Air Accidents Investigation Branch

Department of Transport

Report on the accident to Twin Squirrel AS 355 F1 G-BKIH at Swalcliffe, nr Banbury, Oxfordshire on 8 April 1986

LONDON
HER MAJESTY'S STATIONERY OFFICE

List of Aircraft Accidents Reports issued by AIB in 1987/88

1/87	Bell 212 G–BJJR in the North Sea, 50 miles East of the Humber November 1984	April 1987
2/87	Lockhead TriStar G–BBAI at Leeds Bradford Airport May 1985	September 1987
3/87	Gulfstream Rockwell Turbo Commander EL–BGL at Jevington, Eastbourne November 1984	July 1987
4/87	Twin Otter G–BGPC at Laphroaig, Islay, Scotland June 1986	December 1987
5/87	Boeing Vertol (BV) 234 LR G–BISO in the East Shetland Basin of the North Sea May 1984	January 1988
6/87	Shorts SD3–60 EI–BEM 3.5 km from East Midlands Airport January 1986	January 1988
7/87	Twin Squirrel G–BKIH Swalcliff, Nr Banbury, Oxfordshire April 1986	
8/87	Boeing 747–136 G–AWNB London (Heathrow) Airport November 1986	
9/87	Bell 214 G–BKFN in the North Sea, 14 miles North East of Frazerburgh, Scotland May 1986	
1/88	DH 89A Dragon-Rapide G–AGTM at Duxford Airfield, Cambridge June 1987	

Department of Transport
Air Accidents Investigation Branch
Royal Aircraft Establishment
Farnborough
Hants GU14 6TD

16 December 1987

The Rt Honourable Paul Channon
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr R C McKinlay an Inspector of Accidents, on the circumstances of the accident to Twin Squirrel, AS 355 F1 G–BKIH at Swalcliffe, nr Banbury, Oxfordshire on 8 April 1986.

I have the honour to be
Sir
Your obedient Servant

D A COOPER
Chief Inspector of Accidents

Contents

First published *1988*

ISBN 011 550827 9

Air Accidents Investigation Branch

Aircraft Accident Report No. 7/87
(EW/C959)

Operator:		McAlpine Helicopters Limited
Registered Owner:		Fellowrate Limited
Aircraft:	*Type:*	Aerospatiale Ecureuil 2 (Twin Squirrel)
	Model:	AS 355 F1
	Nationality:	British
	Registration:	G–BKIH
Place of Accident:		Swalcliffe, Near Banbury, Oxfordshire
		Latitude: 52° 01.5′ North
		Longitude: 001° 27′ West
Date and Time:		8 April 1986 at 0905 hrs
		All times in this report are UTC

Synopsis

The accident was notified by McAlpine Helicopters Limited to the Air Accidents Investigation Branch (AAIB) at 0945 hrs on 8 April 1986 and an investigation began the same day.

The helicopter with one pilot and five passengers on board was flying in Instrument Meteorological Conditions (IMC) under a radar advisory service when the pilot transmitted a distress call because of engine failure. The helicopter descended through a layer of stratiform cloud and crashed with considerable vertical velocity into a field. The six occupants were killed at impact. A major part of the fuselage was consumed by an intense fire.

The accident was caused when the helicopter, whilst flying at 2500 feet in IMC, suffered a total loss of power and did not accomplish a normal autorotative descent and landing due to a significant decrease in rotor rpm. The most likely cause of the power loss was the ingestion of slush which had formed near the intake area of the engines. It was not possible to determine whether both engines failed simultaneously or in succession.

1. Factual Information

1.1 History of the flight

The purpose of the flight was to convey five passengers from a landing site near Pangbourne, Berkshire, to Alton Towers near Uttoxeter, Staffordshire. The aircraft was based at Hayes heliport and had recently been acquired by the registered owner. The pilot, who was a staff pilot of McAlpine Helicopters Limited, obtained information about the weather conditions for the flight from the company operations room. He was obliged to delay the time of take off until the weather in the London Heathrow Control Zone (CTR) improved sufficiently to permit a flight under Special Visual Flight Rules (SVFR) along the defined helicopter routes. The helicopter took off from Hayes shortly before 0820 hrs. It flew via helicopter route H2 to Marlow, at the boundary of the Heathrow CTR, and then landed at Purley Manor which is situated to the east of Pangbourne.

When the passengers had embarked, the helicopter took off again at about 0845 hrs and the pilot obtained clearance from the Air Traffic Control Unit at RAF Benson to climb to an altitude of 2400 feet. At 0852 hrs the pilot contacted the Oxford (Kidlington) aerodrome approach controller. His request to overfly the airfield at 2400 feet was approved and the pilot reported his position overhead the airfield at 0900 hrs. Five minutes earlier the pilot had contacted the Radar Advisory Service Zone (RASZ) controller at RAF Upper Heyford with a request to pass two miles west of Upper Heyford airfield at a height of "about two and a half thousand feet". The helicopter was identified on radar by the RASZ controller who assigned it a transponder code.

At 0903 hrs the pilot reported that he was turning left onto a heading of 270° (M) in response to advice from the RASZ controller that radar traffic was observed directly ahead of him at a range of 5 miles. When clear of the traffic, the helicopter resumed its northerly track towards the Coventry locator beacon. Its position was identified by RAF Upper Heyford as being three miles north west of Barford Saint John, a disused airfield. Seconds before 0905 hrs the pilot of G–BKIH transmitted a distress call to Upper Heyford saying that he had suffered engine failure.

When asked by the RASZ controller to repeat his call the pilot transmitted "MAYDAY, MAYDAY, ENGINE FAILURE ...." followed by some garbled phrases. There was no further communication with the helicopter.

Villagers in Swalcliffe (O.S. Sheet 151 G.R. 3838) heard the aircraft approaching from the south. Eyewitnesses saw it emerge from the base of low stratiform cloud when it was almost overhead the village. It appeared to be under control but descending quite rapidly. The predominant noise described by witnesses was a low frequency "swish" of the main rotor blades.

The helicopter crashed almost vertically into a cultivated field at the northern edge of Swalcliffe at a height of 480 feet amsl. It was banked slightly to the right. As soon as the main rotor struck the ground the helicopter was "pole vaulted" to its left, snapping off the tail boom which came to rest lying alongside the main fuselage. The six occupants were killed on impact. A fierce fire began almost immediately after the impact.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	1	5	–
Serious	–	–	–
Minor/None	–	–	

1.3 Damage to aircraft

The aircraft was destroyed at impact and partially consumed by fire.

1.4 Other damage

Part of a field of winter barley was destroyed by impact identations and subsequent contamination by aviation turbine fuel spillage.

1.5 Personnel information

1.5.1

Pilot:	Male, aged 38 years
Licence:	United Kingdom Airline Transport Pilot's Licence (Helicopter/Gyroplanes). Valid until 15 May 1989
Aircraft Rating (A) Part 1 Pilot in Command	Gazelle, MBB 105, AS 350B, AS 355F, AS 365N. The last Certificate of Test on the AS 355F was dated 5 December 1985
Instrument Rating (Helicopters):	Last renewal test on AS 355F was on 5 December 1985. Valid until 31 January 1987
Medical Certificates:	Last examination 30 May 1985. Valid for the exercise of the privileges of a Commercial Pilot's Licence until 30 May 1986
Flying experience:	Total: 3874 hours Total on type: 469 hours Total in previous 12 months: 356 hours Total in last 24 hours: 50 minutes
Rest period prior to accident flight:	More than 12 hours

1.6 Aircraft information

1.6.1 Leading particulars

Type:	Aerospatiale AS 355 F1 Twin Squirrel
Constructor's No:	5246
Date of Construction:	1982
Maximum permissible weight:	2400 kg
Weight at time of accident:	2303 kg (estimated)
Centre of gravity limits:	3.245 metres forward to 3.49 metres rearward (at 2300 kg) both aft of datum
Centre of gravity at time of accident:	3.30 metres aft of datum
Certificate of Airworthiness:	Transport Category (Passenger) Valid until 30 December 1988
Certificate of Maintenance Review:	Dated 30 December 1985
Certificate of Release to Service:	Certified at 50 hour check at 960.30 airframe hours on 28 February 1986.
Total airframe hours:	984.15 (to 6 April 1986)
Engines:	Two Allison Model 250 C20F turboshaft engines
Total engine hours:	986.15 (each engine)

1.6.2 Maintenance History

The Certificate of Airworthiness required the aircraft to be maintained to the Light Aircraft Maintenance Schedule CAA/LAMS/H/1978, as amended. The maintenance records showed that the aircraft had been maintained to this schedule and all applicable airworthiness directives had been implemented.

