Rotorway Executive 90, G-ROTO

AAIB Bulletin No: 5/99 Ref: EW/C98/8/1 Category: 2.3

Aircraft Type and Registration:	Rotorway Executive 90, G-ROTO
No & Type of Engines:	1 Rotorway RI 162 piston engine
Year of Manufacture:	1991
Date & Time (UTC):	1 August 1998 at 1344 hrs
Location:	Near Six Mile Bottom, Cambridgeshire
Type of Flight:	Permit to Fly renewal flight test
Persons on Board:	Crew - 1 - Passengers - 1
Injuries:	Crew - Fatal - Passengers - Fatal
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Airline Transport Pilot's Licence (Helicopters and Gyroplanes) with Flying Instructor Rating
Commander's Age:	43 years
Commander's Flying Experience:	6,759 hours (of which at least 59 were on type)
	Last 90 days - 69 hours
	Last 28 days - 27 hours
Information Source:	AAIB Field Investigation

Background to flight

The build of G-ROTO was completed in April 1995 and, after 76 flying hours it was sold in the summer of 1997; the sale occurred shortly after the successful completion of the annual Permit to Fly renewal on 30 July 1997. The second owner was a student pilot who then completed just less than 10 dual flying hours in G-ROTO before reselling it in June 1998; during this period, there were no significant unserviceabilities reported with the helicopter which was hangared at, and flown from Cambridge Airport. Prior to this final transfer of ownership, the new (third) owner had not flown the helicopter but a qualified pilot had flown it on 23 May 1998 and reportedly found it fully serviceable. This qualified pilot was also the pilot who had flown exclusively with the second owner and was also the pilot during the accident flight of 1 August 1998. Following the final transfer of ownership, the new owner flew a short familiarisation flight with another pilot on 4 July 1998. However, this flight was curtailed when the pilot found that the yaw pedals were abnormally stiff and that there was some restriction with the cyclic control; this latter problem became evident when, hovering out of wind, right cyclic movement was restricted by the left occupant's right leg, which in turn was restricted by the collective control between the two seats.

The new owner thought that the yaw pedal stiffness was caused by lack of end float in the pedal shaft and so consulted, by telephone, the manufacturing company test pilot and another employee of Rotorway International in the USA to ask their advice. They advised him to disconnect the cable from the left hand bell crank and check that the rest of the controls were free. If this were the case, they agreed that the owner could reduce the thickness of an aluminium alloy bush on the end of the pedal shaft to achieve the required end float.

The Rotorway employees also suggested that both cyclic sticks should be displaced to the left by adjusting the left-hand clevis screw by two turns. This would have the effect of changing the cyclic authority from swash plate angles of 5û each side, to a left hand cyclic swash plate angle of 4û, and a right hand range of movement of 6û. The owner made a second call to Rotorway to confirm that this was acceptable.

About three weeks before the accident, the new owner and a friend made the adjustments to the controls. The bolt through the tail rotor cable clevis was removed, and the cable was found to be free, so the thickness of the left-hand pedal shaft bush was reduced by 0.020 of an inch. It was then reassembled, using loctite on the bolt before it was wire locked. The clevis was removed from the bottom of the left-hand cyclic stick and screwed in by two turns, and reassembled using loctite. The owner tried to get a qualified engineer to check the work, but was unsuccessful in finding anybody to do the check before the permit renewal was necessary. He reportedly discussed the lack of an independent check with a licensed aircraft engineer, and also with the permit renewal flight test pilot who decided that he would fly the helicopter if he was happy with the work done. The modification to the cyclic control was further discussed, and it was decided that although this had been recommended by employees of Rotorway International, the control should be returned to its original configuration.

The Permit To Fly certificate was valid until 5 August 1998 and the new owner arranged with the pilot to carry out the renewal air test on 1 August 1998 from Cambridge Airport. The owner has stated that, on the day before the air test, he asked the pilot if he would like him to remove the dual collective stick but he replied that he did not think it necessary.

History of flight

On the morning of the accident flight, the owner collected the pilot from his home at about 1030 hrs and drove him to Cambridge Airport; the pilot seemed in good health and humour and, on the way to the airport, they stopped for a sandwich. They arrived at Cambridge at approximately 1230 hrs.

