, the holder could be cautioned about the need to renew it before exercising any licence or rating privileges. The following Safety Recommendation is therefore made:

**Safety Recommendation 2008-070**

It is recommended that the Civil Aviation Authority standardise a requirement for all Authorised Examiners to check the licence and/or other applicable documentation of candidates presenting themselves for proficiency checks or skills tests. This requirement should be stated in the applicable Standards Documents, together with the action to take in the event that the validity of any required documentation has expired or is approaching expiry.

**Conclusion**

The cause of the accident was not positively determined. Although no technical reason was found to explain it, a technical fault, whilst considered unlikely, could not be ruled out entirely. The available evidence indicated that the helicopter was intact when it struck the trees and that the engine was delivering power. The aircraft's trajectory suggested that the pilot was in control of the aircraft at the time of impact and was attempting to recover from a significant deviation from his intended flight path when the helicopter struck the trees.

The descent into the Mouse Water Valley appears to have been a deliberate manoeuvre. Considering the video evidence, the pilot's intention was probably to fly a hard, right turn at low height within the valley, possibly leading to a further, final zoom climb before landing at the helipad. A high-speed, low-level turning manoeuvre in the heavily wooded valley was a demanding one, which would have subjected the helicopter and its occupants to an increased risk. The circumstances of the accident, which included a strong tailwind, suggest that the pilot needed to fly an unexpectedly high performance manoeuvre which led to, or contributed to, the flight path deviation. This deviation may have been due to a servo transparency encounter, spatial disorientation, misjudgement or some other factor or combination of factors.