Aerospatiale AS355 F1 Ecureuil II, G-MASK

AAIB Bulletin No: 2/2000 Ref: EW/C98/7/7 Category: 2.2

Aircraft Type and Registration:	Aerospatiale AS355 F1 Ecureuil II, G-MASK
No & Type of Engines:	2 Allison 250-C20F turboshaft engines
Year of Manufacture:	1985
Date & Time (UTC):	26 July 1998 at 1637 hrs
Location:	Near Rochester Airport
Type of Flight:	Air Ambulance
Persons on Board:	Crew - 1 - Passengers - 2
Injuries:	Crew - Fatal - Passengers - Fatal
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	40 years
Commander's Flying Experience:	4,640 hours (of which 242 were on type)
	Last 90 days - 55 hours
	Last 28 days - 18 hours
Information Source:	AAIB Field Investigation

Background

The Kent Air Ambulance helicopter was based at Rochester Airport. It operated daily from 1000 hrs to 1800 hrs and was crewed by one pilot and two medical staff. The same crew had been on duty for three days and they had been busy, particularly on the day of the accident and the day before. The commander was employed by a specialist company which primarily provides helicopters, maintenance and operational support to police and air ambulance aviation services within the UK. The commander was not permanently based at Rochester airport; he flew the AS355 for units in the south of England and his work pattern was split between police and air ambulance work. He had been on Kent Air Ambulance duty for 60% of his work pattern during the six months which preceded the accident.

The weather at the time of the accident was fine with a temperature of 20°C, light winds from the west, good visibility and a few clouds at 4,000 feet. It was clear from an examination of the crash site and the wreckage that the accident occurred when G-MASK collided with an electric power cable and very shortly thereafter struck the ground.

Preceding flights

On the day of the accident the air ambulance had flown twice to public relations commitments and on six operational flights. There was only one occurrence of significance to the investigation during the seven flights which preceded the accident flight. Whilst searching for a casualty on the beach in Sandwich Bay during the afternoon, one of the ambulancemen spoke to his control room on the ambulance frequency saying that they were "standing down from the emergency with an engine problem" and returning to base. A minute later the ambulanceman reported that "we've managed to solve our problem" and that they were returning to the task. They located the casualty and transported him to hospital before returning to base. No RTF messages from the commander which might have explained the engine problem were transmitted to the ATC units within range.

The task from which the helicopter did not return began at 1604 hrs when the crew took off from Rochester to attend a road traffic accident about 3 nm north of the airport on the M2 motorway just north of the Medway Bridge. The crew had some difficulty in locating the accident because the vehicle had left the road and entered bushes and they circled the area at low altitude for a while before finding the location. There was no suitable landing site beside the car so the commander landed in the corner of a field a few hundred metres north of the car, beside an underpass leading to a housing estate. The commander shut down the helicopter and remained with it whilst the ambulancemen went to the scene of the car accident. Their services were not required and they returned to the helicopter, stowed their gear and boarded. By this time people had made their way through the underpass to watch the helicopter depart. As it did so, two boys reported seeing what looked to them like sparks or flashes of light coming from the main rotor head mast area. The flashes stopped before the helicopter took off; apart from these observations and one report of an oily smell, there were no reports from the onlookers to suggest anything remarkable about the helicopter's departure. It lifted to the hover, transitioned to the north-west and then turned left onto a heading which the observers thought was consistent with a return to Rochester Airport. The ambulancemen sent a coded message to their HQ reporting that they were airborne, returning to base, and available for tasking; this message was timed at 1625 hrs, some 12 minutes before the helicopter crashed.

Radar recordings

A direct return flight to Rochester Airport should have taken no more than two minutes and yet the helicopter was airborne for at least 12 minutes. G-MASK was fitted with a transponder which was operating on modes A and C and normally the pilots used a discrete mode A code which identified it as the Kent Air Ambulance. Mode C provided information on helicopter altitude. National Air Traffic Services were asked to search their radar recordings for any data bearing that code. Relevant data was recorded at the Debden radar head north of Stansted Airport. The data covered the time period 16:28:31 to 16:36:16 at 6 second intervals with no significant 'gaps' in coverage. The data stopped approximately 74 seconds before power in the electricity power cables at the accident site was cut. Just before the data stopped, the helicopter was in level flight travelling at about 125 kt groundspeed on an easterly heading taking it towards Rochester Airport. A plot of the radar data is attached to this report at Figure 1.

The route the helicopter flew from the departure site beside the motorway can be described as comprising three 'legs'. The first was south-westerly to the village of Culverstone Green; the route was not a straight line and the helicopter was climbing gently throughout the leg. The helicopter then turned about to the right and began the second leg heading north-east towards the village of Luddesdown; again the route was slightly erratic but this time the height slowly reduced. The third leg began near Luddesdown when the helicopter turned to the right and headed in a straight line towards Rochester Airport.

The Mode C altitude of each radar data point was corrected to show altitude above mean sea level which was then compared to the height of the terrain beneath the radar return. The points were then plotted graphically to illustrate height above ground. The graph showed that the helicopter had been flown between 400 and 500 feet above ground during the first and second legs. On the third leg it was 600 feet above the River Medway and 300 feet above the ground at the last radar return as it approached Rochester Airport.

Radio recordings

Recordings of radio and data messages between the ambulancemen and their headquarters for the whole day were made available to the investigators. Apart from the 'engine problem' messages from Sandwich Bay, there were no indications of anything abnormal.

The ATC staff at Rochester Tower finished work at 1600 hrs but one RTF message from the commander was recorded in the control room some time later. The recording system was installed for commercial use and was not required to conform with any regulation or legislation. It was voice activated and had no time base. The voice message was "rochester traffic medic kilo alpha helicopter joining from the west low level". The commander's voice sounded normal and spectral analysis of the background noise did not reveal any unexpected mechanical sounds. There were no other recorded messages made by the commander at a time close to the accident on any likely ATC frequency including the distress frequency. The absence of recordings at other ATC units was not considered unusual given the good weather and the helicopter's normal VFR operating style at low altitude and outside controlled airspace.

Ear witness evidence

The Kent Police interviewed a large number of witnesses. There were no reports of anything unusual about the helicopter after it took off from the field beside the M2 until soon after it began the third leg towards the airport. Of the witnesses who were close to the helicopter's flight path between its right turn near the village of Luddesdown and the crash position, the majority were in vehicles travelling at speed on the M2 motorway. Given that their hearing would inevitably have been affected by their being inside a moving vehicle with the attendant road, engine and wind noises, few mentioned the helicopter's sound. However, there were 18 people who were within hearing distance, not in moving vehicles and whose testimonies are consistent with seeing the KAA helicopter at the appropriate time. Of these 18 witnesses; 14 stated that it sounded abnormal; two stated that it sounded normal and two made no comment about the sound of the helicopter. Of the four who made no comment or stated that it sounded normal, only one was in the open air and within 1,000 metres of the helicopter's last few seconds of flight. One was directly beneath the helicopter's sharp right turn onto the final leg and it is possible that the noise had not yet started, another was outdoors but some 2,000 metres from the closest point on the helicopter's flight path and the fourth was sitting inside his car at least 1,000 metres away.