The weather was good with an estimated cloudbase over the airport of 1,000 to 1,500 feet agl; the surface wind was approximately 8 kt from the east and the visibility was greater than 10 km. Subsequent to the accident, an aftercast of the weather was obtained from The Meteorological Office at Bracknell. The synoptic situation showed a ridge of high pressure extending southwards across England and Wales with a northeasterly airflow established over the Cambridge area. The visibility was 25 to 30 km, the surface wind was 030°/10 kt, cloud was few/scattered base around 2,500 to 3,000 feet amsl and broken base 5,000 feet amsl; mean sea level pressure was 1019 mb, air temperature was 19°C and dew point was 12°C. The wind at 2,000 feet amsl was 090°/17 kt.

On arrival the owner, watched by the pilot, adjusted the cyclic control back to the original position and then he and the pilot went for a coffee and reviewed the weight and balance of the helicopter for the proposed flight. With their combined weights, they decided that they could not take sufficient fuel to allow the profile to be completed in one flight. They then asked the resident flying instructor of the company whose office they were using if the part time operations assistant could accompany the pilot on the flight as an observer. The instructor agreed, with the proviso that the assistant was also in agreement; she had flown on a 'Permit' renewal before, albeit in a fixed wing aircraft, and she agreed to the request. Accordingly, the pilot then did a weight and balance calculation and concluded that he could carry 75 lb of fuel to bring the take-off weight to the maximum of 1,425 lb. The pilot and owner then wheeled G-ROTO out of the hangar and dipped the fuel tanks; following this, they uplifted a further 25 litres of fuel to make the total fuel on board 48 litres. The pilot, watched by the owner, then completed a pre-flight inspection of the helicopter and found no faults. He then returned to the office and briefed the observer on how to fill out the flight test form; during this time, she was given a clipboard to use for the paperwork. Shortly afterwards, the pilot, his observer and the owner walked out to G-ROTO. The owner helped the pilot and the observer to strap in; the pilot sat in the left seat which is the normal commander's seat in this helicopter. The cyclic and collective controls were already installed in both the pilot's and passenger's positions. The owner retreated about 10 metres away and then watched the pilot start the engine at about 1305 hrs and apparently complete the normal warm up and control checks; the owner estimated that the pilot lifted off at about 1315 hrs.

The Cambridge ATC recordings show that the pilot called for lift-off clearance at 1318 hrs. He was cleared as requested to a hovering area where he remained for approximately two minutes before he asked for clearance to lift and depart the circuit to the east. Then, at 1322 hrs he advised ATC that he was "clearing to the east" and was transferred to Approach Control on frequency 123.6 MHz. Shortly afterwards, he checked in with Cambridge Approach, agreed a Flight Information Service with the controller and received the latest regional pressure setting. No further messages were heard from the G-ROTO; the first intimation to Cambridge ATC that an accident had occurred was when a police helicopter pilot transmitted at 1351 hrs to advise the controller that he was responding to a reported helicopter accident.

The first call to the police had been received at 1344 hrs. It was made by one of the eye witnesses who had seen the last few seconds of flight of G-ROTO. These witnesses had seen the helicopter from various angles. None made any comment that there were any abnormal noises although most of the witnesses were in cars and one was indoors. Their evidence indicated that G-ROTO was travelling in a straight line from approximately east to west and at a normal height. There was some conflict of evidence on the estimated height varying from 4,000 feet to 40 feet but none described the height as appearing excessively low and the surrounding terrain allied to the witness positions could account for some variation. From a subsequent review of the position of one of the witnesses and where he saw the helicopter, it was calculated that G-ROTO was at approximately 500 feet agl. One witness described the helicopter as turning suddenly to the right before falling to the ground and others described the helicopter as suddenly falling without any apparent turn. Most witnesses also described something falling off the helicopter before it apparently went out of control and then bits coming off as it descended. There were also comments that the rotors were either not turning as it descended or were rotating very slowly. There was a significant ground fire.

Accident site

The helicopter had crashed approximately 540 feet northeast of a 20 feet high line of trees in a field of 3 feet high standing wheat; the line of trees was orientated northwest/southeast. The initial impact point was defined by ground marks made by the skids on a heading of 215°(M). Two pieces from the bottom section of the No 2 cast aluminium alloy bulkhead from the tail boom, which were buried in the ground, corroborated the impact point and the orientation. The aircraft had then bounced forward approximately 4 feet before coming to rest on the same heading.