The maintenance records and technical log were examined for any event in the aircraft's history which might appear significant in light of the accident. Two such events were found:-

a. On 15 January 1986 the technical log recorded that No. 1 engine suffered power loss to 40% torque on several occasions. The fuel control unit was removed and sent to the engine manufacturer's regional agent for rectification. The defect was confirmed and was found to be due to contaminated air bleeds within the unit. One seal was also found to be split but this was not thought to be significant in terms of the power loss.

b. A technical log entry in August 1983 reported the pilot having difficulty in lowering the collective below the "one quarter up" position. The corresponding rectification worksheet reported high friction in the system due to imperfect routeing of the anticipator cable. The condition of this system in the wreckage of G–BKIH precluded any assessment of whether such a problem might have been present at the time of the accident. The anticipator cable system contains a spring strut so that, even if the cable suffers complete seizure, it is possible to move the collective lever to its minimum position.

1.6.3 *Air intake system*

Each engine is served by a separate pitot intake which is an integral part of each main gearbox compartment door. The one-piece windscreen and cabin roof present an exceptionally smooth approach to the intakes; the only discontinuity in the surface being the lip formed around the "eyebrow" windows in the cabin roof. The main gearbox housing projects forward between the intakes to form a ram intake for the oil cooler. The left and right lips of this intake are swept back at about 45° and are smooth and well radiused.

Each intake entry is protected by a 5 mm wire mesh. The mesh geometry is approximately that of a quarter conical surface attached to the vertical surface of the gearbox housing and the horizontal surface of the cabin roof. It covers the outside lip of the intake. Aft of each air intake entry is an S-duct with a discontinuity, in the form of a bellmouth, at the point where the moveable door-mounted section of the intake abuts the fixed engine intake. The engine intake is smaller in diameter than the airframe trunking and the bellmouth effects the reduction in diameter. The leading edge of the bellmouth presents an annular, flat surface perpendicular to the airflow.

The bellmouth, being an aircraft part, does not receive any active anti-icing from the engine's hot air system. Results from the icing tests carried out during certification suggest that some anti-icing effect does reach this area presumably by conduction through the attached metal components.

1.6.4 *Rotorcraft Flight Manual (RFM) limitations*

The Twin Squirrel helicopter was approved for "day and night operations in VMC and out of icing conditions". Supplement No. 4 to the flight manual sets out the limitations and conditions that permit flight under Instrument Flight Rules (IFR) but flight in icing conditions is prohibited.

When operating in temperatures lower than +5°C the engine air intake anti-icing system must be selected 'ON'. This system delivers hot air from the exit stage of the centrifugal compressor and introduces it via the inlet guide vanes to the compressor hub and thence to the air stream. There is no protection against the formation of ice on the intake guards, which are wire grills, or the ducting forward of the engine face. Other than the level positions and an increase in turbine exhaust temperature at the time of selection there is no indication provided of the engine anti-icing status.

For operation at temperatures lower than +4°C an anti-icing additive to the fuel is mandatory. Details of these and other relevant flight manual limitations are given in Appendix 1.

1.6.5 *Emergency procedures*

The emergency procedures to be adopted in the event of a single or double engine failure are given in Section 3 of the flight manual. Relevant extracts are shown in Appendix 2. When both engines fail simultaneously or in rapid succession the pilot must quickly establish the helicopter in autorotative flight. The time delay between moving the collective pitch lever from its position for cruising flight to that required for autorotation, ie minimum pitch, varies with the weight of the aircraft, air temperature, and the cruise power setting. Typically it is of the order of 3 seconds. Any delay greater than this can cause the rotor rpm (NR) to decrease to a value below which normal autorotation of the blades will not be possible. In the case of the Twin Squirrel this is thought by the manufacturer to be about 64% (250 rpm) of the nominal NR (394 rpm).

In the case of a single engine failure there will be typically a reduction of 34% of the original cruise torque after the other engine has automatically increased to full power. This means that a single engine will provide less power than is required to maintain the normal IAS in cruise flight. NR will fall, but not as rapidly as in the case of a double engine failure, and the pilot must restore NR to the normal operating band by making a small reduction in the collective pitch setting. In either case the low rotor rpm aural warning will sound when NR drops below 360 rpm. The aural warning horn will be cancelled either by an increase in NR above this value or by a further reduction in NR below 250 rpm.

Following failure of one or both engines the pilot should close the fuel control lever of the failed engine(s) as soon as he has regained control of the helicopter. This is a precautionary action to minimise the possible effects of an engine fire. If any attempt is made to restart the failed engine the lever should be moved to the Ground Idle position, which is an intermediate position between the closed and the flight governed position, once the starter/generator has produced an Ng of 15%. Where only one engine has failed it is clearly vital to identify correctly the fuel flow lever to be closed. Misidentification can result in the engine which is still functioning being closed down inadvertently.

1.6.6 *Cockpit indications of engine failure*

Following the loss of one engine the pilot will receive the following warnings and indications. At a cruise power setting and close to the maximum permitted operating weight of the helicopter, the rotor rpm will drop below 360 rpm and the aural warning horn will sound continuously until collective pitch is reduced and the NR is retored. The needle on the dual torque-meter that indicates the torque of the failed engine will read zero. The needle on the dual gas generator gauge which indicates the Ng of the failed engine will reduce towards zero.

The pointer at the edge of the triple tachometer which indicates the free turbine speed of the failed engine will fall towards zero. The needle on the dual turbine outlet temperature gauge which indicates the turbine outlet temperature (T4) of the failed engine will reduce slowly indicating a cooler temperature, provided there is no fire within the engine casing or exhaust duct. When the gas generator of the failed engine reduces in speed below 50% of its governed range the associated starter/generator will trip off line and the amber caption GEN LH or GEN RH will illuminate on the central warning panel. As the oil pressure of the failed engine drops the single red caption ENG OIL P will illuminate. This caption is triggered by a loss of oil pressure in either or both engines and confirmation must be sought by referring to the appropriate engine oil pressure gauge. As soon as the ENG OIL P caption lights the WARN lights on either side of the instrument panel will flash.

If both engines fail simultaneously, the sequence of warnings will be the same, except that on all the dual indication gauges both needles will reduce, the GEN LH and GEN RH captions will light, and both engine oil pressure gauges will reduce towards zero.

It is of interest to note that at least two other types of twin engined helicopters from the same manufacturer are fitted with Power Loss Indicators. This is a warning caption associated with each engine which automatically identifies a failed engine either by analysing the relationship between the gas generator (Ng), free turbine (Nf) and rotor rpm (NR) or by detecting a reduction in the gas generator speed (Ng) of either engine.

1.6.7 *Ice detector*

The helicopter was fitted with a serviceable Rosemount ice detector (Model 871 FA). Its purpose is to give prompt warning of ice accretion. In view of the location of the sensor on the forward fuselage below the co-pilot's chin window, the equipment is mainly of use in detecting airframe icing conditions. When ice begins to build up on the sensor probe a frequency shift is detected in the electronically induced vibration of the probe and a warning light located on the right side of the instrument panel is lit. A time delay circuit allows the probe to be heated in order to disperse any ice accretion. If ice reforms within 60 seconds the warning light remains lit. McAlpine Helicopters Ltd Supplement No. 9 to the Flight Manual clearly indicates that installation of the ice detector does not allow for flight in icing conditions.

1.7 Meteorological information

1.7.1 *The synoptic situation*

A large Scandinavian anticyclone had brought cold north easterly winds to the United Kingdom. A depression centred in the south west approaches was filling and moving westwards. An associated partially occluded front lay to the north east, with an ill defined warm sector located over southern England. At the time of the accident the warm front was almost stationary; it later moved southwards allowing the cold north easterly airflow to resume its passage over the whole country. The freezing level was forecast to be at 5000 feet near the warm front and in the warm sector. It was forecast to be at 1000–1500 feet in the area north of the front. The accident occurred in a slow moving warm frontal zone of transition between mild air over south east England and cold air (which was capable of producing snow) further north and west.