Of the 14 who stated that the helicopter sounded abnormal, a cluster of witnesses beside the River Medway, in or near the villages of Cuxton and North Halling, reported that their attention was drawn to the helicopter by its unusual sound. They saw nothing obviously wrong with it but they variously described it's sound as *"graunching like a car not properly in gear"*, *"off tune"*, "*misfiring*", "*really noisy as if the exhaust was blowing*", and "*running rough*". More witnesses in the residential area just north of the airport reported that it sounded strange. One, a piano tuner who was used to hearing the helicopter, said the engine's pitch was lower than normal. Another witness said it was "*clattering*". A third witness who was very familiar with the helicopter and had seen and heard it earlier that afternoon on its way to the road traffic accident saw it coming towards her home. As it got nearer she became progressively more aware of an unusual sound which she described as "*spluttering*". The noise was sufficiently abnormal for her to consider that the helicopter was in some difficulty.

Eye witness evidence

There were no witnesses who were stationary and who saw the final minute or so of flight without interruption. Numerous witnesses on the motorway saw the helicopter. There were so many witnesses that a range of opinions formed as to the height, speed, route and manoeuvres flown during the machine's last few minutes of flight. The disparity between some reports was so significant that no single eye witness report was considered to be the most probable view of events. However, several themes were common amongst the many statements. Firstly, the helicopter had flown in level flight at low altitude on a path which, initially, was either parallel to the motorway or gently closing with it. Secondly, at a location close to the north-west corner of the airport, the helicopter either crossed over the motorway or very nearly did so whilst flying at low airspeed. Thirdly, the helicopter then executed a very steeply banked turn, probably through about 90° to the right but possibly through some 270° to the left, which took it on a south-westerly track towards the crash position. Fourthly, the helicopter descended steeply into the valley beside the motorway before flying up the valley at low height. Finally, the helicopter pitched up sharply into a near vertical climb before yawing or pitching into a steep dive from which it did not recover. The helicopter burst into flames on impact with the ground.

Rescue

Eye witnesses rapidly alerted the emergency services to the accident. The crash site was some distance from any accessible road and some witnesses attempted to reach the accident site from the M2 but found it impossible to penetrate thick vegetation in their path. A Metropolitan Police Air Support Unit (ASU) helicopter arrived at the site approximately 20 minutes after the accident but determined that there were no survivors. Pathological evidence showed that G-MASK'S occupants had been killed on impact.

Aircraft

The AS355 is of conventional layout (Figure 2) with a three-bladed main rotor rotating clockwise as viewed from above. Directional control is by means of a two-bladed tail rotor. The helicopter structure has an aluminium core mounted on steel alloy landing gear cross tubes and fitted with extensive composite skin panels and plastic transparencies, an aluminium tailboom and aluminium/composite doors. G-MASK was not fitted with any form of wire-strike protection system and neither was there any requirement for such equipment to be fitted.

Main and tail rotor blades are of composite construction with metal leading edge covering strips. Two turboshaft engines are mounted on the roof, driving the main rotor gearbox via a combiner gearbox. A power offtake from the combiner gearbox drives a tail rotor gearbox shaft system that also directly drives two plastic bay cooling fans located in the aft end of the engine bay area. The cabin was configured with a pilot's seat at the front right, two stretchers on the left side and paramedic seats at the rear. It was estimated that G-MASK's weight at the time of the accident was approximately 2150 kg (maximum allowable weight for helipad operation 2200 kg).

Each engine is mounted to a yoke on the combiner gearbox via a liaison tube. The tube and yoke are connected by a flexible gimbal arrangement with four steel pivot pins. Each pin fits in a steel bush installed in an aluminium gimbal ring and is retained by two spring clips fitted through holes in the bush. The spring clips, similar to large safety pins, are of steel, plastic coated. Similar clips are used to retain main gearbox support strut attachments, but are uncoated. The drive shaft from each engine passes through the respective liaison tube and joins to a combiner gearbox input shaft via a flexible coupling located inside the gimbal ring.

A compressor bleed air flow from each engine is combined at a 3-way valve for ducting into the cabin. The valve is intended to act as a double non-return valve to prevent bleed air from a live engine from being vented into the compressor of a non-operating engine and thereby reducing the power available during single-engine operation. A number of failures of the 3-way valve had occurred on AS355 helicopters.

Each engine is fitted with a magnetic chip detector (MCD) system intended to provide a warning to the pilot of excessive bearing wear or impending break-up. A substantial chip of ferrous material in the engine oil can be attracted to a permanent magnet probe immersed in the oil system and, by bridging an insulated gap between two parts of the probe, complete an electrical circuit. This illuminates an 'ENG CHIP' warning caption on a central warning panel in the cockpit. Nuisance warnings can be caused by an accumulation of very fine normal wear particles, or 'fuzz', on the probe that does not signify a hazardous condition. A 'fuzz busting' facility is therefore provided whereby on receipt of a warning the pilot can momentarily apply a voltage to the probe to disrupt an accumulation of fine particles and eliminate the warning; significant chips will not be affected and will continue to trigger the warning, requiring a landing 'as soon as practical'. Unlimited fuzz busting was not permitted and further maintenance investigation was required if an engine produced 3 MCD warnings in 50 operating hours.

The tail rotor gearbox comprises 90° bevel gears in an aluminium casing, with the tail rotor mounted on the output shaft. The tail rotor blades are carried on a yoke, with a tapered bore, that is clamped onto a taper on the end of the gearbox output shaft by a bolt screwed into the end of the shaft. The bolt is locked by a tab washer. The rotational orientation of the yoke in relation to the shaft is fixed at installation by a steel woodruff key fitted into slots in the yoke and shaft. It is intended that drive torque to the rotor is transmitted by friction forces between the mating surfaces of the shaft and yoke. Nominal 100% tail rotor speed is 2,088 RPM.

Take-off site

The area of the field from which G-MASK made its last take off had a relatively smooth surface that sloped down slightly in the landing direction and was covered with rough grass. Various piles of building rubbish were found near the edges of the field, a short distance from G-MASK's reported ground position, but reports from eyewitnesses indicated that this had not been disturbed by the take off. No ground marks or debris suggestive of any abnormality were found.

The two boys who had come forward and reported seeing sparks or flashes of light were interviewed in detail at the site. Their accounts were coherent and established that, from a position approximately 50 metres from G-MASK, they had seen two short series of momentary white flashes in the main rotor head mast area over a period of around 7 seconds as the rotors ran up prior to take off. The flashes stopped shortly before lift-off.

Crash site

G-MASK crashed in a long narrow valley running up the north-east facing slope of the North Downs (Figure 3.1). The valley was oriented north-east to south-west and extended from the west side of the M2 motorway, at a height of 160 feet amsl, to near the top of Blue Bell Hill, at 450 feet amsl. The slope of the valley axis was 2.4° to the horizontal in the accident area and fairly constant along its length. The hillside in the vicinity of the valley was generally densely wooded but the central part of the valley floor was clear of trees, generally over a width of 100 to 120 metres. The surface of the cleared floor area in the lower portion of the valley was somewhat rough with long oilseed rape stubble and in the upper portion was relatively smooth with a cover of short grass. The surface in the ground impact area was of moderate density, dry and fairly firm earth.

An electricity transmission line running approximately east to west (084-264°T) crossed the valley. The line consisted of a three cable, 33 kV, 3-phase system, powered at the time of the accident with 11 kV. It was suspended over the stubble-surfaced part of the valley at an angle of 65° to the valley axis, just to the north-east of the stubble/grassland dividing line. The cables were in a triangular formation, with the centre cable 13 feet above the outside ones. The cables were generally carried on crossbars mounted on single wooden poles, approximately 40 feet high and 85 metres apart. However, the cables crossed the valley in a long single span and this was supported by a more substantial structure on either side, referred to here as H-Towers, consisting of two pairs of double poles approximately 50 feet high joined by crossbars. The H-Towers were situated 320 metres apart.