The tubular steel structure of the helicopter showed considerable distortion from the ground impact in the area supporting the rotor mast, with the rotor tower deformed through approximately 45û to the right. The right skid had been bent backwards and the two supports joining it to the lower fuselage frame had collapsed, allowing the skid and the frame to lay adjacent to one another. The left hand skid had been bent outwards until it lay horizontal, away from its fuselage frame. The ground fire had burnt out all the non-metallic parts and melted most of the aluminium alloy components, including part of the engine block and one cylinder head. (See photograph at Appendix 1).

There were no indications that the main rotor had struck the ground whilst under power. The tail rotor section had been separated from the tail boom by multiple impacts from the main rotor blades and was found approximately 100 feet from the main wreckage to the southeast. One blade was missing from the tail rotor, and that was found approximately 360 feet southeast of the impact site.

Debris from the acrylic windscreen, doors and windows, and pieces of skin from the tail boom, were found in an area extending from beyond the tail boom to the tree line. The flight test schedule documents were found later, in the field beyond the tree line, approximately 975 feet from the site of the main wreckage.

Examination at Farnborough

Main rotor

The two-bladed main rotor had no significant impact damage on the leading edges of the blades, which both carried traces of red paint from the tail boom. However, the blades showed pronounced upward bending along their length. One blade had severe downward root end bending damage from the ground impact, which had fractured the blade retaining bolt, releasing the pitch link. The other blade had some fire damage. Both main rotor bump stops had been bent back at right angles from their original orientation. There had been no blade delamination.

Although both main rotor shaft bearings had been affected by the fire, which had caused them to corrode, they were free to rotate after application of oil. Both main rotor blade elastomeric bearings were undamaged, apart from the effects of the fire.

Transmission

The engine output speed is reduced to the main rotor speed in two stages. The first stage reduction is achieved by multiple belts which drive a secondary shaft through a large diameter aluminium alloy pulley. All the rubber belts associated with this assembly were destroyed in the fire. The upper end of the secondary shaft is connected to a sprocket through a freewheel unit. This sprocket is connected by a chain to the large diameter main sprocket on the main rotor shaft.

The main sprocket and hub had been completely melted in the fire, although one of the four bolts joining the sprocket and the hub was recovered, complete with unbroken locking wire, from the re-solidified aluminium alloy under the wreckage. The chain was still engaged on the secondary shaft sprocket, and there were no marks on the adjacent structure to indicate that the chain had come off the main sprocket. The aluminium alloy components on the secondary shaft had partially melted, jamming the freewheel unit. An X-ray showed that the elements in all the bearings on the secondary shaft were intact, although the fire had caused them to seize.

The freewheel unit comprises two clutch assemblies, working on the roller and ramp principle, allowing drive in one direction and freewheeling in the other. Initial inspection of the freewheel unit showed that it contained a restriction which only allowed 1.45 degrees of shaft movement. The unit had been subjected to intense heat, which had melted part of the large transmission pulley, and had damaged other aluminium alloy components. When the two clutches were removed from their housing it was found that the restriction was caused by one of the bearings which lay adjacent to the clutches. A strip examination showed that the bearing race containing the ball elements had been contaminated with burnt oil, which prevented rotation. The bearing tracks and balls were cleaned and showed no evidence of rotational damage. The two clutches were also examined, and they, too, showed no signs of mechanical distress other than that caused by the heat of the ground fire.

Engine and fuel system

The engine had been badly overheated in the ground fire; the No 4 cam cover and cylinder head had melted, releasing both valves. The piston from this cylinder had been deformed by the ground fire. The crankshaft flange next to the No 4 connecting rod had received an impact, whilst static, which had deformed the crank flange and the connecting rod; this distortion had jammed the big end bearing on the crankshaft.

The induction, carburettor and dual electronic ignition systems had been completely destroyed. The oil pump, cam shaft, pistons, cylinder liners, big and little ends and the three remaining cylinder heads showed fire damage which had caused partial seizure of the main bearings and gudgeon pins. There was no evidence of any pre-impact mechanical problem in the engine.

The engine output drive pulley, which may have had witness marks indicating whether or not the engine was rotating at impact, had been melted in the fire.

The fuel system, including the carburettor had been destroyed in the fire, the only evidence remaining was that the fuel cock was in the **ON** position. The log book showed that the throttle linkage Mandatory Compliance Directives: "M-16 throttle clevis; and M-17, dual throttle shaft weldment" had been completed.