1.7.2 *Meteorological forecasts*

The pilot obtained information about the weather along his route in the operations room of Hayes heliport probably by telephone as the telex and fax facilities were not available until 0830 hrs. As it was early in the morning, some of the routine weather information was not available to him but he was able to study various aerodrome forecasts (TAF's) for airfields along and near to his route. He also obtained by telephone the Routine Met Aerodrome Reports (METARS) of these airfields. A handwritten note recovered from the pilot's operations folder included the following information "0°C; 4000–5000 feet; 2000–3000 feet". Those most pertinent to his route are detailed below.

Heathrow: (TAF)

0700 hrs to 1600 hrs

Surface wind:	050° at 15 gusting 25 knots
Visibility and weather:	3000 metres in rain
Cloud:	8 oktas stratus cloud at 600 feet

Temporary conditions between 0700 hrs and 0900 hrs: 1500 metres visibility with 8 oktas stratus cloud at 200 feet

Temporary conditions between 1000 hrs and 1600 hrs: 8000 metres visibility with 6 oktas stratocumulus cloud at 1400 feet

Manchester: (TAF)

0700 hrs to 1600 hrs

Surface wind:	040° at 18 gusting 35 knots
Visibility and weather:	greater than 10 km in rain 4 oktas stratus cloud at 1200 feet
Cloud:	7 oktas stratocumulus cloud at 1800 feet

Temporary conditions between 0700 hrs and 1600 hrs: 5000 metres visibility in rain and snow with 5 oktas stratus cloud at 800 feet

East Midlands: (TAF)

0700 hrs to 1600 hrs

Surface wind:	030° at 18 knots
Visibility and weather:	greater than 10 km in rain
Cloud:	6 oktas stratus cloud at 800 feet. 7 oktas stratocumulus cloud at 1500 feet

Intermittent conditions between 0700 hrs and 1100 hrs: 3000 metres visibility in drizzle with 6 oktas stratus cloud at 500 feet. There was a 20% possibility of temporary conditions between 0700 hrs and 0900 hrs of 1500 metres visibility and 8 oktas stratus cloud at 200 feet

(METAR)	Actual conditions at 0720 hrs	
	Surface wind:	050° at 15 gusting 25 knots
	Visibility:	6000 metres
	Cloud:	2 oktas stratus cloud at 600 feet. 8 oktas stratus cloud at 900 feet
	Temperature:	+2°C

1.7.3 *Actual conditions at Upper Heyford at 0906 hrs*

Surface wind:	050° at 11 knots gusting to 16 knots
Visibility and weather:	2300 metres in drizzle
Cloud:	1 okta stratus cloud at 300 feet, 3 oktas cloud at 400 feet, 8 oktas cloud at 500 feet The top of the lowest layer of cloud was reported to be at 5000 feet
Temperature:	+3°C
Dew Point:	+2°C
Barometer:	QNH 1020 mb

A significant weather information report (SIGMET) was issued by the Heathrow Meteorological Office at 0830 hrs and valid to 1200 hrs. It forecast severe icing below Flight Level 120 north of latitude 52° North with the area of risk moving slowly north west. The SIGMET was issued after G–BKIH had left Hayes and, unless the pilot had received it from one of the ATC agencies contacted en route he would not have been aware of it.

1.7.4 *Actual conditions at Swalcliffe*

The Meteorological Office, Bracknell, provided an assessment of the actual weather conditions that existed at the time of the accident. On the surface there was a 15 knot north easterly wind with continuous slight drizzle. There was a complete cover of low stratus cloud with the base at about 600 feet amsl. Some large patches of cloud at 400 feet produced hill fog on the high ground. The temperature, if reduced to sea level, would have been about +4°C.

A warm front aloft was positioned over Birmingham, moving north only slowly, perhaps becoming stationary. The advection of cold air from the north east at low levels meant that the surface position of the front was probably much further south, near to the south coast of England. At Swalcliffe the base of the warm air was at about 3300 feet with temperatures of about –2°C in the cold air just below. The lowest 0°C Isotherm was about 2000 feet giving a sub zero layer from 2000 to 3000 feet amsl.

The adiabatic liquid water content (LWC) at 2500 feet was calculated to be 0.8 grams per cubic metre, and the water mean droplet diameter (MDD) was probably around 10–15 microns. The depth of well mixed cloud based at 600 feet and a mean wind speed of 20 knots could have produced severe rime ice by itself. There was also the possibility that liquid or partially melted precipitation, probably light in intensity, was falling from the frontal zone above where temperatures between 3000 and 6000 feet were positive. Freezing drizzle, giving clear icing in the 2000–3000 feet zone, in addition to probable rime icing, would have increased the chance of severe icing. A schematic tephigram estimated for the Banbury area at the time of the accident is shown in Appendix 3. The temperature profile was interpolated from surface observations and distant radiosonde ascents, without knowledge of the Beaver crew's observations (see 1.7.5).

1.7.5 *Beaver pilot's weather report*

On the day of the accident a De Havilland Beaver (AL1) aircraft of the Army Air Corps was en route from Middle Wallop, Hampshire, to Aldergrove in Northern Ireland. When 22 miles north northwest of the Staverton NDB at 0851 hrs and at a height of 4500 feet, the crew observed a build up of cloud some 45 miles to the north of them. They decided to descend in order to remain in positive air temperatures. During the descent a small amount of ice accretion was observed until reaching a height of 2200 feet when the aircraft suddenly became enveloped in thick opaque ice of irregular shape. This occurred at 0855 hrs. The crew continued the descent and turned towards Brize Norton. The ice accretion remained unchanged for about 10 minutes after which it vanished in a matter of seconds. The crew observed the following outside air temperatures:

4500 feet:	0°C
3000 feet:	+1°C
2000 feet:	–3°C
1500 feet:	–1°C

1.8 Aids to navigation

The aircraft was fitted with sufficient radio and navigational aids to permit flight under IFR in controlled airspace. At the time of the accident the pilot was navigating by reference to the Coventry locator beacon which radiates on a frequency of 363.5 KHz and codes its identification of 'CT'. Further cross references were available from the twin VHF omni range receivers (VOR) that were fitted. A Bendix RDR–1400 Color Radar was fitted but its status at the time of the accident cannot be determined. If it was being used in the weather mode, moderate rainfall would have appeared as a green return on the black screen background. Rainfall greater than 12 mm/hr could have appeared as a red return.

The Minimum Safe Altitude (MSA) published for the Banbury area is 2400 feet.

1.9 Communications

1.9.1 Radio telephony

Shortly before the accident, the pilot made a radio call to the air traffic controller on duty at Oxford (Kidlington) airport on a frequency of 130.30 MHz. He reported his position as being overhead the airfield at 0900 hrs. He had also contacted the RASZ controller at RAF Upper Heyford on frequency 128.55 MHz. It was on this frequency that the distress call was transmitted just before 0905 hrs. Transcription of part of the tape recording of this frequency is shown below.

Time	To	From	Text
0903:30	Heyford Radar	Macline 04[1]	ROGER RESUMING TRACK FOR THE CHARLIE TANGO BEACON AND I AM INDIA MIKE CHARLIE
0904:50	Heyford Radar	Macline 04	MAYDAY MAYDAY MAYDAY MACLINE ZERO FOUR ENGINE FAILURE
0905:00	Macline 04	Heyford Radar	MACLINE ZERO FOUR SAY AGAIN
0905:30	Heyford Radar	Macline 04	MAYDAY MAYDAY ENGINE FAILURE *** ***

The words following the asterisks are garbled and difficult to decipher. By means of filtering the playback it has been possible to determine that the most likely phrase used by the pilot was "ROTORS FALLING – IT'S LOW". Thereafter the transmission became completely undecipherable, although the transmitter was keyed for a further brief time. A subsequent transmission was made by the Upper Heyford RASZ controller and this obscured any other transmissions on the frequency.

1.9.2 Transponder

G–BKIH was fitted with an ATC transponder that included the facility to transmit the encoded height measured on the aircraft's altimeter (Mode C). The 'squawk' code assigned by Upper Heyford ATC was observed on the radars of London Air Traffic Control Centre (LATCC). Since these observations are automatically recorded it was possible to determine the height of the aircraft just before the pilot transmitted his first distress call. At 0903:30 hrs the height of the aircraft was indicated at 2350 feet (+ or –50 feet and corrected for non-standard atmospheric pressure). At 0904 hrs, some 50 seconds before the time of the distress call, the corrected height was 2150 feet (+ or –50 feet). The radar return was lost at this point. The final track of the helicopter, plotted from the radar recordings, is shown at Appendix 4.