All of the transmission line supports in the vicinity of the valley were located in the woods on either side of the cleared floor area. This included both H-Towers, which were of a similar height to the adjacent trees. The single poles were somewhat shorter than the trees. The transmission line continued through the woods on the east of the valley for around 500 metres before exiting onto open ground. To the west the wood was narrower and after a run of 230 metres the line exited and ran along the edge of a stubble field, close to a long narrow hedge-like extension of the wood to the south. In their runs through the woods the transmission lines were accommodated in an approximately 10 metres wide clearway, in which large trees had been removed. Substantial re-growth had occurred since the clearway had been cut and the edges of the clearway were not sharply defined and substantial bushes and other vegetation grew on its floor.

Each of the transmission line cables was 0.7 inch in diameter, and consisted of 7 steel core wires of 0.1 inches diameter wrapped with exterior aluminium wires, which had oxidised to a matt grey finish. The height of the cables above the valley floor varied somewhat across the valley but the concave cross section of the floor roughly matched the cable catenary and the top cable had been approximately 90 to 95 feet above the floor over most of the valley's width.

The conspicuity of the transmission lines from the air was assessed by AAIB by flying a helicopter over the valley a few days after the accident in weather conditions similar to those prevailing at the time of the accident and at a similar time of day. There were a number of transmission lines in the local area, generally running across fields and highly conspicuous. When flying up the valley towards the accident cables, at low speed and somewhat above the level of the cables, both the pilot and the observer found that no features of the transmission lines were visible from any appreciable distance, even knowing their location. The line feature formed by the clearway was not apparent until virtually in line with it; the cables and poles in the woods were hidden by the trees; the small portions of the tops of the H-Towers that were not hidden tended to merge into the trees; and the cables spanning the valley were invisible at any significant range against their background of the rising ground of the valley. Additionally, the part of the line in the field to the west of the woods was quite inconspicuous against its background of the hedge of trees, with only the bottom of the poles showing (Figure 3.2).

The severed cable was replaced some weeks after the accident and conical spiral markers were added to the cables across the valley to increase their conspicuity. The transmission line owner noted that no standards exist to define where cable conspicuity markers should be used and that it commonly encountered considerable opposition on environmental grounds to proposals for markers.

Cable strike

Examination of the accident site and the wreckage clearly showed that G-MASK had struck the upper cable of the transmission line at a position close to the centre of the valley (Figure 4) where the cable had been approximately 92 feet agl, 350 feet amsl. There was no evidence of aircraft contact with the lower cables; the possibility that contact had occurred without having caused apparent cable damage could not be dismissed. The fault logging system (see below) indicated that the first circuit breaker trip had been at 16:37:29 and that the cable had been carrying 79 amp at the time. The cable had been severed, with heavy deformation of the aluminium strands adjacent to the severance point. A few small aircraft fragments were found trapped between the strands but they had no identifying features enabling their origin to be established. Scattered wreckage was found in a trail starting beneath the line and spreading out up the valley. It consisted of small pieces of the aircraft, predominately fragments of broken transparency but including a number of items from the cabin interior, together with the cabin left rear door and the baggage compartment door located immediately behind it and the window from the cabin right forward door.

Markings on the upper part of the cabin left rear door showed that it had made heavy rubbing contact with the cable. The left baggage bay door was lightly marked. The damage markings were consistent with the doors having been attached and the aircraft generally level in pitch at the point where they had contacted the intact cable, and with the cable having been angled from the front right to the rear left of the helicopter at the time. The positions of the two doors showed that they had detached shortly after the cable strike. The original location in the aircraft of the other wreckage items in the trail suggested that the cable had penetrated into the upper and mid parts of the cabin.

Localised areas of damage were evident on the leading edge of each main rotor blade near the tip, generally similar on each blade. The damage consisted of small dents, in places accompanied by light blackening of the adjacent surface, and was consistent with sequential impact by the rotating blades with a powered cable. It was possible that the cable had already been damaged at the time, as it was considered likely that a strike on a completely intact part of the cable would probably have caused more severe blade damage. No signs of contact of other parts of the aircraft with the cable were found, but it was likely that much evidence was destroyed by fire damage (see below).

The transmission line owners provided the information that a fault detected on the lines should cause automatic isolation of the system by the opening of a circuit breaker after 0.3 seconds. The circuit breaker should automatically re-close after 5 seconds and again trip 0.3 seconds later if the fault is still detected. The events were automatically logged, with timings referenced to an accurately calibrated radio clock with a resolution of 0.01 second. The damage from G-MASK's cable collision caused the system to trip in this manner, initially at 16:37:29. An unsuccessful manual re-closure of the breaker was later attempted at 17:34.

Ground impact

Ground marks and wreckage distribution showed that G-MASK had impacted the ground 88 metres beyond the cable strike point. It had struck towards the eastern margin of the valley floor immediately beyond the stubble/grassland boundary. The evidence indicated that it had contacted the ground while pitched approximately 90° nose down, with moderate vertical speed and low horizontal speed. The forward end of both landing gear skids buried themselves in the ground and broke off and one main rotor blade sustained a heavy ground strike normal to the ground surface, ie while rotating in an approximately vertical plane. The blade penetrated the ground to a maximum depth of 0.3 metres. The helicopter came to rest upright, heading approximately south-west up the valley.

G-MASK was then severely damaged by fire (see below) but many parts of the burnt wreckage were found generally in their normal orientation. The evidence indicated that gross ground impact damage had been concentrated towards the front and, while the cabin had been severely disrupted, the remainder of the aircraft had probably been appreciably damaged but not extensively broken-up by either the cable strike or the ground impact.

Cable strike parameters

The cable collision position was at Ordnance Survey reference TQ 733644, ground elevation 260 feet amsl. The collision point was 0.57 nm south-west of the displaced threshold of Rochester's Runway 16, elevation 383 feet amsl. The evidence from the crash site showed that G-MASK had been tracking up the centre of the valley with a maximum skid height of 85 to 90 feet agl when it hit the cable. Other parameters could not be accurately quantified from the wreckage evidence because of the gross fire destruction suffered by most of the wreckage and the double impact nature of the accident. The available evidence suggested that the helicopter had been approximately level in pitch and had probably not been climbing or descending steeply; roll and yaw attitudes could not be determined. The groundspeed was judged to have probably been in the range 60 to 90 kt, based on available site and wreckage features.

Ground fire

Witness evidence showed that G-MASK caught fire almost immediately it struck the ground and continued to burn. Much of the wreckage was found to have been subjected to intense ground fire and reduced to ash or re-solidified molten metal. No unburnt fuel or oil was found at the site and all the aircraft's flammable fluid contents had clearly burnt and contributed to the fire, which had possibly been intensified by the burning of magnesium alloy parts of the helicopter and by the release of medical oxygen bottle contents. The evidence indicated that there had been a substantial quantity of fuel on board. It was estimated that approximately 80% of the aircraft was destroyed or so severely fire damaged as to retain little useful information for the investigation. The parts that survived without gross disruption consisted of those that remained outside the fire area (the items in the scattered wreckage trail and outer portions of the main rotor blades); a few instruments that were shielded by other wreckage; and steel and titanium components (engines, engine bay firewalls, transmission gears and landing gear crosstubes). In addition, the fire was less intense around the rear part of the tailboom, with the vertical fins, the tail rotor, the tail rotor gearbox and much of the tail rotor drive shafting surviving with only moderate fire damage.

Detailed wreckage examination

After examination on site, the wreckage was taken to the AAIB at Farnborough for more detailed examination. Attempts were made to establish the pre-impact airworthiness of the helicopter and to identify any anomalies that could have been responsible for an unusual noise in flight. The aircraft manufacturer and its UK agent were consulted and provided assistance. The examination was protracted, because of the severe fire damage to the wreckage, and firm conclusions about many aspects were not possible.