Tail boom

The tail boom was of sheet metal construction around stringers fastened to four cast aluminium alloy bulkheads. Bulkhead No 1 attaches the front of the boom to the helicopter fuselage, and bulkhead No 4 carries the tail rotor assembly. Bulkhead Nos 2 and 3 carry the pulleys used to transmit power to the tail rotor.

Two pieces of the lower section of bulkhead No 2 were found embedded in the ground at the first impact point. The tail boom between bulkhead Nos 2 and 4 had been subjected to multiple main rotor strikes, which had produced many pieces of tail boom debris, scattered over a wide area. Only about 50% of bulkhead No 3 was recovered, whereas bulkhead No 4 was intact and still on the detached tail rotor assembly.

Tail rotor

The detached tail rotor blade had failed by rotating backwards against the normal direction of travel. The blade leading edge carried traces of red paint and the tail boom ahead of the rotor carried an arc of damaged paint exactly where the tail rotor blade would strike if the boom/tail rotor assembly were sufficiently distorted to allow contact.

The tail rotor pitch stops were fitted to the yaw control pedals, and the severance of the tail boom had rendered them ineffective. The carriage slider assembly, which alters tail rotor pitch angle, was found to have been displaced and was on top of the shaft key, in a position beyond that normally allowed by the yaw pedal limit stops. However, in this position the bellcrank which positions the carriage slider was in close proximity to the pulley on the tail rotor drive shaft. There were no witness marks indicating contact had taken place when the pulley was rotating.

The ends of the two belt tension adjustment rods, normally contained within the glass reinforced plastic (grp) tail cone, had moved off the tailcone centreline and had extended through the back of the grp tail cone. The rods had been bent in compression, and the sliding assembly carrying the final pulley and the tail rotor drive shaft had been displaced off its four tracks, which were also bent. This damage was consistent with the heavy ground impact through the tail skid which had been transmitted through bulkhead No 4 to the damaged components.

Flying controls

The flying controls were operated by a heavy duty bowden cable system, with the collective and both cyclic pitch and roll controls each having two cables, one in tension and the other in compression, to remove backlash. The yaw control system was operated by a single cable. The aluminium alloy attachment fittings in the cockpit of all seven cables had been melted. One main rotor blade pitch control link had been detached in the impact.

The pilot's collective stick was still attached, and the dual collective stick, fitted between the two seats, was found loose in the aircraft. It was secured by a pinch bolt at the base of the stick and could not have been easily removed during flight. It is considered that it came off during the impact. The collective actuator fork on the rotor head had fractured during the ground impact. The helicopter construction manual requires a main rotor blade angle of minus 1.5 degrees when the collective is fully down, and 9.5 degrees fully up. The negative setting is required to take account of drag in the rotor drive system and to maintain the correct autorotation RPM under certification conditions of low gross weight.

Both cyclic sticks had been fitted and the adjusting screws, complete with nuts were recovered, but the aluminium alloy cable attachments had melted in the fire.

Due to the disruption of the structure and control runs it was not possible to reconstruct the rigging angles. However, the recovery of the steel components showed that a control disconnection had not taken place.

Acrylic windscreen, doors and windows

The remains of both doors and some acrylic from the tinted windscreen were found scattered to the south and east of the accident site. The standing wheat, and a lack of knowledge of the amount of material that had been consumed in the fire, made it difficult to determine when the collection of debris was complete. The AAIB returned to the site later, with a helicopter, and were able to recover some significant further pieces of the doors and windscreen. Nevertheless, more debris was collected by other people after the wheat had been harvested, although many of these items had been further damaged by the combine harvester.

Many pieces of tinted acrylic, used for the windscreen and windows, were recovered, these represented approximately 50% of the total windscreen and window area. Approximately 60% of the left hand door acrylic was found, predominantly in large pieces, and with the failures emanating from the two door hinges; both door catches were found in the closed position. The right hand door material amounted to about 30% and was in smaller pieces (although some of this material had passed through the combine). No evidence of rotor blade impact damage was found on any of the acrylic recovered.