[1] The pilot was using the company radio telephony designator which was 'Macline'.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

G–BKIH was not equipped with a flight data recorder or a cockpit voice recorder (CVR). Under existing legislation they were not required to be fitted. Those CVRs that are fitted to helicopters in higher weight categories have the facility to record NR on the fourth channel of the recorder. Had such a device been fitted to G–BKIH it would have significantly assisted the investigation of this accident.

1.12 Wreckage and impact information

1.12.1 Examination on site

The helicopter crashed in open farmland 300 metres north of the village of Swalcliffe at a ground altitude of 147 metres (480 feet) amsl. It had descended vertically and was upright and virtually level, with no forward speed, when it hit the ground. Its heading at impact was 278°(M). The fuselage structure had been crushed in the first impact, but had then been catapulted out of the crater thus formed when the rotating main rotors struck the ground and it came to rest a few metres further south. A fire developed which consumed much of the cabin area and caused severe damage to both engines.

Although ground damage showed that the main rotor and tail rotor had been turning, this evidence, together with the damage to the components themselves, was consistent with only low rotational rates. Only one of the tail rotor blades had entered the ground, leaving a single slash mark and causing permanent deformation of that blade. The tail rotor drive shaft had not suffered any torsional damage which might indicate high rotational energy in the transmission or the presence of engine power driving the system at the time of the impact. The initial examination indicated that the airframe, engines, transmission and rotors were intact before ground impact. The ground surrounding the crash site was polluted with fuel over a large area and the impact crater contained a pool of fuel, some of which was recovered for analysis.

1.12.2 Engine strip examination

1.12.2.1 Rotating components

Both engines had been subjected to intense heat in the ground fire which had included the combustion of the magnesium alloy engine gearbox casings. The internal components and passages were therefore heat damaged and contaminated with combustion products. The bulk strip examination showed that there had been no mechanical failure in either engine and although the destruction of the gearbox casings had liberated the internal gearwheels and shafts all these components were identified and, after cleaning, were found to exhibit no signs of damage or distress other than that clearly caused by the fire. The compressor blades were badly contaminated with fire products but it could be seen that they had not sustained any damage of the kind which would indicate that the engines had ingested any solid material such as large pieces of ice.

The engines were examined for evidence which might give some indication of the level of power or the rate of rotation at impact. In the gas passages and, in particular, in the combustion chamber there was found to be no trace of compacted mud or debris as is often found if an engine is operating at high power at impact. The abradable plastic lining material on the inside of the compressor casings had been consumed by the fire and no rub evidence was available from this area. There was no damage on the tips of the compressor rotor blades or stators which would indicate rotation at impact. In both gas producer turbines the interstage seal showed a light rub, distinct from normal wear, in the bottom centre sector. In the power turbines evidence of rotation was non-existent in a number of locations where it might be expected to be seen but the third stage rotor blade paths did show some light localised rub marks at the bottom centre position. On the left engine the fourth stage turbine showed rubbing damage at top centre on the nozzle guide vane rear rim and in the blade tip path, this being in the correct plane for the impact loads but diametrically opposite the other damage in this turbine assembly. The complete destruction of the fuselage structure indicated a severe ground impact. It was, therefore, assessed that both engines showed evidence of only low rates of rotation, the evidence was somewhat stronger in the power turbine sections than in the gas generators.

1.12.2.2 Left engine fuel control system

The casing of the Fuel Control Unit (FCU) was substantially destroyed by heat, liberating the functional components inside, some of which were not found. The input lever as found on site was selected to 30° (Ground Idle). As this is an intermediate position and not at either limit of movement it is thought unlikely that this position was the result of crash loads but that it is a reliable indication of the pre-impact selection (this is confirmed by evidence of the position determined for the cockpit levers). A few components were not found but those which were found and examined showed no significant defect and no evidence was seen of pre-existing contamination such as had caused the previous power reduction recorded in the technical log.

The Power Turbine Governor (PTG) casing had been destroyed by heat. With the exception of the two metering bleeds all the internal components were identified and no fault was found. The fuel pump was intact but had taken damage which was clearly due to impact and heat. Only the mesh of the filter was found and this was so badly contaminated with fire debris that no assessment of its pre-crash condition could be made.

1.12.2.3 Right engine fuel control system

The FCU casing had been partially destroyed by heat. Two metering orifices were missing but no fault or pre-existing contamination was identified in the remaining components. The input lever as found on site was selected to 30° (Ground Idle) and the comments made with respect to the port engine apply. The PTG casing was almost complete although badly heat damaged. All the internal components were present and, under examination, no fault or contamination was found. The fuel pump was intact but seized through heat effects. The filter bowl was clean and the filter was normal apart from some heat discoloration at one end. No significant contamination was found.

1.12.3 *Aircraft's fuel system*

The fuel tanks had been crushed and fragmented in the crash. Fuel splash at the crash site showed that the aircraft had contained a large amount of fuel and the trapped positions of the indicator floats indicated that each tank had contained more than half of its capacity.

The fuel boost pumps had suffered crash damage and could not be run but strip examination revealed no defect which could have prevented their normal operation. Indications were found that they had been receiving electrical power at impact. The fuel transfer valve between the tanks was found to be closed. Some of the fuel supply lines had been destroyed by fire but all the pipe connections were found and no blockages or pre-impact disconnections were identified.

The firewall shut-off valve to the left engine was open and that to the right engine closed but it was apparent that the right valve had been turned to that position during the crash by local deformation of the firewall. Evidence from the cables to the two valves showed that they had been open. Little of the flexible, plastic piping which formed the tank vent lines was found but no defect was noted in that recovered. The pilot's fuel control levers themselves were destroyed and their positions at impact could not be determined. However, the aft end fittings of both FCU operating cables had been bent and trapped in positions which represented an FCU input of "Ground Idle". This corresponded to the input lever positions found on both FCU's (see paragraphs 1.12.2.2 and 1.12.2.3).

1.12.4 *Fuel analysis*

At 0700 hrs on the morning of the accident G–BKIH was refuelled with 349 litres of Jet A1 from the operator's bulk supply. The "end of nozzle" sample taken at 0545 hrs had been certified "Water free and clean". Tank drain samples were recorded as being taken at 0800 hrs and were "Satisfactory". The tank drain samples were retained and later fully analysed in the fuels laboratory of the Materials Quality Assurance Directorate (MQAD) of the Ministry of Defence at Harefield. At the accident site fuel was found to be lying in the impact crater and sufficient of this was recovered to provide samples for analysis. It was reported that the aircraft fuel drain samples taken before the accident flight were water free and clear. Fuel samples were taken from another AS 355 aircraft which had diverted to RAF Cottesmore with a single engine failure on the day of the accident. (See paragraph 1.17.1.3). These were also sent to MQAD, Harefield for analysis. All samples gave similar results in that they were free of visible water or other contamination and were within specification for JET A1 with the exception of a deficiency in the water separation rating, being graded 3 as against a requirement of 2. The analyst advised that the discrepancy was minor and that such a discrepancy is quite common in samples returned from aircraft or airfield supplies and is considered acceptable for use. The specification referred to is a manufacturing specification and slight changes to fuel qualities can occur with age and handling. The engineer who examined the aircraft at Cottesmore reported no evidence of water in the aircraft's fuel system.

The fuel recovered from the accident site comprised 4 separate samples and one of these did exhibit some solid contamination but, given the manner in which it was recovered, it is assumed that the other samples, which were clear, are representative of the fuel on the aircraft. The fuel was found to contain anti-icing additive at a concentration of 0.02 to 0.03% which is less than the minimum amount specified in the Flight Manual (0.08%) for operation at temperatures below +4°C. It will be seen in paragraph 1.12.6 that, from bulb filament analysis, the fuel filter blockage indicators were not illuminated and therefore the lack of anti-icing additive in the fuel can be discounted as a causal factor.

1.12.5 *Flying controls*

Much of the flying control system was fragmented by the ground impact or destroyed by the post-crash fire but most of the critical areas, in consideration of disconnection or obstruction, such as the collective/cyclic mixer assembly and the collective lever within its housing, were identified and examined. All the failures seen were clearly caused by crash loads or heat and no evidence of any control restriction was found.