No evidence was found to indicate detachment of parts of the helicopter before it had struck the cable. It was not possible to establish from the wreckage that cabin, baggage bay and equipment bay doors had remained fastened shut prior to the accident but witnesses indicated that this had been the case.

The tail rotor control system aft of the tailboom mid point survived and was found with all connectors intact. With this exception, almost all components of the flight control system were destroyed in the ground fire and no conclusions as to the pre-accident serviceability of the system could be drawn.

Most cockpit instruments were also consumed, but some survived in relatively good condition and were examined in detail. The GPS (Global Positioning System) unit was undamaged, but was found to have a software standard that did not record position history, and in any event the unit was found to have been last selected off during a previous flight. The central warning panel (CWP) escaped gross damage, and bulb filament examination indicated that 26 of the 29 captions were Off at the time of major shock loading of the bulbs, which was considered likely to have been at the ground impact point. Of the remaining captions, 2 were probably Off, and for the other one the evidence was inconclusive. Examination of system selector push-button captions indicated that most were Off and the state of the remainder was indeterminate. The significance of the evidence could not be established as it was not possible to determine if the CWP or the system caption indicators had remained energised at ground impact, or whether cable strike damage had caused aircraft electrical power to be partially or completely lost.

Some indications were found from torquemeter and T_4 indicator markings suggesting that both engines were delivering around 58% torque, with T_4 in the range 370 to 390C at the time of major shock loading. Markings found on the face and mechanism of the triple tachometer strongly suggested rotational speed indications of 390 to 400 RPM for the rotor and both engines at the time the gauge was disrupted. The indicator has green arcs over the range 375 to 395 RPM for rotor speed and 375 to 405 RPM for engine speed.

The engines were strip examined with the assistance of the engine manufacturer and their UK agent. Both had suffered severe generalised overtemperature damage, consistent with the effects of the ground fire, to the point where steel components had been partially destroyed. Engine control system components had been almost completely destroyed. With this exception, the main rotating assemblies and casings were intact and almost completely undeformed and it was clear that no pre-impact failure of the major components of either engine had occurred. The lack of casing deformation, together with a complete absence of signs of abnormal contact between rotating and static components, showed that the accident impacts had not subjected either engine to large external contact loads or gross inertial shock loading. Small amounts of debris had been ingested into both engines, but again with little damage to rotating components. Overall, the evidence indicated that no pre-accident failure of either engine causing major engine damage had occurred but it was not possible to establish that the engines had been operating normally. Both engines had been rotating at the point of ground impact, but at an indeterminate power level. The steel bleed air system 3-way valve was identified; it remained intact and operable.

The depth of penetration into the ground of the main rotor blade at the helicopter's ground impact suggested that the main rotor speed had been substantial at this point. All gears and bearings of the main rotor and combiner gearboxes were identified, with no signs of pre-accident anomaly apparent. No remains of either gearbox casing or the bay cooling fans were found.

Two spring clips similar to those used to retain the pivot pins for the engine mounting gimbal rings were found separated, but intact and still fastened. The clips could not be positively identified as having originated from the gimbals as fire damage had rendered them indistinguishable from the largely similar pins used to retain the main gearbox support strut fasteners. As the clips, the gimbal pivot pins and the bushes through which the clips fastened were all steel and therefore were unlikely to have been destroyed by the fire, the separation of the still-fastened clips appeared possibly anomalous. Previous accidents had resulted from the detachment or omission of pivot pin clips. A portion of one liaison tube and the remains of seven of the eight pivot pin/bush assemblies for the two gimbal rings installed on the helicopter were located after further extensive searching of the wreckage debris, including much of the considerable quantity of resolidified metal ingots. Two of the pivot pins were found bent, consistent with the effects of overload due to engine and transmission inertial loads at initial ground impact. The pin bending was particularly severe in the case of one of the assemblies, and had resulted in fracture of the associated bush through the holes in the bush for the spring clips. The clips had separated from the assembly. It was concluded that release of the two isolated spring clips found still fastened had probably resulted from fracture of the associated pivot pin bushes due to ground impact forces.

A number of other similar spring clips were found unfastened or partly destroyed and separated. Their condition was generally suggestive that ground impact and/or fire damage had caused the separation, but there was no positive evidence for this. However, neither engine drive shaft flexible coupling had suffered the severe break-up that would have been expected in the event of pre-accident gimbal disconnection.

Approximately 75% of the tail rotor drive shafting was identified and the tail rotor gearbox remained installed on the tailboom with the tail rotor attached. It was noticeable that there was a complete absence of impact damage to the tail rotor blades. Additionally, it was found that the bolt attaching the tail rotor yoke to the gearbox output shaft was approximately one turn loose and that the woodruff key locating the yoke on the shaft had sheared. These features initially appeared inconsistent both with the likely effects of the ground impact and with an apparent lack of torsional damage to the input shafting to the gearbox. However, detailed examination showed that the key failure had been in the sense of the tail rotor overrunning the output shaft in its normal rotation direction, that the yoke had made only approximately one revolution on the shaft and that relative rotation in this direction would unscrew the yoke attachment bolt. Intact sealant showed that the bolt had not turned relative to the yoke. In particular, there were no signs of fretting or prolonged rotational rubbing contact between the yoke and the shaft, and it was concluded that failure had resulted from torsional overload when the main rotor blade struck the ground. The strike would have induced very rapid rotational deceleration of the whole drivetrain and high inertial torsional loads as a result; these could possibly have been augmented by the dynamic response of the drivetrain. The conclusion was reinforced by information from the helicopter manufacturer on a previous AS355 accident where the tail rotor yoke/shaft interface had been similarly affected by a main rotor blade strike on a tree.

Strip examination found the tail rotor gearbox to be in good condition. A debris seal fitted to the output shaft had been fitted incorrectly but no adverse effects had resulted and the feature was irrelevant to the accident. Fine metal shavings found internally showed that an output shaft oil slinger had momentary contacted the gearbox casing while the shaft had been rotating at a substantial speed, consistent with the effects of component minor distortion and/or relative displacement as a result of ground impact forces. Both this feature and the effects evident at the yoke/shaft interface indicated that the tail rotor had been rotating at substantial speed at ground impact.

The examination found no evidence to suggest that a pre-accident mechanical anomaly of possible relevance to the accident had been present, but the possibility could not be dismissed in view of the absence of evidence in a number of areas caused by the high level of destruction of the wreckage.