Permit to fly

The helicopter was operated under a Permit To Fly issued by the Civil Aviation Authority, the Operating Limitations associated with the Permit contained the following clauses, amongst others:

> 4. The aircraft shall not be flown unless the pilot in command has satisfied himself that it is in an adequate state of repair and in sound working order.
>
> 6. No alterations, modifications or replacements shall be made to this aircraft or to its engines, propellers, or equipment, unless approved by the CAA or other Organisations approved by the CAA for that purpose.
>
> 8. A Flight Release Certificate shall be issued and in force certifying that the aircraft has been inspected and is fit for flight. This Certificate shall only be issued by such persons as are authorised by the CAA. The Certificate shall be re-issued after required maintenance and/or inspections, or because the airworthiness of the aircraft has been altered.

The owner showed the AAIB the extent of the work carried out on the yaw and cyclic flying controls using another helicopter. The work on the yaw controls, as described, was carried out by removing and replacing bolts only; no adjustments were made to the tail rotor control rigging**.** No documentation was raised, either for the original work on the cyclic and yaw controls, or for the reinstatement of the original cyclic control settings.

Previous accidents

The CAA database listed eight previous occurrences involving Rotorway Executive helicopters (all marks). The AAIB investigated six of these and found definitive reasons for five accidents which were not relevant to G-ROTO. A fatal accident involving G-BIOZ on 17 July 1982, reported in Bulletin 11/82, had similarities to G-ROTO in that the main rotor struck the tail boom (and the canopy), and there was no evidence of any mechanical failure. However, there were significant differences between the rotor system of G-BIOZ and G-ROTO which Rotorway International maintained prevented direct comparison of the dynamic behaviour of the two systems**.**

Operational considerations

Flight test procedures

The pilot had been authorised by the CAA to carry out flight tests and had already completed 23 renewals on single-engined helicopters of which three had been completed in the last two years. His most recent flight test in a Rotorway Exec 90 helicopter was on 1 July 1998. The conduct of flight tests is comprehensively detailed within Civil Air Publication (CAP) 520: Light Aircraft Maintenance. This states that, "Whenever possible an observer should be carried"; however, it also details that the pilot is responsible, among other things, for ensuring that the observer is capable of performing duties in connection with the flight, is familiar with the procedures and is a willing volunteer. Additionally, the CAA produce an Airworthiness Information Leaflet (AIL) which details the CAA requirements and responsibilities of the pilots for flight tests for continued airworthiness of helicopters; this document confirms many of the requirements of CAP 520 but states that an observer must be carried. Discussion with another authorised flight test pilot indicated that approximately 35 to 45 minutes would be needed to complete the required test profile on the Rotorway Exec 90 helicopter.

CAA Flight Test personnel and other personnel involved in flight tests of Rotorway helicopters confirmed the practical need for an observer; one licensed engineer contacted had been a regular observer during previous flight tests of G-ROTO and was acquainted with the accident pilot. All those contacted also considered that the observer's dual controls should be removed, whenever possible, before any flight test.

Flight test results

The Airworthiness Flight Test Schedule form used on the accident flight was found in a wheat field adjacent to the crash site some three weeks after the accident. This form was Issue 2 dated August 1989; the most recent version is Issue 3, dated May 1995 but included no major or relevant changes. The form as found was intact and in good condition; some marks on the form were reviewed by the AAIB using microscopic examination to confirm that they were not the results of burning. Aircraft details, including loading information, had been completed in ink; other annotations on the form were in pencil. During the investigation, it was confirmed that the annotations in pencil were in the handwriting of the observer. The partially completed form was later examined by AAIB Investigators and CAA Flight Test personnel in order to review the results and to try and determine which aspect of the schedule was being undertaken at the time of the accident.

Many of the sections of the form only required a 'tick' to indicate a satisfactory result and would normally only require a comment if it was not satisfactory. Therefore, many of the apparently incomplete sections could be interpreted as satisfactory, with the pilot intending to complete the paperwork after the flight. This would not be unusual particularly with an observer not totally familiar with the helicopter or the form.

The pre-flight information and weather information had been completed and appeared normal. Post accident calculations confirmed that the helicopter was within normal weight and C of G limitations. The pre-flight inspection and start-up also appeared to have been completed whenever figures were required and seemed normal. Thereafter, there is a requirement to assess the handling and performance of the helicopter in the 'hover' and 'low speed envelope'. Figures had been entered where necessary for the 'hover' and an external observer (the owner) had stated that he watched the pilot lift-off and hover taxy away. Thereafter, the pilot was required to carry out turns on the spot, sideways flight left and right, and rearward flight. Although the form only required a 'tick' for these events if satisfactory, the radio recordings and evidence from ATC indicate that these parts of the flight test were not fully completed. Normally these would be done at the start of a flight test. The pilot may have completed some during the hover transit to his departure point. Alternatively, he may have been content that G-ROTO was handling normally since he had been flying the helicopter regularly over the last year. Nevertheless, it would be a surprising omission considering his awareness of the recent adjustments to the control systems.