1.12.6 *Central warning system*

The central warning panel was recovered intact together with the separate "WARN" captions and the bulbs which had served each caption (2 bulbs per caption) were examined. Except where noted below, the bulbs were normal with no deformation of the coiled filament which would indicate that they had been illuminated when subjected to the high decelerations in the crash. A few had broken in a brittle fashion which again would indicate that they had been cold at impact.

Both generator captions (GEN LH and GEN RH) gave strong indications of illumination at impact. Both filaments of the single oil pressure caption (ENG OIL PRESS) showed slight indications of hot deformation. The "WARN" captions, flashing indicators which alert the pilot to the fact that a red caption has illuminated, gave slightly differing evidence of illumination; the right hand having very marked hot deformation on both filaments while the left hand showed only slight stretching on one of its filaments.

It should be noted that the captions warning of fuel filter blockage were amongst those giving no indication of illumination.

1.12.7 *Engine anti-icing system*

No evidence was found for the pre-impact position of the anti-icing valves by examination of the valves themselves or their operating cables. The slotted steel plate which restrained the movement of the pilot's selection levers did contain some damage indicative of lever position at impact. The left lever showed signs of damage near the "OFF" position but this was not fully in the "gated" position and there were indications that the lever had moved from the "ON" end of the slot during impact. The right lever showed some damage near the "ON" position, again not in the "gated" position and this was not entirely distinguishable from normal wear. This evidence, demonstrating a possibility that anti-icing had been selected "ON", cannot be taken however as conclusive proof that this was so.

1.12.8 Ice detector

The probe and control box of the Rosemount icing detector were examined and evidence was found that the system had been receiving electrical power at the time of the crash and had, therefore, been switched on. No evidence could be found, however, as to whether it had signalled the detection of ice on the probe.

1.13 Medical and pathological aspects

All of the occupants died at impact from severe multiple injuries. Post-mortem examination of the pilot revealed no medical factors which could have caused or contributed to the accident.

1.14 Fire

A severe fire started within a few seconds of impact. The fire was refuelled by aviation turbine fuel from the aircraft's two ruptured fuel tanks and much of the aircraft's composite cabin structure was consumed. The fire destroyed both engine accessory gearbox casings which were manufactured from magnesium.

Banbury Fire Station received notification of the accident from an emergency services telephone call at 0907 hrs. Two pumping applicances from Banbury and one from Hook Norton arrived at the crash site at 0917 hrs. An immediate attack on the fire was made using foam making equipment, with the water supply being supplemented from a fire hydrant. When the major part of the fire had been extinguished, the magnesium fire was tackled using locally obtained blasting sand.

1.15 Survival aspects

Due to the severity of the vertical impact it is considered that none of the occupants could have survived. Two passengers were thrown clear of the wreckage at impact and therefore escaped the effects of the post-impact fire.

1.16 Tests and research

1.16.1 Computer simulation of helicopter performance in autorotation

Using the known rotor characteristics of an AS 355 F1 at similar weight and cruising conditions as G–BKIH, a computer simulation was performed at RAE Farnborough. Time delays between one and three seconds before lowering the collective pitch lever were simulated. Conditions were further varied by initiating cyclic pitch nose up inputs coincident with the lowering of the lever. Results of these simulations are shown at Appendix 5. A 2 second delay in lowering the lever resulted in the rotor rpm (NR) falling below the minimum required for normal autorotation. A 3 second delay resulted in an NR which may be too low for recovery. This includes the beneficial effect of a cyclic nose up pitch input to minimise NR decrease.

1.16.2 *Pilot response time following power loss*

Following an accident to a Westland Wessex in August 1981 (Aircraft Accident Report 4/83) tests were conducted to establish the mean and maximum reaction time of pilots experiencing a sudden and unexpected double engine failure.

Electronic recordings of a pilot's performance in a helicopter simulator indicated that a realistic expectation of the time taken to respond to a sudden and complete loss of power by lowering the collective pitch lever fully was about three seconds. A small, but not negligible, chance that a pilot's response time will exceed five seconds was recorded.

The Aircraft Accident Report referred to above included a recommendation that British Civil Airworthiness Requirements (BCARs) relating to helicopter main rotor behaviour following total power loss should be reviewed. Consideration of a rotor speed decay warning system and means by which rotor decay rates might be reduced was recommended. An appropriate revision to Chapter G6–1 required an audible warning to be fitted "to indicate when the rotational speed of the rotor system approaches a value below which a hazardous condition could exist". Such a warning system was installed in G–BKIH.

The Civil Aviation Authority (CAA) agreed to reconsider the subject of pilot reaction times and rotor speed decay characteristics but stated that it would be a long term item. Meanwhile, design guidance for the power-unit failure case is contained in an appendix to BCARs Chapter G2–8 paragraph 2. This recommends a minimum delay period of 2 seconds when the rotorcraft is under manual control and 5 seconds when the rotorcraft is under automatic pilot control such that the rotor speed does not fall below the safe minimum autorotative speed. Whilst this paragraph of BCARs refers to the case of failure of the "critical power unit" it is inconceivable that any greater delay periods could be recommended for the double engine failure case.

1.17 Other information

1.17.1 *Related incidents*

1.17.1.1 During the course of the investigation several instances of engine flameouts involving similar types of helicopter were noted. In a telex dated 27 February 1985 to all Twinstar operators (Twinstar is the designated name of the AS 355 F1 used in the United States) the US subsidiary of the manufacturer drew attention to six flameouts of Allison 250–C20F engines in AS 355 helicopters during a two day period. Two aircraft experienced dual flameouts. Each of the flameouts occurred within a radius of 100 miles during temperature conditions of 0°C to +1°C and in high humidity or rain. In all of the reported incidents engine anti-ice bleed air was not being used. It was suggested that the cause of the flameouts was the ingestion of "soft rime ice".

1.17.1.2 Five days before the accident to G–BKIH, a Twin Squirrel helicopter was approaching a landing site near Elstree aerodrome in Visual Meteorological Conditions (VMC) but passing beneath a large cumuloform cloud in heavy rain and sleet. The ambient temperature was +2°C and the engine anti-ice had been selected 'ON'. The Rosemount ice detector that was fitted did not indicate the presence of any airframe icing. The pilot noticed a large amount of water and slush flowing over his windscreen. Without warning the left engine (No 1) ran down. The pilot received immediate indications from the low rotor speed warning horn (NR below 360 rpm) and the GEN LH caption. He completed the engine shut down drills and made a single engined recovery to his base. Subsequent examination of the engine revealed no damage.

1.17.1.3 On the morning of the accident a Twin Squirrel was flying at 2,500 feet in IMC from Hayes to Nottingham. The pilot experienced in-flight conditions of moist cloud and an ambient temperature of 0°C. Engine anti-ice remained selected 'ON' as it had been since shortly after take off at 0806 hrs. A small amount of ice began to form on the windscreen wiper arms and moisture was seen to be flowing over the unheated windscreen. The pilot began to plan an instrument recovery to East Midlands airport. At about 0850 hrs the right engine (No 2) flamed out. The pilot's first indication of the power loss was from the low rotor speed warning horn followed by the 'WARN' caption and engine oil pressure caption (a single caption that draws attention to low oil pressure in either or both engines). He lowered the collective pitch lever sufficiently to restore the rotor rpm to about 93%, transmitted a distress call and arranged an instrument recovery to RAF Cottesmore. During the recovery he was able to restart the right engine and it performed normally until shut down on the ground. Subsequent inspection of the engines revealed no damage but it was noticed that the first two stages of the axial compressor of the right engine were comparatively clean as if they had been washed recently.

1.17.1.4 On 14 December 1984 a Super Puma helicopter (AS 332 L) was returning to Aberdeen from an offshore oil rig. The aircraft was flying in cloud, with an outside air temperature of approximately −1°C. Both of its Turbomeca Makila 1A engines failed within a short time of each other. No technical reason was found to explain the failures and it was suggested that an accumulation of soft ice might have been ingested by the engines in sufficient quantity to have caused them to flameout. This incident was reported in AIB Bulletin No: 2/85 (Ref EW/C 899).

1.17.2 *Certification of AS 355 Twin Squirrel*

The Aerospatiale AS 355E Twin Squirrel flew for the first time in September 1979 and received initial French airworthiness certification in October 1980. A development of the original model, the AS 355F, of which G–BKIH was a variant (AS 355F1), received type certification for IFR operation in November 1982. French certification was validated by the Civil Aviation Authority on the basis of the equivalence of British and French requirements. G–BKIH was equipped, as specified in a CAA flight manual supplement, for single pilot IFR operations out of icing conditions.