Maintenance

Records indicated that G-MASK (Serial No 5326) had been maintained by the operator's maintenance department in accordance with the CAA Light Aircraft Maintenance Schedule (CAA/LAMS/H/1978 Issue 2). Examination of the records for the two year period before the accident showed that a number of defects had been reported in this time, but the manufacturer and the operator considered that the frequency and type of problem had been in no way abnormal. They had included 3 cases of engine MCD caption illumination, at the following points:

DATE	AIRCRAFT OPERATION SINCE NEW		EVENT
	TSN	CSN	
14-8-97	3126	6011	Engine 1 Chip Light ON
29-11-97	3214	6476	Engine 1 Chip Light ON
11-6-98	3321	7071	Engine 2 Chip Light ON

TSN - Operating time since new - hours

CSN - Flight cycles since new - cycles

These had reportedly been investigated by inspecting the MCD and oil filter and checking for further indications during ground running and did not represent an abnormal situation. Two months before the accident work was carried out to improve the power output from both engines; both passed a power assurance check, but with the No 1 on the check limit. Rectification action for all the reported problems had been taken and on the day prior to the accident there were no recorded outstanding deficiencies. Aircraft records of the flying on the day of the accident were believed to have been destroyed in the accident ground fire. With estimated allowances for the last day's flying, the helicopter and engines had accumulated the following approximate operating times and flight cycles since new:

DATE	AIRCRAFT		ENGINE 1		ENGINE 2		EVENT
	TSN	CSN	TSN	CSN	TSN	CSN	
9-5-98	3289	6903					Major Inspection Segments
20-6-98	3335	7105	3197	6787	3223	6825	Last 50 Hour Inspection
26-7-98	3377	7340	3239	7022	3265	7060	Accident

Crashworthiness

G-MASK caught fire almost immediately it struck the ground, and burnt fiercely. AAIB experience of a number of investigations to AS355 and AS350 accidents in recent years suggested that in these cases the occurrence of post-crash ground fire had been considerably more common for the AS355 than the AS350. It was however noted that the impact severity was not the same in all cases and the experience was not sufficient to allow positive conclusions. The AS350 is a single-engined version of the Squirrel, generally similar to the AS355 apart from the powerplant, but with a different fuel system. On both models the fuel is carried in tank(s) located in the centre of the fuselage behind the cabin rear seats. The single tank fitted in the AS350 is plastic (polyamide) and non-structural; the previous experience indicated that it tends to tolerate significant inertial loads and structural disruption associated with ground impact without rupture. The two tanks used on the AS355 are aluminium and form an integral part of the fuselage structure. It was also noted that the main aircraft batteries (either one or two, depending on the option standard of the aircraft) are mounted in the right equipment bay, almost in contact with the outboard wall of the AS355 right fuel tank. G-MASK was fitted with two batteries.

The previous experience suggested that the integral nature of the AS355 fuel tanks may have made them more susceptible to leakage as a result of accident impact forces. It was also possible that disruption in the area of the heavy aircraft batteries mounted close to the tank may have generated heating and sparking that acted as an ignition source. Positive conclusions could not be reached as it had not been possible either to establish the details of the post-crash fire mechanisms in the previous cases or to establish an equivalence with regard to the crash conditions that had been experienced. However, the possibility that the fuel tankage, battery position and possibly other features tended to lead to a higher probability of post-crash fire for the AS355 could not be dismissed. The manufacturer conducted a study of 27 accidents in which severe impact had occurred, 19 for the AS355 and 8 for the AS350 and concluded that the incidence of post crash fire was not appreciably different for the AS355 (74%) and the AS350 (63%).

An AS355 modification is available by which the batteries can be relocated to the forward part of the tailboom to permit the elimination of tail ballast weights that are commonly required to achieve an allowable centre of gravity for the helicopter.

Analysis

The accident was caused by the helicopter striking the power cable suspended across the valley. Because the supporting pylons on each side of the valley were hidden by trees and because the cables blended into the background of the gently rising field beyond them, the commander was most unlikely to have been able to see the cables in time to avoid them. The impact of the cable strike rendered the machine uncontrollable and the impact with the ground was not survivable. Many witnesses saw this event and described the helicopter as pitching sharply up into a near vertical climb before yawing or pitching into a steep dive from which it did not recover. None of the witnesses saw the power cables involved. The focus of the investigation was aimed at explaining why the helicopter flew up the valley at low altitude after abruptly breaking off what appeared to be a normal approach to land at Rochester Airport.

Six possible reasons were considered:

a. sighting something unusual in the field,

b. pre-emptive task,

c. deliberate low-flying,

d. loss of power to the rotor system,

e. malfunction of the flying controls,

f. other technical malfunction.

Sighting of something unusual

There was no evidence which pointed to the presence of any person in the fields or woods near the crash site and nobody reported seeing any unusual occurrence in the local area such as a riderless horse, a driverless tractor in motion, a person prostrate in the fields or smoke from a fire, which might have prompted the crew to break off an approach and investigate.

Pre-emptive task

Checks of the airport, police and ambulance radio frequencies in the minutes preceding the crash determined that there were no radio messages likely to have alerted the crew to a medical emergency.

Deliberate low-flying

The pilot had experienced tactical low flying in the RAF but there were no reports that he had indulged in any comparable manoeuvres whilst flying the air ambulance. Indeed, a number of ambulance service colleagues stated that he was very safety conscious, that they had complete faith in him and that no-one had observed him taking unnecessary risks. In particular there were no reports of him low-flying except when necessary for take off or landing. Moreover, the crew were due to finish work at 1700 hrs (1800 hrs local time) and the helicopter had to be refuelled, checked and secured for the night in the remaining 20 minutes of duty time. Had the crew, for some reason, decided to enjoy some low flying, they could have done so whilst returning to base from Luddesdown rather than waiting until they had almost reached the airport boundary. Therefore, although deliberate tactical low flying could not be completely dismissed, this explanation seems illogical and most unlikely.

Loss of power to the rotor system

Afternoon engine problem

There was no positive evidence about the nature of the engine problem reported during the flight on the afternoon of the accident. However, the rapidity with which it was overcome points to an engine 'chip' warning that was eliminated by a fuzz busting operation. The operator's experience showed that such warnings occurred occasionally on the AS355 and could be dismissed as nuisance warnings that did not signify an impending engine problem, provided the frequency of occurrence was limited. Records indicated that G-MASK had experienced 3 such engine chip warnings in the year prior to the accident and this frequency was reportedly quite normal. It is most unlikely that the pilot, having reported the problem and taken the aircraft off the task, would have resumed the sortie and subsequently conducted further flights unless he was fully satisfied that the original indications had been spurious.

Manoeuvres on radar

There was only circumstantial evidence to explain the 8 minute 'three-legged' return route to the airport. The height above ground was sufficient to exclude tactical low flying for enjoyment and there were no signs of manoeuvres consistent with a 'flypast' beside a person or house. The groundspeed varied, with a marked acceleration to 120 kt at the end of the second leg. The flight pattern could be explained by the daily requirement for engine power assurance checks. During such checks, one engine is throttled back and power on the other is increased to the first encountered limit. The crew must then note parameters such as torque, main rotor RPM, outside air temperature, T4 (an engine temperature) and pressure height before repeating the procedure on the other engine. This activity requires the pilot to devote much of his attention to the engine instruments, possibly at the expense of holding a steady heading. This may explain the slightly erratic tracks on the first and second legs and the need to fly at 500 feet agl well away from fixed-wing traffic in the airport circuit pattern. The third leg back to the airport was much straighter and flown at ground speeds in excess of 100 kt which is consistent with returning to the airport for a transition along the 'out of use' Runway 16. The radar evidence does not suggest that there was anything untoward with the helicopter during this 8 minute period and it seems likely that engine power assurance checks were being completed.

Flight after loss of radar contact

The final sharp turn near the motorway and steep descent into the valley could have been a response by the pilot either to a sudden loss of power or to a loss of drive to the tail rotor, particularly if the helicopter was at a low airspeed where the power requirement would have been higher. Under this circumstance he would have wanted to regain airspeed by turning and descending steeply into the valley and away from the motorway. The helicopter was visible to all four eye witnesses in Rochester when it started its sharp turn beside the motorway which means that it was slightly higher than the airport at the start of the turn. To have flown over half a mile from this position to the point where it subsequently collided with the power cable (at essentially the same height) and with considerable groundspeed would not have been possible with a total loss of power. Furthermore, the heavy main rotor ground strike was consistent with substantial main rotor rpm. The evidence also indicated that the tail rotor had been rotating at substantial speed at the time of the cable strike, and that the failure of its connection to the gearbox shaft had occurred at ground impact as the result of loads induced by the main rotor blade ground strike. It was therefore concluded that there had been neither a total loss of power to the rotor system nor a loss of drive to the tail rotor.