The performance climb portion of the flight test had been completed under conditions which were similar to the previous year's test. In 1997, the results showed that G-ROTO had climbed from 500 feet to 2,650 feet in three minutes, an average climb rate of just over 700 feet per minute; this was very close to the results for 1996. On the accident flight, G-ROTO had climbed from 500 feet to 2,000 feet in three minutes, an average climb rate of 500 feet per minute. This indicates a decrease in performance but assumes accurate flying and recording.

The next part of the flight test was in normal cruise flight culminating in steep turns in both directions and then an acceleration to maximum cruise speed in level flight. Both these sections had been annotated and seemed normal.

Thereafter, the pilot would be testing the autorotation qualities of G-ROTO. The requirement was for a slow entry, followed by a moderate and then a rapid entry, all from an initial speed of 52 kt. If these were satisfactory, the pilot would repeat the three entries from a speed of 80 kt. The form only required a 'tick' to indicate a satisfactory result. The only annotation on the form was for engine RPM during the established autorotation. This was noted as 3,000 RPM; experienced operators of the helicopter would have expected a figure of 2,000 RPM. This may have been an error in recording but, even if accurate, should not have caused a major problem.

The only other parts of the form concerned functional checks of instruments and systems and shut down procedures which would normally be completed after the flight.

Radar recordings

Recordings of intermittent primary radar returns from G-ROTO were obtained from Stansted and Debden radars; there were no secondary radar returns. The first primary return was detected at 1326 hrs and the last return was detected at 1341 hrs; the first return was positioned 1 km southeast of the accident site (9 km east of Cambridge Airport) and the last return was positioned approximately 1/2 km west of the accident site. With no transponder code being transmitted, no height information was available. The recording shows that the pilot flew generally eastwards after his departure with radar returns showing for approximately four minutes; there is then some indication of manoeuvring before the helicopter again takes up an easterly heading for another three minutes. Contact is lost for about one minute before further returns are visible for four minutes with the helicopter heading north before contact is again lost at 1337 hrs. Just over two minutes later, the helicopter is seen approximately 5 km west of this position and seems to maintain a heading slightly south of westerly up to the last radar indication at 1341 hrs.

The radar information was examined to determine the approximate groundspeed of the helicopter during the different phases of the flight profile. For the first two minutes, the helicopter averaged 32 kt on a constant heading. The next two minutes were flown at an average of 57 kt on a new heading to the southeast. Then, following some manoeuvring, the average speed increases to approximately 72 kt on an easterly heading. The next portion of the flight was on a northerly heading at an average of 44 kt. Between contact being lost to radar acquisition again, the average speed on an westerly heading was 55 kt. The final portion of the flight was flown at an average speed of 84 kt. During this time, the surface wind speed was 030°/10 kt; at 1,000 feet amsl the wind speed was 070°/15 kt and at 2,000 feet amsl the wind speed was 090°/17 kt.

Correlation of the test profile, the radar information and the wind indicated that the medium level test profile was completed in accordance with the flight test schedule. By 1333 hrs, the performance climb, cruise flight (including manoeuvring) and the maximum speed run had been completed. The next part of the profile would be the autorotations and these would involve intermittent descents and climbs. The speed calculations indicate that the autorotations from 52 kt had probably been completed. The next series of autorotations would be done from 80 kt and it is possible that this was the portion of the flight that the pilot was involved in just prior to the accident.

The absolute minimum height for recovery from an autorotation would be 500 feet agl although CAA Flight Test personnel considered that 1,000 feet to 1,500 feet agl would be a more practical minimum. To allow at least 30 seconds in autorotation, would require an entry at least 1,000 feet above recovery height.