1.17.3 *British Civil Airworthiness Requirements (BCARs)*

The BCARs for rotorcraft (Section G) contain no definition of icing atmospheric conditions. The requirements specify the necessary protection for fuel vents, windscreens, pitot-static heads and radio aerials but are non-specific in their treatment of engine intake protection. Chapter G5–5 Air Intake Systems, Para 3, states "The requirements for de-icing and anti-icing precautions shall be agreed with the Authority". For airframe and rotor anti-icing equipment

Chapter G6–1 Equipment Installations Para 5.5, states "The equipment (shall be installed) necessary to provide protection in the degree of ice-forming conditions for which endorsement of the Certificate of Airworthiness is sought".

In 1973, when it had become apparent that helicopters had reached a stage of development where approval for flight in IMC might be given, the CAA issued a paper, No G160, containing proposals for more specific requirements for icing protection and defining icing atmospheric conditions. Lack of international agreement on icing environments and the paucity of data available prevented the CAA from formally incorporating the proposals into BCARs but the paper has since been used as the working document for approval of rotorcraft for operation in IMC or icing conditions. In 1981 the paper was re-issued with some revisions and clarifications but differences with other authorities still existed, notably with the Federal Aviation Administration (FAA) whose proposals would introduce into rotorcraft requirements the definition of icing atmospheric conditions contained in Federal Aviation Regulations (FAR 25 Appendix C).

From evidence contained in the FAA documentation the CAA considered that these atmospheric criteria were too severe at low altitudes. It was considered that the most severe icing conditions would occur in the altitude range of 10,000 to 25,000 feet.

The working paper recognised that aircraft certificated for, and operating in, IMC conditions may inadvertently encounter icing. It was intended, therefore, that "all rotorcraft with an IMC approval . . . . will be required to incorporate ice protection features such as pitot, engine and pilot's windscreen ice protection so that rotorcraft systems are not unduly susceptible to icing which can occur following inadvertent entry". This was formalised in a proposal contained in paper No G610, Issue 2 (Chapter G4–1 Para Y) which required it to be demonstrated that ancillary features such as engine intakes would not be affected in such a way as to hazard the aircraft in icing conditions defined in the proposed Chapter G1–2 Para X. The proposed requirement for powerplant protection was contained in Chapter G5–5 and Appendix 2 to that chapter. Chapter G5–5 reiterated the requirements for the complete power unit, including intakes, to be demonstrated as capable of functioning without unacceptable loss of power in the defined icing conditions. Thus, although a rotorcraft might be approved for operation in IMC out of icing conditions, its engine and intake system would be subject to the criteria for operation in icing applied to a craft with full icing clearance.

Issue 2 of paper No G610 introduced an intermittent icing condition which was more severe than the continuous case originally specified but which did not encompass altitudes below 5000 feet. In that part of the defined icing conditions which is of interest in relation to the accident of G–BKIH (ie, at 2500 feet and an outside air temperature of 0°C to –2°C), the Maximum Liquid Water Content (LWC) which should be considered under the requirements would be 0.48 grams per cubic metre with a MDD of 20 microns (requirements for continuous operation). The more severe requirement for intermittent icing conditions is at present alleviated below 15,000 feet such that at 5000 feet (the cut-off point for this requirement) a maximum LWC of 0.9 grams per cubic metre is specified at the accident temperature range (approx 0°C).

1.17.4 *Certification icing tests*

Prior to the French certification of the AS 355 various tests were carried out on rigs and on test aircraft to demonstrate acceptable behaviour of the engine, intake, and intake grill in conditions of icing, snow, rain and hail. The intake rig tests encompassed a variety of ambient and flight conditions, intake configurations, and engine conditions including accelerations and decelerations. Particular attention was paid to the behaviour of ice on the wire mesh grill over the intake entry for any indication of a restriction of airflow as ice built up or for any indication of hazardous amounts of ice being shed from the grill (at the end of each test heat was applied to melt and release the ice). The system is shown diagrammatically at Appendix 6. Typically, 1% or less change in pressure loss across the grill was measured and engine behaviour was not affected either by blockage or ice ingestion. Some light deposits of ice were observed within the duct and on the bellmouth and it was noted that, without the integral hot air anti-icing of the engine intake, there were large build-ups on the inlet arms and nose bullet. The behaviour of the grill and intake described in these tests accords well with experience in the UK with intakes on other aircraft of similar construction and geometry. The tests were conducted in water concentrations of up to 0.7 grams per cubic metre (continuous) and up to 2.4 grams per cubic metre (intermittent); the intermittent condition representing 16% of the 30 minute test run at each condition. The temperature range used was from –2°C to –30°C. Minus 2°C was considered to be the closest temperature to zero which could be achieved under test to give stable conditions and reliable measurements.

Tests in simulated or actual rain conditions were successfully conducted up to water concentrations of 4% of engine airflow which is equivalent to an LWC of 48 grams per cubic metre and is higher than the standard representing the most severe tropical rain condition. However, the engine manufacturer had conducted tests on an early variant of the Model 250 engine which demonstrated that flameout could occur with the instantaneous ingestion of relatively small amounts (in the order of 100 grams) of water, ice or snow (see para 1.17.5).

1.17.5 *Service information*

In September 1980, the engine manufacturer, Allison Gas Turbines, issued Commercial Service Letter (CSL 1092) warning owners, operators and pilots of the hazard of snow or ice build-up on an aircraft. The letter said "slugs of snow or ice entering the compressor of these engines models can cause flameout". Subsequently, revisions of this letter were issued to include later engine variants and the most recent was published in September 1982. In February 1985, Aerospatiale Helicopter Corporation, the US subsidiary of the French manufacturer issued a telex to all Twinstar operators. This communication which was later issued as Service Information Letter 355/SE/053 reported six cases of engine flameout described in paragraph 1.17.1.1. In June 1985 Aerospatiale issued a Service Letter (No 684-01-85) containing this information for general distribution. The operator of G–BKIH has reported that, at the time of the accident, he had not received a copy of this letter. The manufacturer states that this letter was sent to the operator on or about 28 June 1985. Service letters are issued to disseminate items of information of widely differing character on technical or commercial subjects. Aerospatiale highlighted service letters containing technical information by over-printing them with a blue hatched border and Service Letter 684–01–85 was so treated. It required no technical or operational modifications and merely alerted operators to the cases of engine flameout and the relevant circumstances. It reminded operators of the limitations in the Flight Manual that they were already obliged to observe. The service letter numbering system included no indication of any technical content equivalent to the blue hatched border on the document itself and therefore in any reference to the index the documents significance was indicated solely by the title. The title of 684–01–85 was:

> "AS 355 All versions limitation
> Reminder of Flight Manual limitations and procedures regarding:
> 1. Flight in icing conditions
> 2. Use of engine anti-icing
> 3. Engine relighting in flight".

1.17.6 Airworthiness Directive (AD)

Following the accident, AAIB wrote to the CAA on 9 May 1986 drawing their attention to the several instances of engine flameout in AS 355 helicopters. The letter expressed concern at the apparent inability of the engine installation to tolerate certain combinations of temperature and precipitation such that flame-outs could occur even in VMC conditions. The CAA wrote to all operators of the type on 10 July 1986 highlighting the dangers of operating "in circumstances which are likely to give rise to engine problems". At the same time the authority, manufacturer and UK distributor all explored means of improving the situation in time to offer better protection prior to the winter of 1986/7. On 15 September 1986 AAIB again wrote to the CAA to give them advance notice of the provisional conclusions and recommendations contained in this report. The need for some remedial action before the onset of winter operations was stressed.

On 2 October 1986, the Direction Generale de L'Aviation Civile (DGAC) as the primary certification authority, issued an AD which, in essence, limited operation of the helicopter in both VFR (in heavy precipitation) and IFR to temperature regimes above +5°C. In the case of VFR flight the restriction did not apply to flight in snow at temperatures below –5°C or in light drizzle. Furthermore, the restrictions could be removed once modifications to the power-plant installation to provide automatic re-ignition had been approved by the authorities.

1.18 New investigation techniques

None.