The possibility of a single engine loss of power

Engine examination indicated that no pre-accident failure of either engine causing major engine damage had occurred and that both had been rotating, but did not positively establish that the engines had been operating normally. However, evidence from cockpit instruments provided some indications of engine conditions and rotor speed at the time of major shock loading. The evidence therefore suggested that both engines were operating at a low cruise power level and indicated that the RPM of both engines and main rotor were all normal at the time of the cable strike. It was therefore concluded that a single engine loss of power was unlikely.

Malfunction of the flying control system

The disparity between the accounts of those witnesses travelling along the M2 may have arisen because many witnesses had only a brief glimpse of the helicopter, and many of them had their perceptions of its motion distorted by their own motion along the motorway. The majority of witnesses reported that the helicopter made a sharp turn to the right when it was near the motorway, but a number reported that it turned to the left through about 270°, before diving down into the valley. The possibility was considered that this manoeuvre could have been caused by a malfunction of the flying control system.

Cyclic control

An unwanted input of lateral cyclic might have induced a sudden roll but, if this had been the case, it would appear that the problem was transient because the helicopter then appears to have continued in controlled flight until the impact with the power cable. Such a malfunction would therefore appear to be unlikely.

Tail rotor pitch control

A disconnection of the tail rotor pitch control mechanism would have made directional control difficult, particularly if it occurred at a time when airspeed was reducing and power was being increased. In such a case the helicopter could have yawed uncontrollably to the left. The reaction of the pilot would possibly have been to reduce power and gain airspeed by descending steeply into the valley. Previous accidents to this helicopter type have shown that directional control is possible with a reasonable airspeed and, having dived into the valley, the pilot might have wished to continue at a low height in order to maintain speed. The extensive fire damage after impact consumed much of the tail rotor pitch control system and it was not possible to eliminate the possibility of a malfunction.

Collective pitch control

With the reduction of airspeed to below minimum power speed as the helicopter approached the airfield the pilot would have had to apply power. Had he experienced a restriction which prevented him from increasing collective pitch at this point he may have been unable to continue the approach. As with the case of loss of power, a solution would have been to turn away from the motorway and regain airspeed by diving down into the valley. If continued flight had not been possible, the grass area towards the far end of the valley would have presented itself as an attractive emergency landing site. However, continued flight might have been possible even though, if the control restriction had remained, the helicopter might have been capable of no more than a slow rate of climb. Again the extensive fire damage after impact consumed much of the control system and it was not possible to eliminate the possibility of a restriction of the collective control.

Other technical malfunction

The witness reports of white flashes in the main rotor head mast area during run-up prior to take off were considered in detail. After considering the possible causes and observing similar helicopters running up on the ground it was concluded that the observations were probably of ambient light reflecting off parts of the rotating head, such as the pitch change links, and did not represent an abnormal condition.

The numerous reports of strange noises from the helicopter were suggestive of mechanical trouble. However, a damaged bay cooling fan or some other relatively minor problem could have generated an unusual and alarming noise without causing any control problem. Many components were consumed in the ground fire and unavailable for examination and there was nothing within the available evidence to link the reports of strange noises with any technical defect of significance.

Many technical problems require the pilot to land as soon as practicable and some as soon as possible. In either case, when the commander made the sharp turn over the motorway, he was within metres of the airport which was the most suitable area for an immediate landing and in the direction he was travelling; the fields beside the motorway were far less suitable for several reasons. He was heading towards a clear region of the airport and had there been a fire or a gearbox chip warning he could have continued the approach and landed on the grass within seconds. It was highly unlikely that the pilot's reaction to any unusual noise, however alarming, or to any postulated failure signified by the noise, would have been to break-off his approach to the airfield at such a late stage and at an apparently normal height and speed, and dive down into the valley.

The examination found no evidence to suggest pre-accident mechanical anomaly with the helicopter that could have been relevant to the accident or could have produced an abnormal noise. However, the possibility that a pre-accident problem had been present could not be dismissed in view of the absence of evidence in a number of areas resulting from the high level of fire damage to the wreckage.

Safety recommendations

Accident Recorder

Cockpit voice recorders (CVRs), which are required by law on many public transport aircraft are an invaluable tool for analysing aircraft accidents and thereby enabling regulatory bodies to formulate preventative measures. A recording can provide records of radio messages, crew conversations, and particularly for helicopters, aircraft mechanical noises. For instance, frequency analysis has aided the identification of components, such as helicopter gearbox components, as they progress towards ultimate failure. If a recording of cockpit ambient noise and crew conversations had been available in this accident it might have been possible to identify the source of the unusual noise reported by so many witnesses or to have explained the sudden turn near the motorway.

The JAA have recently amended JAR-OPS 3 to raise the weight discriminant for helicopters required to install CVRs from 2730 kg to 3120 kg. The CAA have stated that it would be inappropriate for the UK to introduce a national requirement for the wholesale introduction of such equipment unilaterally. However, specified operations conducted under JAR-OPS 3 will require the fitment of usage monitoring systems (UMS) with the intention of improving operational safety standards by providing operators with on-going and easily accessible system information. If the recording system were also to include audio (CVR) and other data, such as that derived from a Global Positioning System, significant additional benefits would accrue.

Whilst satisfying the prime intent, it might be possible to utilise UMS to supply useful post-accident data. In order to be of benefit, systems would need to protect a non-volatile recording medium against impact forces and fire. Whilst the cost, weight and space penalties of current CVRs and FDRs are prohibitive for light aircraft, recent developments in recording technology when combined with the lower operating speeds of helicopters should now permit the development of an inexpensive, light and small accident recorder with an acceptable level of impact and fire resistance, albeit not to the same level as currently mandated recorders.

Safety recommendation 2000-1

It is recommended that the CAA should:

a. Encourage the development of a suitable lightweight and low-cost Voice, Data and Combined recorder and the installation of such equipment by operators.

b. Consider whether such flight recorders should be introduced for operations such as dedicated police and HEMS operations involving as they do, the exposure of third parties to risk not present in normal Public Transport operations.

Post-Crash Fire

The evidence from this investigation and previous AAIB investigations of Squirrel accidents suggested that the incidence of AS355 post-crash ground fire may be relatively high, and appreciably greater than for the AS350, and the type of fuel tanks and the installed position of aircraft batteries were identified as possible factors.

Safety recommendation 2000-2

It was recommended that the CAA in conjunction with the DGAC assess the record of post-crash fire occurrence for the AS355 helicopter and consider the necessity for crashworthiness improvement measures.

Wire strike protection and warning

A wire strike protection system is an optional extra for the AS355, consisting of centre windscreen pillar reinforcement, windscreen wiper deflectors and an upper and lower scissor blade to cut the cable. The system weighs 21 lb and costs approximately £17,000 for installation at build and £22,000 for retrofit. Protection systems are not commonly fitted to UK helicopters; they are reportedly generally fitted to emergency service helicopters in the USA. It is uncertain whether the system would have protected G-MASK from catastrophic damage, given the size of the cable involved. Nevertheless, since 1985 there have been an average of 2 to 3 accidents/incidents per year where helicopters have hit wires in the UK resulting in major damage or destruction in approximately half of them. In a number of these the cable(s) broke and in many of the cases it is likely that a cable cutter would have been effective in preventing a crash.