On 13 January 1999, another Rotorway Exec 90 was flown in the same area. The purpose of this flight was to try and establish the probable altitude of G-ROTO on the day of the accident and to try and determine the altitude and heading of G-ROTO just prior to the crash. Additionally, the flight would be used to calibrate the last recorded position of G-ROTO relative to the known accident site. To achieve these aims, the pilot was requested to fly around the same route as G-ROTO and to approach the crash site from different directions and different altitudes.

From the radar trials that were conducted it was possible to conclude that the last recorded position on the accident flight was close to the accident site. For the radar trials the final track was flown at various altitudes, from 2,000 feet down to 600 feet. The helicopter was visible on radar throughout and therefore it was probable that loss of radar returns of the accident helicopter meant that it was below 600 feet. This indicated that the accident pilot was probably involved in the latter part of an autorotation during the times that radar returns were lost. However, the radar coverage indicated that radar returns may have been evident throughout autorotations if recovery was completed by about 600 feet.

One of the original witnesses positioned himself near the crash site in the same location as on the day of the accident. He subsequently stated that, on 13 January 1999, he saw the helicopter fly over his position on three occasions. He considered that the first run was similar to the direction he recollected seeing on the day of the accident; this run was from Northeast to Southwest. The final run was the closest to the last altitude of the accident helicopter but was still slightly high; the final run was at 700 feet agl and the witness then considered that on 1 August 1998, the helicopter was at approximately 500 feet agl just prior to the accident.

Post mortem results

There were no medical aspects arising from the post mortem examination of the victims which would have had any bearing on the accident. The pathologist concluded that the predominant forces suffered by the occupants were severe and in the vertical direction.

Analysis

Engineering aspects

The disposition of debris, witness marks on the ground and distortion of the structure led to the conclusion that the helicopter had landed with a high vertical, and a small forward, component of velocity, and banked approximately 30 degrees to the right. The disposition of some of the windscreen and tail boom material, and the Airworthiness Flight Test Schedule - 435 feet beyond a line of 20 feet high trees situated 540 feet to the southwest of the accident site - indicated that the cockpit integrity was breached during the flight. No blade impact damage was evident on the windscreen or door acrylic recovered, and the majority of the left hand door frame was found adjacent to the accident site.

Prior to the ground impact, the main rotor blades had struck the tail boom, scattering debris over a wide area. This occurrence has been associated on other light helicopters with low rotor RPM or flight below 1g. The pronounced upward bending visible on the rotor blades has also been an indication of low rotor RPM. The lack of leading edge damage to the rotor blades indicated that the blades had very low rotational energy at ground impact.

The damage to the flying controls in the cockpit, and the distortion to the main mast mounting structure precluded any rigging measurements after the accident. However, it was established that no flying control disconnection had taken place. Had the changes to the yaw and cyclic controls been carried out by the owner in the manner described, the rigging of these controls would have remained unchanged. Although the control adjustments were not carried out in accordance with required procedures, no evidence was found that the work contributed to the accident**.**

The tail rotor carriage assembly was found to have been displaced and to have travelled beyond the limit of its keyway. It could not have been in this position at the start of the flight test without the pilot being aware of it, and could only have gone to that position before the accident if the tail rotor control rigging had changed dramatically in flight. There was no evidence that this had occurred. It is considered that the abnormal position of the tail rotor carriage slider arose during the accident, and after the normal range of movement had been invalidated by the severing of the control cable.

Whilst the engine electronic ignition system and the carburettor had been destroyed, most of the mechanical equipment survived the ground fire. Three of the four drive pulleys and sprockets in the drive train between the engine and the main rotor had melted in the fire, but most other components, including the bearings and the freewheel unit, were capable of being examined. Within these constraints no mechanical pre-impact defects were found.

No evidence was found to explain the apparent reduction in climb performance compared with the previous flight test

Operational aspects

The pilot was experienced and qualified for the proposed flight and familiar with G-ROTO. On the day, the weather was suitable for the flight test.

Some time prior to this date, some work had been carried out on the controls of G-ROTO. The pilot watched the owner re-adjust the cyclic on the day of the accident. He had final responsibility for ensuring that the helicopter was fit for flight and should have been aware of the requirement for a duplicate inspection.