2. Analysis

2.1 General

From the evidence of the pilot's distress call it is clear that the emergency occurred suddenly and without warning. One minute before the distress call the pilot acknowledged a routine air traffic instruction, and made no mention of any problem with his flight. Further evidence from the distress call indicated that the pilot had diagnosed engine failure and, subsequently, a low value of rotor rpm. There are therefore two possibilities following a loss of power, either the helicopter did not become established in autorotative flight, or perhaps the rotor rpm was restored but the pilot was unable to accomplish an autorotative landing because of the low cloud base. The lack of rotational energy exhibited by the rotor at impact is confirmed both by examination of the wreckage and witness accounts. It is also known that at the time of impact neither of the engines was delivering power to the main rotor gearbox.

This analysis discusses the weather that was encountered by the flight and flight planning considerations. The encounter with icing conditions and possible situations leading to the failure of one or both engines is then discussed. Possible reasons for the failure to make a safe landing, having their origin during some stage of the descent, are suggested. Finally the method by which important safety information is disseminated is examined.

2.2 Flight planning and the weather

The flight was possible only because this type of helicopter is permitted to operate in IMC. Nevertheless, the flight was delayed whilst waiting for the weather to improve sufficiently to allow flight under SVFR in the London CTR and to enable a landing at the site where the passengers were embarked. Considering the meteorological aspects of the flight from Pangbourne to Alton Towers, the flight originated in the warm sector of a depression, had to transit the warm front and was planned to terminate in the cold sector. The pilot could therefore expect a low cloud base, with perhaps hill fog, in the warm sector and frontal area but with a relatively high freezing level. Once through the warm front and into the cold sector he could expect a higher cloud base but lowered freezing level.

It is probable, therefore, that the pilot's intention was to conduct the first part of the flight in IMC whilst remaining in the warm sector, and then, in order to achieve the necessary Visual Meteorological Conditions (VMC) for landing at Alton Towers, to make an instrument let-down at a suitably equipped airfield along his route. For this plan to be successful and to remain clear of icing conditions the instrument let-down would have to be made before reaching the cold sector. Thus knowledge of the position of the front was crucial to the planning of the flight. From his study of actual and forecast conditions along his route the pilot could have deduced that the front would be well south of Manchester and was most likely to be in the area of East Midlands Airport. Provided that the front was no further north than this, the plan to terminate the flight at Alton Towers in VMC was feasible. Almost certainly the pilot was unaware of the sub-zero temperature layer which existed between 2000 feet and 3300 feet in the area of the front. This is a somewhat unusual feature of the characteristics of a classic warm sector depression, but not entirely unexpected in the case of an occluded front or, as in this case, a stationary front about to reverse its direction of movement.

Frontal positions on a "surface" chart are usually based on surface precipitation patterns and mean temperatures and cloud through a considerable depth of atmosphere, but often do not show cold air layers at low level, especially in winter. On the chart in question the true surface position of the front was ill-defined and had become disassociated from the upper front. Although the importance of cloudy thin sub-zero temperature layers, often found at such a frontal surface, is well recognised by meteorologists, no attempt has ever been made to forecast them, or to describe in detail the synoptic conditions in which they occur. However, if the pilot had been aware of the information contained in the SIGMET issued at 0830 hrs he might well have reconsidered his plan to continue in IMC north of latitude 52 degrees North.

2.3 The encounter with icing conditions

The limitations of the Flight Manual and the IFR supplement are quite explicit. The pilot, who was experienced in this type of operation, knew that any inadvertent encounter with icing conditions had to be terminated without delay. His options would normally be to climb or descend into warmer temperatures or to alter his track into an area of known warmer air. The least attractive option was to climb, since failure to find either clear air or warmer air would result in a worsened icing situation. In the case of the accident flight, descent was impossible since the MSA for the relevant part of the route is 2400 feet. Thus the only reasonable option was to reverse course towards Oxford where the pilot knew that icing conditions at 2500 feet did not exist. However, such a plan pre-supposes adequate warning of the icing conditions. From the evidence of the Beaver pilot (paragraph 1.7.4) it is apparent that the icing conditions manifested themselves virtually instantaneously. The most likely early warnings, if any, would have been received from the Rosemount ice detector, ice accretion on the windscreen wiper arms, or close observation of the outside air temperature gauge, but all these indications are more relevant to airframe icing only. It is, however, known that icing of the engine intake system can occur in quite different conditions of high humidity and in temperatures above 0°C. The flight manual limitation, which contains a safety margin, is + 5°C. It is to overcome this problem that engine anti-icing is provided and in the conditions that G-BKIH was flying it was likely that the pilot had made the appropriate selections. Although from examination of the wreckage its status could not be determined with certainty, the probability is that engine anti-icing was in use.

Icing of the main and tail rotor blades' leading edges is unlikely at temperatures close to 0°C. The effects of kinetic heating, blade flapping and flexing and centrifugal spanwise forces tend to require a lower temperature to cause ice accretion. When, however, large super cooled water droplets are encountered the possibility of leading edge ice accretion at relatively high temperatures cannot be totally discounted.

It appears highly probable that G-BKIH encountered rapid and severe icing in the conditions previously described. These conditions are more severe than those considered in the relevant CAA proposals for BCARs. Thus it would seem that there are grounds for the CAA to reassess the evidence of likely icing conditions at low altitude and to review the existing differences between the current CAA and FAA proposals.

British validation of a foreign certification depends on an assessment of whether the foreign requirements, though different in detail, are equivalent in overall effect and adequate in specific critical areas. The icing conditions simulated during French certification tests do appear to have satisfied the proposed BCARs as reflected in Working Paper G610 with little alleviation for low altitude. The "intermittent" conditions created were more severe in terms of LWC and MDD than those considered to have existed in the local weather system which G-BKIH entered. The tests, however, because of practical difficulties did not simulate conditions at 0°C.

In reality G-BKIH was in a much more complex environment than any that could be readily simulated with changing air, water and airframe temperatures. The risk of inadvertent entry into icing conditions is acknowledged for IMC capable rotorcraft which are not necessarily cleared for operation in icing conditions. It is also recommended that measures be considered that give improved protection to IMC aircraft in the temperature region 0°C.

2.4 The loss of power

2.4.1 *Engine flame out due to ice/slush ingestion*

In view of the circumstantial evidence provided by the six engine flameouts in the US in February 1985, and the two reported incidents in UK (see paragraph 1.17.1), the investigation concentrated on the possibility that the sudden power loss experienced by G-BKIH was due to an icing encounter. The exact manner in which ice formation may cause engines to flame out is uncertain but, given the actual meteorological conditions at the time of the accident, it is possible to identify the most likely mechanism.

Pre-requisites for the thick lumpy opaque ice reported by the Beaver crew are large super cooled water droplets, a high liquid water content and a temperature inversion. The temperature was between 0°C and +1°C, the liquid water content (LWC) was 0.8 grams per cubic metre and the Mean Droplet Diameter (MDD) was probably around 10 to 15 microns. Additionally, some water droplets of much larger diameter could have originated in sub-zero temperatures and passed through a positive temperature band before encountering sub-zero temperatures again. Furthermore, the air mass had been orographically lifted by its passage towards the Cotswold hills thus no doubt increasing the amount of condensation and, in turn, the water droplet size. Although a great deal of research has been conducted into the behaviour of both rotors and engine intake grills of civil and military aircraft, there is less data on encounters at temperatures close to 0°C than there is at lower temperatures.

Unlike glaze ice, which forms in a continuous sheet over aerofoils or intake grills, the larger water droplets, including snow flakes or ice particles, will tend to form into a slush. This may build up in random fashion and can be dislodged by vibration or localised heating. Slush is not retarded by engine intake grills and may thus be a means of introducing a considerable quantity of water into the intake of an engine. Disruption of the normal airflow, due to the greater mass caused by liquid rather than air, can produce compressor stall conditions resulting in engine surge and flameout. In this case there may be no physical damage to the engine compressor. Only when hard pieces of ice are ingested can damage to the leading edges of the compressor blades be expected. The absence of such damage found within the compressors on the accident aircraft does not therefore rule out the possibility that the flameout of one or both engines was caused by slush/ice.

2.4.2 *Double engine failure*

There may be three possible sequences in which both engines could have failed, but there is no doubt that both had failed by the time that the aircraft hit the ground.

(a) Simultaneous flameouts

(b) Successive flameouts

(c) Inadvertent shut down of the remaining engine

2.4.3 *Simultaneous engine flameouts*

The nature of the slush/ice and the configuration of the intake system may have been such that sufficient ice/slush entered both intakes simultaneously causing both engines to flame out together or nearly together. In these circumstances the pilot would be faced with a total loss of engine power whilst flying in cloud.