Safety recommendation 2000-3

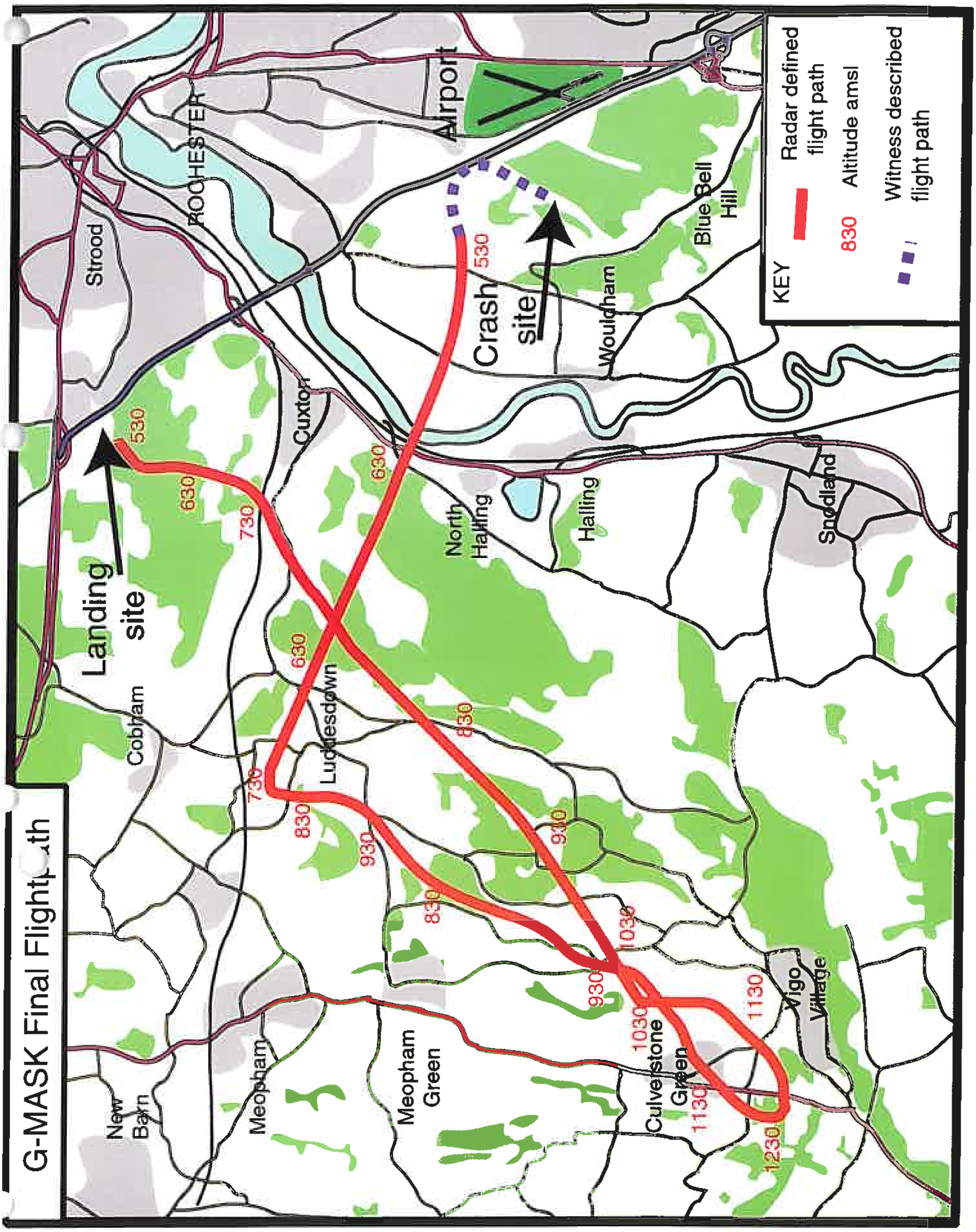
It is recommended that the CAA consider requiring cable strike protection systems for those UK registered helicopters at risk.

A number of cable proximity warning systems are either available or under development, including magnetic field sensing, enhanced ground proximity warning system (EGPWS) and laser and radar systems. A radar system under development is predicted to detect a 10 mm (0.39 inch) diameter cable at a range of 1.2 nm, reducing to 0.7 nm in heavy rain or snow. It seems likely that, with advances in technology, the cost of such equipment could reduce considerably.

Safety recommendation 2000-4

It is recommended that the CAA should monitor technical developments in cable proximity warning systems and, when suitable equipment becomes available, consider requiring such a system to be fitted to those UK registered helicopters at risk.

Figure 1



G-MASK Final Flightpath
KEY
Radar defined flight path
830 Altitude amsl
Witness described flight path
Landing site
Crash site
Airport
ROCHESTER
Strood
Cuxton
Wouldham
Blue Bell Hill
North Halling
Halling
Snodland
Cobham
Luddesdown
New Barn
Meopham
Meopham Green
Culverstone Green
Vigo Village
530
630
730
630
730
830
930
830
930
1030
1130
1230
1130
1030
930
830
630
530