Thereafter, the owner and the pilot discussed the weight and balance and decided that they would not be able to uplift sufficient fuel to complete the flight. At this stage the operations assistant agreed to accompany the pilot on the flight; albeit young and inexperienced, she was very keen on flying and comfortable around aircraft. She was briefed and accompanied to the helicopter where she was helped to strap-in. However, it was surprising that the dual controls were not removed from the helicopter. Dual controls can be useful when experienced pilots occupy the right seat but there is no advantage in retaining them for a non-qualified pilot particularly when that occupant has a clipboard and needs to complete a form during the flight. It would be appropriate for the CAA to require the removal of the dual controls for light helicopter flight tests unless exceptional circumstances prevail.

The flight appears to have followed the schedule in the flight test form; although the form was not the most current, there were no significant differences. However, the pilot did not seem to complete a full assessment of the low speed envelope before leaving the airfield; although he would have been familiar with the helicopter's handling qualities and therefore should have detected any changes, he was aware of the control adjustment. Discussions with test personnel indicated that there would not have been sufficient time to fully complete this part of the schedule although the pilot may have checked the controls to his satisfaction during the hover taxy to his departure point.

The extent of the schedule which was completed indicated that the aircraft appeared serviceable to the pilot. It is most unlikely that he would have continued with the test if he had any doubts. It is noteworthy that he appeared to have completed his manoeuvring and maximum speed run and moved on to other parts of the schedule; any problems with G-ROTO could be expected to have become apparent by then. As noted from examination of the test form, the climb performance recorded a deterioration from the previous year but this may not have been apparent until calculations were completed after landing.

Following satisfactory performance up to the maximum speed run, the pilot would then need to complete a total of 6 autorotations. The entry speed for the first three was 52 kt, which was the established autorotation speed, and the entry rate would be increased each time. The purpose of this test was to confirm that the nose pitch up rate was easily controlled. If the characteristics were satisfactory, then three further autorotations would be done from an entry speed of 80 kt. The flight schedule contains a warning that, "Care should be taken that the rapid entries to autorotation do not result in a significantly low 'g' condition". The radar recording indicated that the pilot had probably completed the first set of autorotations from 52 kt. Thereafter, if the helicopter was performing satisfactorily, he would be expected to complete three more autorotations from the higher speed.

The final radar returns indicate an average speed of just under 80 kt. The radar was capable of maintaining contact down to at least 600 feet which is close to the minimum height for an autorotation recovery. Therefore, the pilot may have completed some autorotations from this higher speed without going out of radar contact. From eye witness accounts and the flight trial, the helicopter appeared to be level and at approximately 500 feet just prior to the accident. This would indicate that if the pilot was completing his autorotations, the accident occurred as he was recovering from, and not as he was entering, an autorotation. The other possibility is that he had completed the test schedule to his satisfaction and was transiting back to Cambridge. Neither of these possibilities can be discounted. However, engineering analysis concluded that the main rotor contacted the tail boom and the cockpit had been breached some hundreds of feet agl. The eye witnesses to the accident all reported that the helicopter turned or dived sharply, that pieces fell off and that the rotors were turning very slowly or stopped as the helicopter fell to earth.

Contact between the main rotor and the tail boom may occur following inappropriate or excessive cyclic control inputs. It can also occur, following loss of power to the main rotor, if the pilot fails to lower the collective lever or some sort of restriction prevents the collective lever being lowered. Such a circumstance would lead to a rapid loss of rotor RPM and possibly excessive blade flapping. In this accident, some sort of system failure or engine problem could not be discounted. It is unlikely that an experienced pilot flying in good weather and in a straight line would lose control without some other factor being involved.

Conclusion

The accident occurred towards the end of an annual Permit to Fly renewal test flight. The pilot was current and qualified to complete the flight. Although adjustments had been made to the primary flying controls, these had not been completed in accordance with CAA procedures. Nevertheless, the pilot was aware of these adjustments and there is no evidence to conclude that these adjustments contributed to the accident. The extent of damage sustained during the ground impact and subsequent fire meant that system malfunction or failure could not be discounted.

Eye witness accounts and engineering analysis indicate that there was contact between the main rotor and the tail boom in flight but the reason for this could not be identified. At the time this occurred, the helicopter was flying in a straight line, at about 500 feet agl and at normal speed. It is unlikely that an experienced pilot would have applied inappropriate or excessive control inputs. Therefore, it is possible that some sort of malfunction occurred but that the pilot could not or did not apply sufficient corrective control to counter the situation.

Safety recommendation

Recommendation 99-17

It is recommended that the CAA require the removal of the dual controls for light helicopter flight tests unless exceptional circumstances prevail.