2.4.4 *Successive engine flameouts*

Following failure of one engine, due to ice or slush ingestion, the possibility of the other engine flaming out for the same reason is increased since it will automatically accelerate to its governed Ng. In so doing, there will be a sudden increase in the mass air flow entering the engine, with a consequent increase in its potential and liability to ingest ice or slush. The pilot, who may be handling a single engine failure successfully, would then suddenly be confronted with a total power loss.

2.4.5 *Inadvertent engine shut down*

In the event of a single engine flameout, the pilot would have restored the rotor rpm by partially lowering the collective pitch lever. His next action, as practised regularly in training, would be to identify and complete the shut down drills on the failed engine. Considering the presentation of warning lights and gauges indicating a failed engine and particularly the absence of power loss indicators, (see cockpit photograph at Appendix 7), it is possible for a pilot, under stress, to mistake the identity of the failed engine. He may then close the fuel flow control lever of the engine that is still operating. This creates the same conditions as a double engine failure at a time when the pilot is fully occupied in coping with the first engine failure and his left hand is manipulating the control levers which are located in the cockpit overhead panel.

Examination of the wreckage revealed that both engine fuel control levers were in the Ground Idle position. If the pilot was following normal operating procedures this could indicate that, either he had partially completed the engine shut down drill, (with a further selection to fuel 'Cut Off' still to be made), or he had moved the levers from 'Cut Off' to 'Ground Idle' as part of an attempted re-light sequence (see Appendix 2). Indeed, faced with a total loss of power and dangerously low rotor rpm, this was the only remedial action he could have taken. On balance this would seem the least likely possibility of the options discussed.

2.5 The descent

Regardless of the way in which the engine failures occurred there is no doubt that the rotor had little or no rotational energy by the time that the aircraft made contact with the ground with considerable vertical impact. There may be two possible explanations for this, either autorotation was never established or, sufficient rotor rpm was regained to establish autorotation but the subsequent landing was not achieved safely. However, it seemed unlikely that the pilot established a successful autorotation following the loss of power because in his distress call he considered it necessary to include a comment about the rotor rpm. Considering the pilot's second distress call, which included some comment about the rotor rpm, and since it was possible to match the timing of the call with the radar recording of the ATC transponder height, it was concluded that the loss of rotor rpm occurred at height rather than close to the ground.

In whatever manner a power loss occurs, it should normally be possible to enter a successful autorotation. However, the rotor decay characteristic of the Twin Squirrel, in common with some other helicopters, allows little margin for delay in fully lowering the collective lever in order to establish autorotation. Considering the evidence of the two related incidents in the UK, involving single engine flameouts in Twin Squirrel helicopters, it is noteworthy that in each case the pilot's first indication of power loss was from the low rotor speed aural warning horn. Viewed in conjunction with the computer simulation of AS 355 rotor decay characteristics, it is apparent that the maximum permissible delay in lowering the collective pitch lever falls short of the period that is recommended in BCARs in the case of failure of the 'critical power unit'. It is considered, within the helicopter industry, that single pilot IFR operations are the most demanding of a pilot's reactions and skill and, in the event of an emergency in IMC, perhaps compounded by a second emergency, the demands on the pilot may well be excessive. One possible reason for the failure to establish autorotation was that the pilot took too long to decrease collective pitch due to his high workload or misinterpretation of cockpit indications. It is recommended that airworthiness authorities should, in the light of previous data gleaned on pilot reaction times, investigate urgently the feasibility of modification to helicopter collective pitch controls so that automatic pitch reduction is made whenever a loss of power results in a dangerously low rotor rpm. This recommendation to review BCARs was first made in Aircraft Accident Report 4/83 and was accepted by the CAA as a "long term item". An additional possibility was that ice had already accumulated on the rotor and degraded its aerofoil characteristics. Whatever the reason it seems probable that the helicopter approached the ground under some measure of control and at a high rate of descent with a rotor rpm which was insufficient to allow the pilot to make a significant reduction in the rate of descent.

2.6 Dissemination of safety information

Service letter 684-01-85 was intended to contribute to safe operation of the AS 355 helicopter by bringing to the notice of pilots and operators four incidents in which aircraft had been hazarded by engine flameout in specific atmospheric conditions. The service letter highlighted the potential hazard and the importance of existing flight manual limitations. Although the information had not, unfortunately, reached the operator before the accident, it cannot be known whether such knowledge would have altered the circumstances leading up to the accident. What may be questioned, however, is the effectiveness of using this method to notify important safety information. Service letters, which may contain commercial, technical and, in this case, safety information can be regarded as having less significance than either service bulletins or "alert" service bulletins. An enhanced designation such as "alert" or "safety" for letters containing safety information would lessen the chance of such information being missed by default.

3. Conclusions

(a) *Findings*

(i) The pilot was correctly licenced and medically fit to conduct the flight.

(ii) The helicopter was correctly loaded and carried sufficient fuel for the flight. Although the fuel contained less than the required percentage of anti-icing additive that is specified in the Flight Manual, it was not considered to have been a causal factor.

(iii) The helicopter had been properly maintained and its documents and maintenance records were in order.

(iv) The pilot had sufficient information concerning the weather along his chosen route. A forecast of severe icing conditions north of latitude 52° North was issued shortly after the helicopter left its base and the pilot was probably unaware of it.

(v) Without warning the helicopter encountered a sub-zero layer of saturated moist air giving rise to the rapid formation of slush/ice.

(vi) The status of engine intake anti-ice bleed air could not be determined with certainty but evidence from the wreckage tends to suggest that it was selected 'ON'.

(vii) No technical reason was found to explain the loss of power. It is most likely that the helicopter engines flamed out due to ingestion of slush but the possibility that the pilot inadvertently shut down an operating engine following a single engine failure could not be ruled out.

(viii) Following a complete loss of power the helicopter did not become established in autorotative flight, and descended rapidly from its cruising altitude to crash in a field.

(ix) The reaction time of a pilot following a total loss of power is critical. The rate of decay to a dangerously low Nr of the AS 355 F1 rotor, like that of other types of helicopters, exceeds the average pilot's reaction time.

(x) Cockpit indications of power loss in the AS 355 F1 are considered to be inadequate for single pilot IFR operations.

(xi) Safety information, despatched by the manufacturer in June 1985, drawing the attention of operators to previously reported incidents of engine flameout did not come to the attention of the UK distributor of the AS 355 until after the accident.

(b) *Cause*

The accident was caused when the helicopter, whilst flying at 2500 feet in IMC, suffered a total loss of power and did not accomplish a normal autorotative descent and landing due to a significant decrease in rotor rpm. The most likely cause of the power loss was the ingestion of slush which had formed near the intake area of the engines. It was not possible to determine whether both engines failed simultaneously or in succession.

4. Safety Recommendations

It is recommended that:

4.1 A review be conducted into the ability of helicopter engine installations (particularly the AS 355 F1) to continue to operate in conditions of high humidity and at temperatures of 0°C plus or minus 5°C. The review should also consider a mandatory requirement to fit automatic re-ignition or continuous ignition modifications to Allison 250–C20 series engines which are fitted to the AS 355 F1.

4.2 Investigations into the feasibility of incorporating automatic collective pitch reduction mechanisms following partial or total power loss should be urgently pursued.

4.3 A review of those BCARs which deal with power unit malfunctions be conducted with a view to improving those indicating systems that enable a pilot to identify a failed power unit correctly.

4.4 An examination be conducted into the most effective and timely passage of SIGMET information to aircraft that are either in flight or detached from their operating bases.

4.5 Consideration is given to the issuing of guidance to operators of helicopters which fly in IMC on appropriate weather minima which will enable an autorotative landing to be made in visual contact conditions. It may be necessary to recommend a minimum cloud base along the helicopter's intended track depending on the type of terrain.

4.6 Manufacturers and other originators of safety information be required to include such information service bulletins at no lesser status than "alert".

4.7 A review of current CAA and FAA proposals relating to the criteria for likely icing at low altitude be conducted.

4.8 Consideration be given to the establishment of test facilities which can provide experimental conditions of engine installations icing at temperatures around 0°C.

R C McKinlay
Inspector of Accidents

Air Accidents Investigation Branch
Department of Transport

December 1987