G-MASK PRE-ACCIDENT

Figure 2.1

AS355 GENERAL ARRANGEMENT

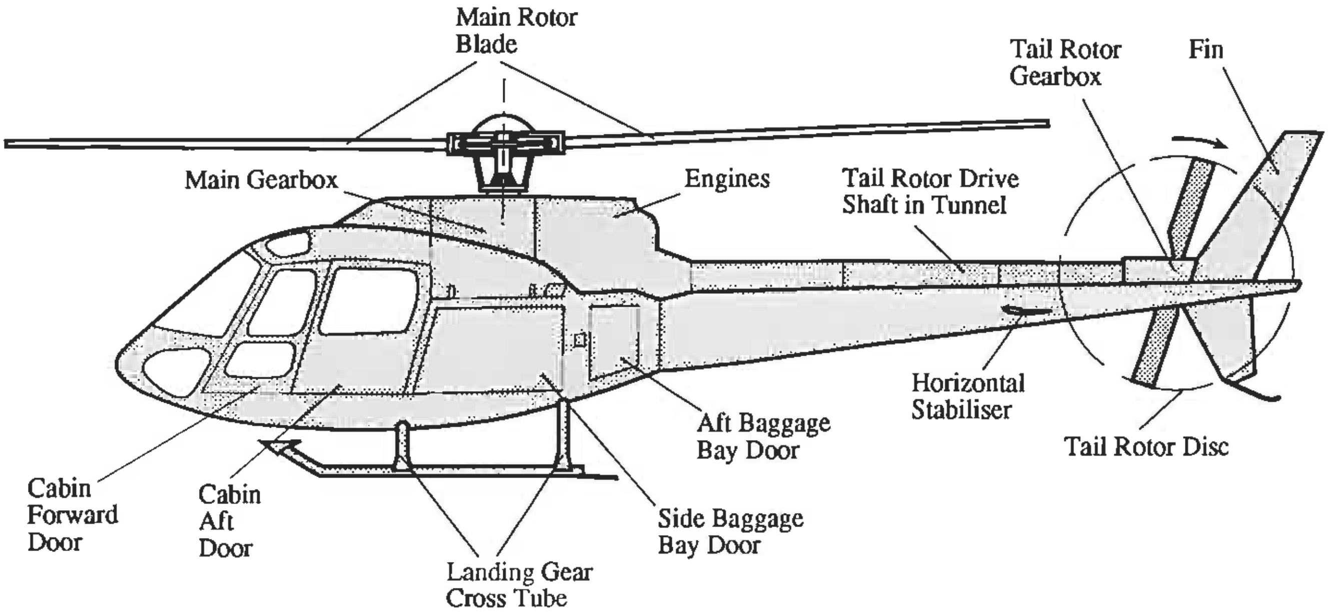


Figure 2.2

VIEW UP ACCIDENT VALLEY

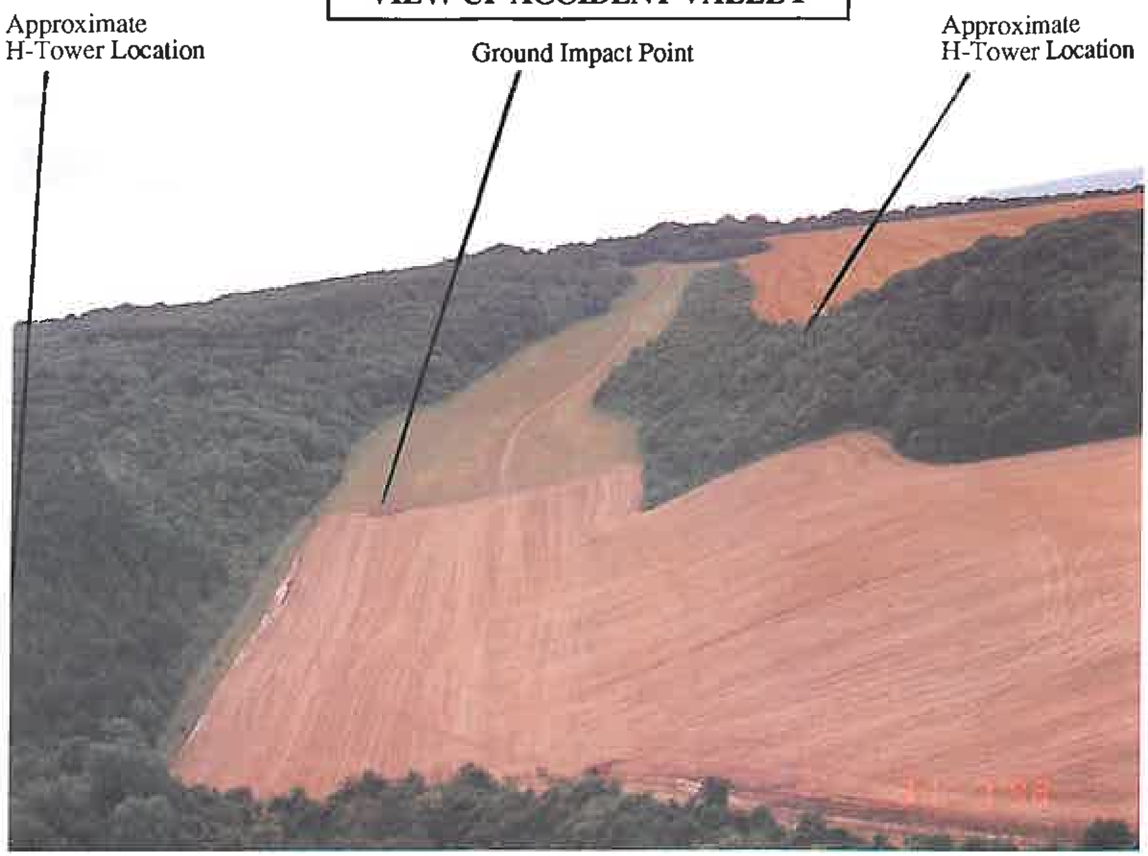
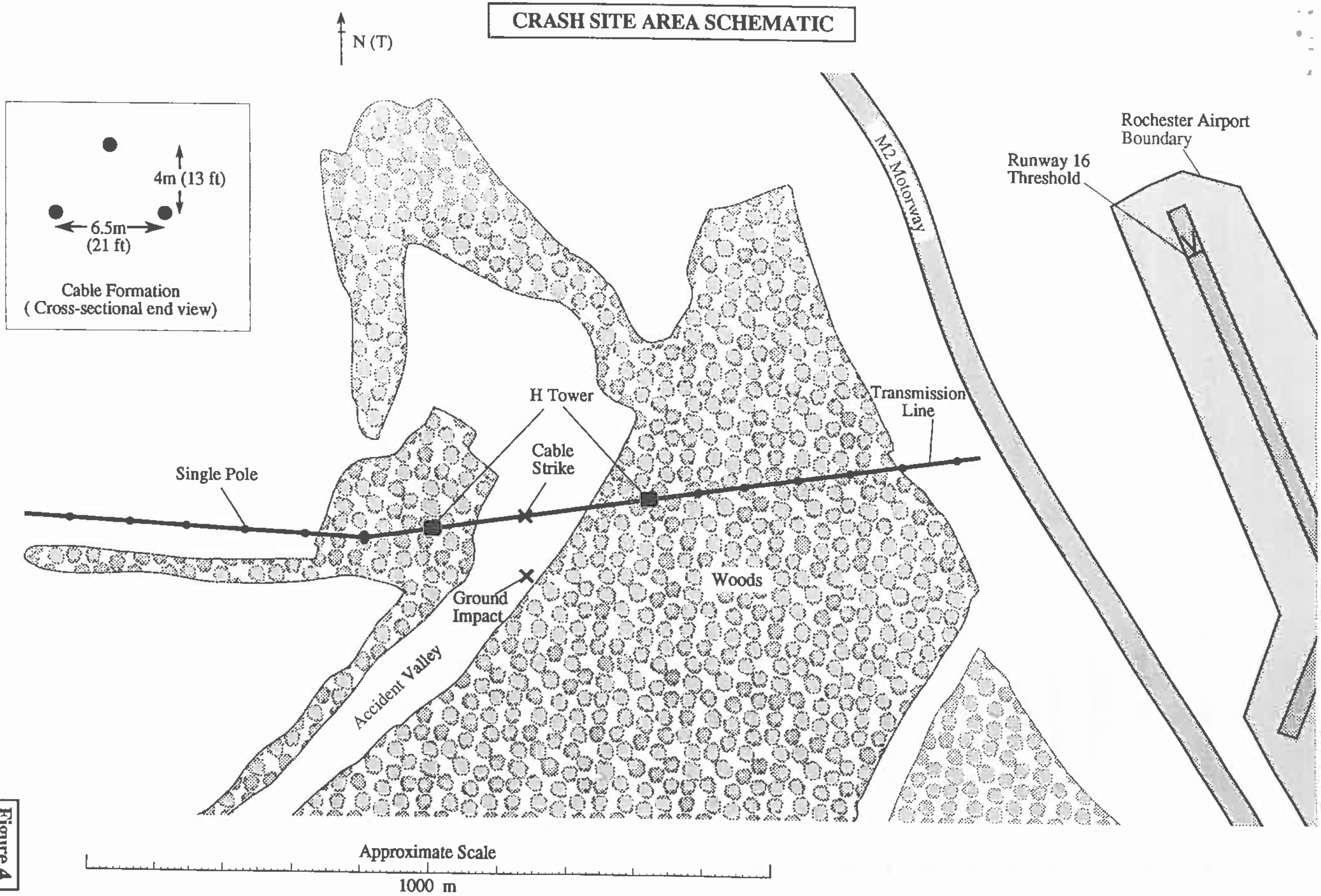


Figure 3.1

TRANSMISSION LINE WEST OF THE CRASH SITE

View of Transmission Line Continuation in the Area West of the Valley

Figure 3.2



CRASH SITE AREA SCHEMATIC
N (T)
4m (13 ft)
6.5m
(21 ft)
Cable Formation
(Cross-sectional end view)
M2 Motorway
Rochester Airport
Boundary
Runway 16
Threshold
Transmission
Line
H Tower
Cable
Strike
Single Pole
Ground
Impact
Woods
Accident Valley
Approximate Scale
1000 m

Figure 4